Asymmetries in the transmission of oil price shocks to inflation in the eurozone*

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Abstract

Theory predicts that the level of inflation in an economy and the trend in the prevailing inflation rate may affect how oil price shocks, through their influence on firms' expectations and price-setting behaviors, are transmitted to inflation. However, empirical evidence regarding this relationship is limited and calls for further exploration. Using data for 12 eurozone countries over the period from 1999 to 2020, we analyze how the inflation environment in which an oil price shock occurs influences its transmission. We find that the inflation environment is a determinant in the way oil supply shocks and oil-specific demand shocks are transmitted to inflation, with positive shocks displaying higher transmission in high inflation environments. Furthermore, transmission of shocks to core inflation, which represents an indirect effect, only occurs in high inflation environments. These findings highlight the need to consider the inflation environment in order to define appropriate monetary policies in response to inflationary pressures caused by oil price shocks.

Keywords: oil price shocks; inflation; state-dependent; asymmetry

JEL codes: E31; E37; Q43

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1. Introduction

The price of oil as well as fluctuations in that price can significantly affect the evolution of a number of macroeconomic variables. The oil price shocks of the 1970s are a clear example of this (Hamilton, 1983; Mork, 1989; Hamilton, 1996); after those events, controlling inflation became a principal economic policy objective, particularly for monetary policy, and oil prices became a fundamental factor in analyzing economic conditions. Currently, most central banks have long-term inflation targets based on a core inflation measure that excludes an energy component. However, medium-term inflation targets are conditioned by the transmission of oil prices to consumer prices.

Oil price shocks affect inflation through two different channels as follows: directly, as fuel prices are part of the energy component of the so-called headline inflation price index and indirectly, whereby oil price shocks alter production costs and generate second-round effects on wages and incomes that are indexed to changes in consumer prices (Peersman and Van Robays, 2009; Alvarez et al., 2011). Oil price changes are one of the main factors that influence the variability of the headline inflation rate in oil-importing countries, including the United States (US) (Blanchard and Gali, 2007) and regions such as the eurozone (Alvarez et al., 2011). Analyzing how oil price shocks are transmitted to inflation is of special relevance, particularly in a context in which cyclical fluctuations in the inflation rate are mainly determined by international factors such as commodity prices (Forbes, 2019), among which oil is key.

In recent decades, inflation has trended downward in developed economies, especially after the global financial crisis, as shown in Figure 1 for eurozone inflation. In a climate of low inflation, analyzing how cost-push shocks such as oil price shocks are transmitted to consumer prices is of major importance. Theoretically, when the inflation trend is low, the degree to which cost shocks are transmitted to inflation is lower than in a high inflationary environment for a number of reasons. In an economy with staggered price settings and monopolistic competition, cost shocks in a low inflationary environment are perceived by firms as transitory such that firms are less likely to transmit these costs through their prices (Taylor, 2000). Following this line of thought, if the frequency with which firms update their prices is endogenous to the inflation environment such that the frequency of price updates increases when the inflation trend is higher (Devereux and Yetman, 2010), the transmission of cost shocks to inflation will be greater in an environment of high-trend inflation as more firms modify their prices more frequently, passing on these higher costs through their prices.

Another possible source of non-linearity in the transmission of oil price shocks to inflation is the existence of an asymmetry that depends on the direction of the shock; in other words, the impact of positive shocks (oil price increases) and negative shocks may differ. This asymmetric transmission may arise from different channels. One such channel is via the direct impact of oil price shocks on fuel prices, as fuels represent an important share of the basket of goods and services in the eurozone’s Harmonized Index of Consumer Prices (HICP) and, therefore, directly affect headline inflation. This is the so-called “rockets and feathers” effect in the retail fuel market (Bacon, 1991) such that positive changes in the price of oil are transmitted to fuel prices to a greater degree than negative changes. This result has several theoretical explanations: the existence of market power in the retail fuel market because of its small number of competitors and/or high search costs (Borenstein, 1991; Borenstein et al., 1997); the asymmetric response of consumers to variations in fuel prices (Balke et al., 1998); or inventory management and accounting techniques used (Balke et al., 1998). Moreover, oil is an input in the production process of many firms and, hence, its price variation affects their marginal costs. In this sense, asymmetry may arise from the existence of menu costs. In an economy with positively trending inflation and monopolistic competition where firms set prices for several periods and face menu costs when changing their prices, firms adjust their prices more frequently in the face of increases in marginal costs than after decreases in those costs (Tsiddon, 1993; Ball and Mankiw, 1994). This implies that positive oil price shocks will transmit to inflation to a greater degree than negative shocks. Further, higher the inflation trend, the greater the asymmetry.

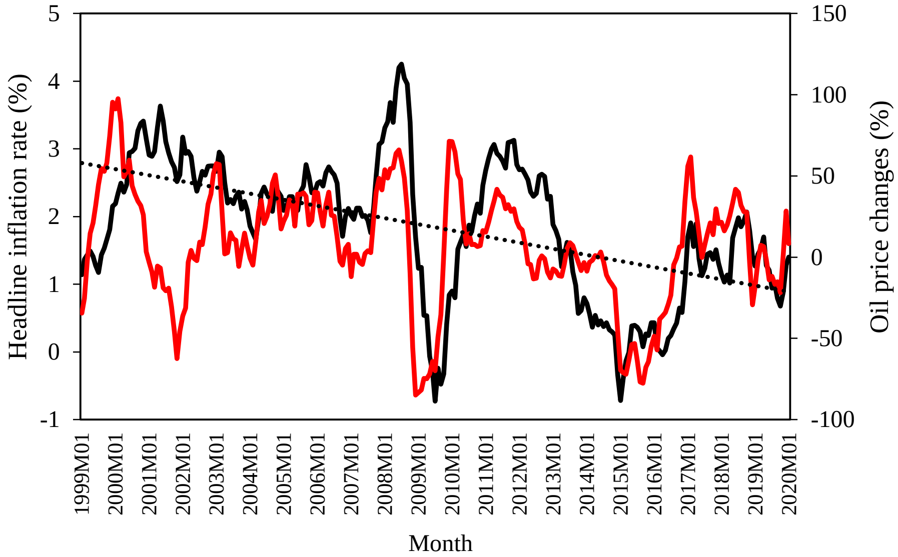

Fig. 1. Evolution of eurozone average headline inflation and oil price changes (1999.01–2020.01). The black line represents the average year-on-year inflation rate of the 12 original eurozone countries. The dashed line represents the linear trend of the inflation rate. The red line represents the year-on-year change of oil prices, proxied by the US imported refiner acquisition cost of crude oil.

Another source of this asymmetry is the differing impact of positive and negative oil price shocks on economic activity. It has been argued that positive shocks have a greater effect on economic activity than negative shocks. This asymmetric response may be caused by one or more factors, including: (1) rigidities in the labor market associated with worker reallocation costs in the most energy-intensive sectors, which amplifies the recessionary effect generated by oil price increases (Hamilton, 1988; Davis and Haltiwanger, 2001); (2) the asymmetric response of monetary policy to positive and negative shocks given that since the 1970s, central banks have shown a clear tendency to have a greater response to positive oil shocks than negative shocks (Bohi, 1991; Bernanke et al., 1997); and (3) the uncertainty and financial stress that amplifies positive shocks and dampens negative shocks, either because of their impact on future investment decisions (Bernanke, 1983; Pindyck, 1991) or their effect on precautionary savings (Edelstein and Kilian, 2009).

As the effect of oil price shocks on inflation differs depending on the source of the shock (Barsky and Kilian, 2004), it is important to differentiate between different types of shocks. Following Kilian (2009), we distinguish three main types of shocks: (1) oil supply shocks caused by exogenous changes in oil production, whereby a decline in oil production translates to an increase in oil prices and vice versa; (2) oil-specific demand shocks, which reflect changes in oil demand caused by speculation, precautionary moves against the risk of future supply disruptions, or changes in firms' oil needs because of changes in their technologies or production processes; and (3) aggregate demand shocks, which represent changes in oil demand caused by fluctuations in global economic activity.

To the best of our knowledge, no study has comprehensively analyzed the effect of oil price shocks on inflation by jointly considering the inflation environment in which such shocks occur and the possible existence of asymmetric response. This study aims to fill this gap by examining how the inflation environment affects the transmission of oil price shocks to inflation as well as the existence of asymmetries, and how they vary depending on the inflation environment in which the shock occurs.

In this study, we analyze the transmission of oil price shocks to inflation using a panel of the 12 initial eurozone countries. We analyze the transmission of these shocks to headline inflation, which includes energy prices, as well as core inflation. This allows us to study the transmission of shocks to prices that are not directly affected by fluctuations in oil prices, thereby allowing us to distinguish indirect effects. Our methodology proceeds using a two-stage approach. In the first stage, we use an SVAR model of the oil market (Kilian, 2009) to identify the three types of shocks. In the second stage, we estimate the effect of the previously identified shocks on inflation, using local projection methods (Jordà, 2005). This method affords greater flexibility for estimating the impulse response function than is provided by traditional VAR analyses and is particularly useful for estimating nonlinear relationships and for the two-stage approach as it allows us to directly include the exogenous shocks we identify. To account for the effect of the inflation environment, we employ a smooth transition state-dependent local projection model (Auerbach and Gorodnichenko, 2012) using standardized past inflation as the state variable on which the transmission of oil price shocks depends. Further, to analyze the existence of asymmetric effects based on the direction of the shocks, we extend our state-dependent model by distinguishing between positive shocks (which increase oil prices) and negative shocks (which cause oil prices to fall) and obtain different impulse response functions for positive and negative shocks.

The main contribution of this work is that, for the first time, the influence of the current inflation environment on the transmission of oil price shocks to inflation, and on asymmetries between positive and negative shocks is jointly analyzed empirically. This allows us to identify asymmetric and conditional behaviors that should be useful in designing the European Central Bank's monetary policy with respect to its economic pillar (ECB, 2011). To date, only Sekine (2020) has studied the existence of non-linearity in the transmission of oil price changes to inflation as a function of the inflation environment. Our work extends that study in several ways. First, we distinguish the sources of oil price shocks as their transmission mechanisms to inflation differ substantially. Second, Sekine (2020) analyzes the effect using a static approach in the framework of an augmented Phillips curve, whereas we analyze the transmission of oil price shocks from a dynamic perspective by estimating impulse response functions. This allows us to obtain a more comprehensive view of the transmission at different time horizons. Finally, we also consider the presence of asymmetric responses in the transmission of oil shocks conditioned on the economy's current inflation environment.

Our main findings are that oil supply shocks as well as oil-specific demand shocks differ depending on the inflation environment in which they occur. Headline inflation shows a greater response to positive shocks in high inflation environments, while negative shocks are transmitted to a greater degree in a low inflation environment. The transmission of aggregate demand shocks depends to a greater extent on the direction of the shock such that negative shocks that reflect depressed global economic activity show a high and persistent transmission to inflation, triggering a significant deflationary effect, while positive shocks show very low transmission, especially in low inflation environments. Finally, the effect of these shocks on core inflation, which reflects indirect effects, is only significant in high inflation environments, while transmission is muted in low inflation environments. These findings imply that when determining monetary policy response to oil price shocks, it is important to consider the inflation environment in which these shocks occur as their transmission to inflation can vary considerably depending on that environment.

This study is related to three strands of literature. First, it is linked to the literature on state-dependence in the transmission of cost shocks. Although there is ample empirical evidence that the transmission of exchange rate shocks depends on the inflation environment (Choudhri and Hakura, 2006; Junttila and Korhonen, 2012; Shintani et al., 2013; Cheikh and Louhichi 2016; López-Villavicencio and Mignon, 2017; Cheikh and Zaied, 2020), evidence on the transmission of oil price shocks is scarce. Only Sekine (2020) analyzes the influence of the inflation environment on the transmission of oil prices to inflation. Focusing on the US, he finds a higher transmission of oil price fluctuations during periods of high inflation. Nevertheless, that study takes a static perspective and does not distinguish among sources of asymmetries.

This work is also related to the literature addressing the existence of asymmetry in the effects of oil price shocks. Although there is a vast body of research on the asymmetric effect of oil price shocks on economic activity, empirical studies of the asymmetric effects of oil price shocks on inflation are scarce, and the results are not conclusive. In the US, positive shocks have been shown to have a greater effect on inflation than negative shocks (Balke et al., 2002), especially when the shocks are larger than usual (An et al., 2014). López-Villavicencio and Pourroy (2019) find that in countries where the central bank does not follow an inflation targeting strategy, positive oil price shocks also exhibit a greater degree of transmission to inflation than negative shocks, although this asymmetry does not hold in countries with inflation targeting. For the eurozone, studies have found that negative shocks have a greater degree of transmission and persistence than positive ones (Evgenidis, 2018) in periods of financial stress. Donayre and Wilmot (2016) found that in Canada, the transmission of negative shocks is higher than positive shocks, especially during periods of low economic growth.

Furthermore, our work is also related to the literature addressing the importance of the source of oil price shocks in their transmission to other variables related to the oil market and domestic variables. Studies show that the degree of transmission of oil price shocks to macroeconomic variables, including inflation, depends on whether those price shocks are caused by supply or demand shocks in the case of the US (Kilian, 2009), the United Kingdom (UK) (Lorusso and Pieroni, 2018), and the eurozone as a whole (Peersman and Van Robays, 2009; Herwartz and Plödt, 2016; Enders and Enders, 2017).

In contrast to the works cited above, our study is the first to jointly consider the influence of the inflation environment on the transmission of oil price shocks, while distinguishing shocks according to their source and sign.

The rest of this study is organized as follows: section 2 describes our methodology and dataset; section 3 presents the empirical results, and section 4 tests the robustness of our findings. In section 5, we discuss the results and their implications and then offer conclusions in section 6.

2. Methodology

Our methodology consists of a two-stage approach as proposed by Kilian (2009), which has been extensively used to analyze the effect of oil price shocks on different macroeconomic variables (Kilian et al., 2009; Habib et al., 2016; Lorusso and Pieroni, 2018; Jibril et al., 2020). In the first stage, we identify oil price shocks through a structural model of the global oil market, following the methodology in Kilian (2009). In the second stage, we estimate the transmission of those shocks to inflation in the eurozone using local projection methods (Jordà, 2005).

An alternative strategy would be to estimate an SVAR model of the oil market extended to include the macroeconomic variables to be studied. However, Kilian and Zhou (2020) point out that to correctly estimate a structural model of the oil market, it is necessary to use a long time series, such as one spanning from 1974 to present. When macroeconomic data are available for a shorter period of time, as is the case of the eurozone that has only been in existence since 1999, the two-stage approach is more suitable than the extended SVAR approach to correctly identify oil price shocks. Furthermore, Hamilton and Herrera (2004) and Kilian (2009) highlight the importance of including a large number of lags in the model to adequately capture the dynamics of the oil market and how oil price shocks are transmitted to the economy, which also supports our decision to use a two-stage approach, given the length of our time series data.

2.1. Identifying structural oil price shocks

To identify oil price shocks, we estimate an SVAR model with recursive identification as developed by Kilian (2009), which has been widely used to study the effect of oil price shocks on other macroeconomic variables (Kilian et al., 2009; Kang and Ratti, 2013; Habib et al., 2016; Enders and Enders, 2017; Kang et al., 2017; Degiannakis et al., 2018; Lorusso and Pieroni, 2018; Jibril et al., 2020)[1]. Thus, we identify three types of shocks: oil supply, oil-specific demand, and aggregate demand shocks by estimating the following trivariate SVAR model:

$$A_0 Y_t = \alpha + \sum_{i=1}^{24} A_i Y_{t-i} + \varepsilon_t \tag{1}$$

[1] An alternative option is to identify oil price shocks using an SVAR model with sign restrictions (Kilian and Murphy, 2012; Kilian and Murphy, 2014; Baumeister and Hamilton, 2019). In section 4, we test the robustness of the results using oil price shocks identified via sign restrictions.

where Y_t is a 3x1 vector of endogenous variables, namely, $\Delta prod_t$, representing the percentage change in oil production, rea_t is the real economic activity index developed by Kilian (2009) representing fluctuations in global economic activity, and rpo_t is the real refiner acquisition cost of imported crude oil expressed in log form. ε_t is a vector of structural innovations that are serially and mutually uncorrelated. To obtain ε_t from the reduced-form errors, we assume that A_0^{-1} has a recursive structure such that we can retrieve the structural innovations ε_t from the VAR reduced-form errors, e_t:

$$e_t = \begin{pmatrix} e_t^{\Delta prod} \\ e_t^{rea} \\ e_t^{rpo} \end{pmatrix} = \begin{pmatrix} a_{11} & 0 & 0 \\ a_{21} & a_{22} & 0 \\ a_{31} & a_{32} & a_{33} \end{pmatrix} \begin{pmatrix} \varepsilon_t^{oil\ supply\ shock} \\ \varepsilon_t^{aggregate\ demand\ shock} \\ \varepsilon_t^{oil-specific\ demand\ shock} \end{pmatrix} \tag{2}$$

To identify the three structural shocks, we use a recursive structure based on the following assumptions:

- First, to identify oil supply shocks, we assume that oil production is inelastic in the short run. This implies that production does not react contemporaneously to changes in global economic activity or the price of oil.

- To identify aggregate demand shocks, we assume that global economic activity can be affected in the same month by oil production changes but not by fluctuations in oil prices. In other words, global economic activity only reacts to oil price fluctuations after a certain delay. We, therefore, identify aggregate demand shocks as innovations in the economic activity index that are not explained by oil supply shocks.

- Finally, in the case of oil-specific demand shocks, we assume that oil prices react contemporaneously to both oil production changes and fluctuations in global economic activity. In this way, we identify oil-specific demand shocks as oil price innovations that are not explained by oil supply shocks and aggregate demand shocks.

After identifying these structural oil shocks ε_t, we construct three variables corresponding to oil supply, oil-specific demand, and aggregate demand shocks for the period from January 1999 to January 2020, which we use to study the transmission of oil shocks to inflation in the eurozone.

2.2. Estimation of the transmission of oil price shocks to inflation

2.2.1. Linear model

To analyze the transmission of oil price shocks to inflation, we use headline inflation and, alternatively, core inflation as dependent variables in an effort to pinpoint the indirect effects generated by those shocks. We estimate the following equation using local projection methods, following other studies such as Sekine and Tsuruga (2018) and Caselli and Roitman (2019):

$$p_{i,t+h} - p_{i,t-1} = \alpha_{i,h} + \sum_{l=1}^{12} \mu_l^h (p_{i,t-i} - p_{i,t-1-i}) + \beta^h Shock_{a,t} + \sum_{l=0}^{12} \theta_l^h \, Control_{i,t-l} + \epsilon_{i,t+h} \quad (3)$$

where $p_{i,t}$ represents the price index, in log form, for country i = 1, 2,…,12 on date t. $Shock_{a,t}$ refers to the three structural oil price shocks identified previously, where a = 1, 2, 3 refers to oil supply, oil-specific demand, and aggregate demand shocks, respectively, whose impacts on inflation we estimate. The estimates for each type of shock are the same for every country in the panel. $Control_{i,t-l}$ is a set of control variables that includes the percentage change in the industrial production index for each country and the euro/dollar exchange rate, including its contemporaneous value and its value at 12 lags. We also include 12 lags of the inflation rate to control for persistence in inflation (Sekine and Tsuruga, 2018). Finally, $\epsilon_{i,t+h}$ represents the error term.

To obtain the impulse response function, we estimate equation (3) for each horizon h and obtain β^h, a coefficient that shows the response of the dependent variable in h to an exogenous shock in t. Therefore, the impulse response function is obtained by adding the coefficients for the entire estimation horizon, represented as $IRF(h) = \beta^h$ for h = 1, 2,…, H. We choose a time horizon of 24 months. To estimate equation (3), we use the Least Squares Dummy Variable Estimator with the Newey West Heteroskedasticity and Autocorrelation-Consistent covariance matrix.

2.2.2. Estimation of the transmission of oil price shocks based on the inflation environment

The local projection method can be extended to estimate impulse response functions in state-dependent models. Specifically, following Auerbach and Gorodnichenko (2012), the local projection method can be estimated as a smooth transition model using a logistic function as the transition between different states. To test whether the inflation environment affects the transmission of oil price shocks to inflation, we estimate the following equation:

$$p_{i,t+h} - p_{i,t-1} = \alpha_{i,h} + (1 - F(z_{i,t-1}))\left[\sum_{l=1}^{12} \mu_{H,l}^h (p_{i,t-i} - p_{i,t-1-i}) + \beta_H^h Shock_{a,t} + \sum_{l=0}^{12} \theta_{H,l}^h \, Control_{i,t-l}\right] + (F(z_{i,t-1}))\left[\sum_{l=1}^{12} \mu_{L,l}^h (p_{i,t-i} - p_{i,t-1-i}) + \beta_L^h Shock_{a,t} + \sum_{l=0}^{12} \theta_{L,l}^h \, Control_{i,t-l}\right] + \epsilon_{i,t+h} \quad (4)$$

where F(.) is the transition function represented by the following logistic function:

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

where $z_{i,t-1}$ is the transition variable. Here, we include the standardized past inflation rate as the state variable, as proposed by Sekine and Tsuruga (2018). Specifically, we use core inflation in our baseline model as we think it is a better indicator of the inflation environment, given that it excludes the most volatile components of the HICP. The state variable is represented as follows:

$$z_{i,t-1} = \frac{\pi_{i,t-1} - \bar{\pi}_i}{\hat{\sigma_i}} \quad (5)$$

where $\pi_{i,t-1}$ is the lagged inflation rate of country i, $\bar{\pi}_i$ is country i's average inflation rate during the period analyzed, and $\widehat{\sigma_i}$ is the standard deviation of that inflation rate. $F(z_{i,t-1})$ denotes the probability of being in a low inflation state. When $z_{i,t-1} \rightarrow \infty$, then $F(z_{i,t-1}) \rightarrow 0$, and the impulse response function would be represented by β_H^h, where the subscript H denotes a high inflation environment. In contrast, when $z_{i,t-1} \rightarrow -\infty$, $F(z_{i,t-1}) \rightarrow 1$, the impulse response function is given by β_L^h where the subscript L refers to a low inflation environment. The parameter γ sets the speed of the transition between states. If $\gamma = 0$, the model becomes the linear model as $F(z_{i,t-1})$ is always ½. On the other hand, if γ is very high, the transition between states is immediate, and the model would approximate a discrete transition model with a threshold dummy variable. Following Tenreyro and Thwaites (2016), we select $\gamma = 3$, which allows an intermediate speed for regime transitions. However, in section 4 we show that our results hold when we use different values of γ. In general terms, the impulse response function is the weighted sum of β_H^h and β_L^h, where the weight depends on the value of $F(z_{i,t-1})$ and is obtained as follows: $IRF(h) = \left(1 - F(z_{i,t-1})\right)\beta_H^h + \left(F(z_{i,t-1})\right)\beta_L^h$. In the extremes, a low inflation environment where $F(z_{i,t-1})$ takes the value 1, the impulse response function is given by $IRF^L(h) = \beta_L^h$ and in a high inflation environment, $F(z_{i,t-1})$ takes the value 0 such that the impulse response function is given by $IRF^H(h) = \beta_H^h$.

2.2.3. Including asymmetry in the transmission of oil price shocks

To analyze the asymmetric transmission of positive and negative shocks, we extend the model represented in equation (4) by substituting the variable $Shock_{a,t}$ for the following variables:

$$Shock_{a,t}^{+} = \begin{cases} Shock_t \ if \ Shock_{a,t} > 0 \\ 0 \qquad\quad Shock_{a,t} \leq 0 \end{cases}, \quad Shock_t^{-} = \begin{cases} Shock_t \ if \ Shock_{a,t} \leq 0 \\ 0 \qquad\quad if \ Shock_{a,t} > 0 \end{cases} \tag{6}$$

where $Shock_{a,t}^{+}$ refers to positive oil shocks, that is, those that trigger an increase in oil prices, and $Shock_{a,t}^{-}$ refers to negative shocks that reduce oil prices. We introduce both variables simultaneously to avoid any possible bias effects that might be induced by truncated variables. Using this method, we can analyze whether there is any asymmetry in the transmission of these shocks depending on their direction and whether these differences vary depending on the inflation environment for the economy at the time of the shock.

2.3. Data

We use monthly data for the period from January 1999 to January 2020 for a panel of the 12 initial countries of the eurozone (Austria, Belgium, Finland, France, Germany, Greece, Ireland, Italy, Luxembourg, the Netherlands, Portugal, and Spain). Our study period ranges from the creation of the euro to the latest data available. The HICP and the HICP excluding food and energy (HICPex) are obtained from Eurostat. The euro/dollar exchange rates are obtained from the International Monetary Fund's International Financial Statistics[2] database,

[2] In the case of Greece for the period from January 1999 to December 2000, we convert the drachma/dollar exchange rate to euro/dollar by multiplying the former by the fixed drachma/euro exchange rate set during the country's adoption of the euro.

and the industrial production index is obtained from the OECD database. The HICP, HICPex, and industrial production indices are seasonally adjusted (see Table A.1 in Appendix A).

To identify oil price shocks following Kilian (2009), we use monthly data from January 1974 to January 2020. The data elements are world oil production and the real refiner acquisition cost of imported crude oil, both obtained from the US Energy Information Administration, and the economic activity index developed by Kilian (2009). After obtaining the three types of structural shocks, we use these variables for the study period from January 1999 to January 2020.

3. Results

3.1. Linear model

Figure 2 shows the response of real oil prices to the three types of shocks[3], identified through the SVAR model defined in equation (2).

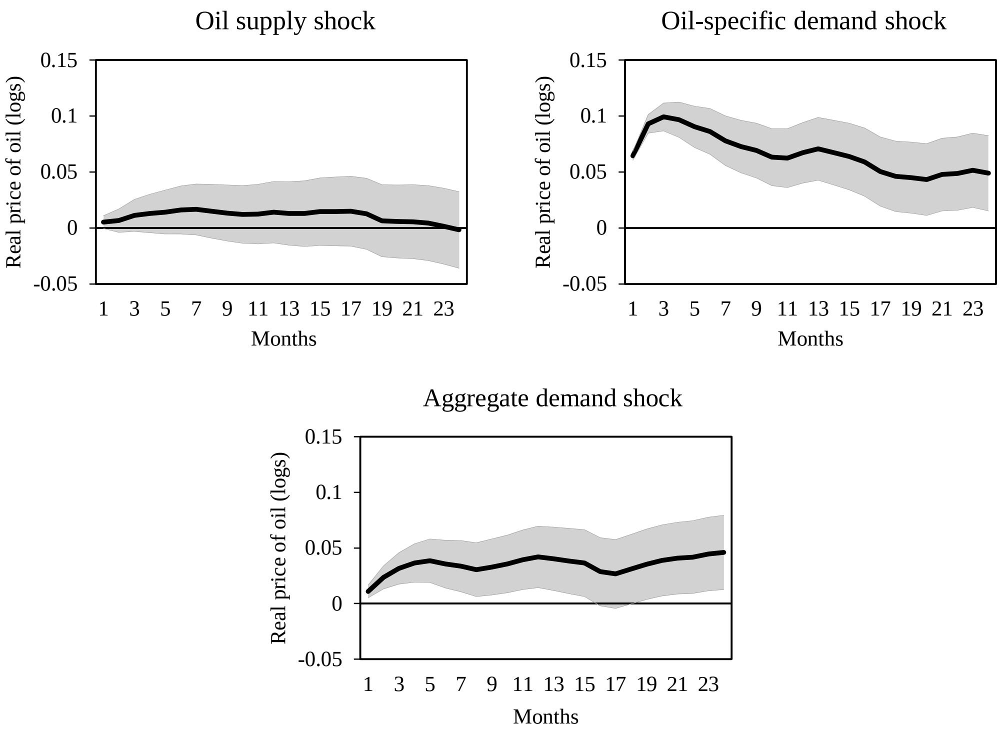

Fig. 2. Response of the real price of oil to one standard deviation of the three structural oil shocks. *Notes*: Oil supply shocks represent a one standard deviation decline in $\Delta prod$. Shaded areas denote 95% confidence intervals.

As seen in the graphs, oil prices respond differently depending on the source of the shock. Oil-specific demand shocks have a more direct impact on and a greater transmission to the price of oil, while aggregate demand shocks show a more gradual and persistent effect. Finally, of the three types of shocks, the price of oil has the lowest response to an oil supply shock, and the impact is reversed at the end of the time horizon.

[3] The three structural shocks are shown in Figure A.1. in Appendix A for the period 1999.01–2020.01.

Figure 3 shows the cumulative response of headline inflation and core inflation to a one standard deviation shock in the linear model in equation (3), estimated through local projections. There is a substantial difference between the effects of these shocks on headline and core inflation. Regarding the effects on headline inflation, supply shocks show a delayed transmission after six months, reflecting a slow transmission to oil prices that tends to disappear in the long term. In contrast, aggregate demand shocks increase the demand for oil because of an increase in global economic activity and have a higher inflationary effect over the long term, triggering a persistent increase in inflation over time, with the maximum accumulated effect observed at the end of the period. These results are in line with Kilian (2009) for the US and Lorusso and Pieroni (2018) for the UK. Finally, oil-specific demand shocks show a high initial impact that persists over the time period, similar to the findings of Enders and Enders (2017) for the eurozone. Kilian (2009) and Lorusso and Pieroni (2018) found a more gradual and persistent transmission for the US and UK, respectively, similar to that observed with aggregate demand shocks.

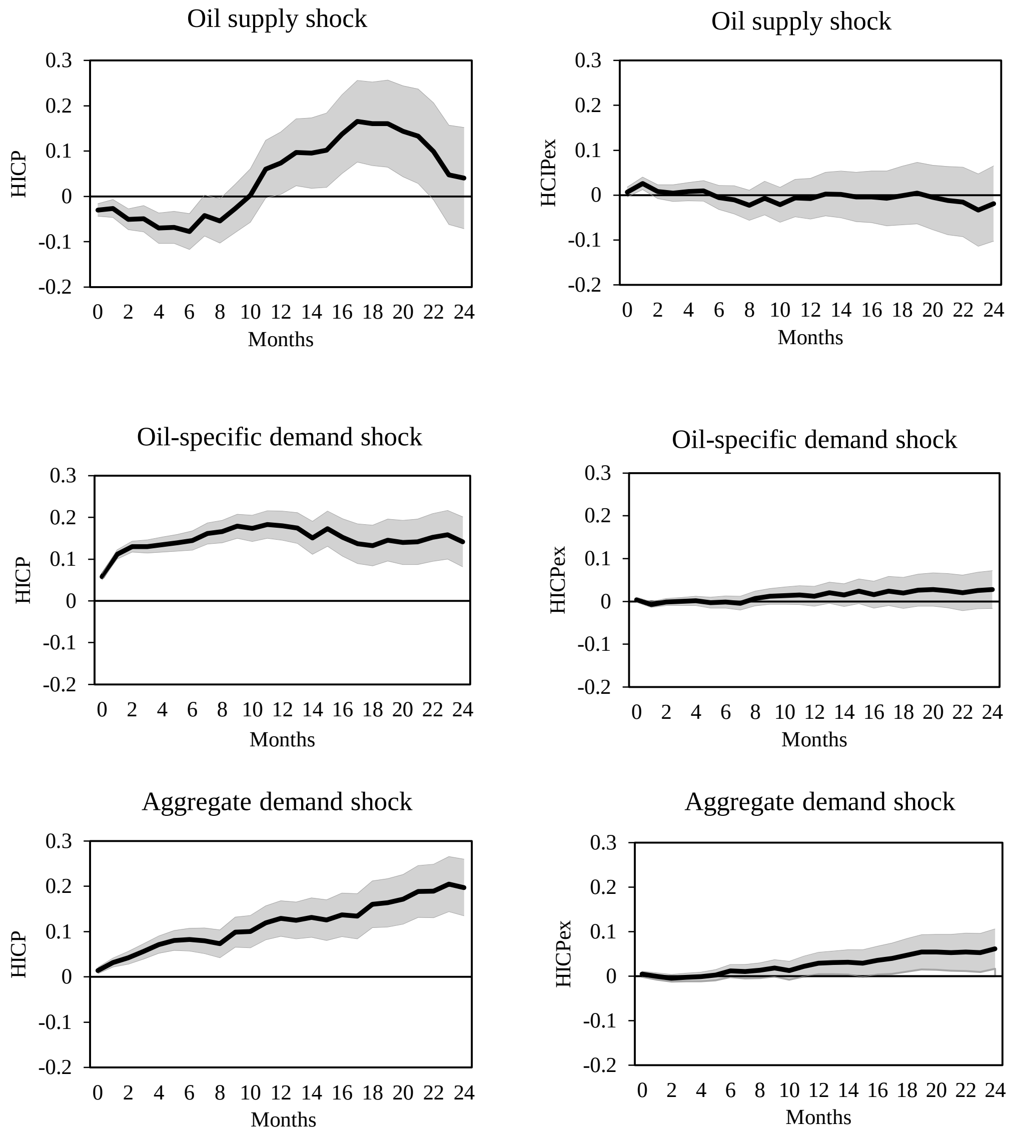

Fig. 3. Cumulative response of headline inflation (column 1) and core inflation (column 2) to the three structural oil shocks in the linear model. *Notes*: Figures show the cumulative effect of a one standard deviation shock to inflation. Shaded areas denote 90% confidence intervals. Supply shocks represent a decline in $\Delta prod$.

Regarding indirect effects reflected in the transmission of shocks to core inflation, the results show that oil-specific demand shocks have little cumulative effect on core inflation; similarly, the impact of oil supply shocks is negligible, which confirms that the effect of oil price shocks takes place through headline inflation rather than core inflation. The transmission of aggregate demand shocks to core inflation is higher than the other shocks as demand shocks are caused by increases in global economic activity that could increase domestic demand in the eurozone. However, the degree of transmission is still much lower than that of headline inflation.

These results confirm that the transmission of oil price shocks to eurozone inflation differs depending on the source of the shock, in line with previous works (Peersman and Van Robays, 2009; Herwartz and Plödt, 2016; Enders and Enders, 2017).

3.2. Introducing the inflation environment

Figure 4 shows the cumulative response of inflation to each type of shock in a low and a high inflation environment, using core inflation as the state variable as described in section 2.

The results show that the response of inflation to oil price shocks differs between these two states. After oil supply shocks and particularly with aggregate demand shocks, the inflation response is higher in a high inflation environment than in a low inflation environment. These results are in line with the predictions of the theoretical models in Taylor (2000) and Devereux and Yetman (2010) and with the empirical findings in Sekine (2020) for the US, although the latter does not distinguish between different types of oil price shocks or estimate transmission using a dynamic approach.

During periods of high inflation, aggregate demand shocks are transmitted persistently and to a greater extent than during periods of low inflation, where the initial impact is lower and is reversed at the end of the horizon. However, the response of core inflation is different: in a low inflation environment, aggregate demand shocks are initially transmitted to core inflation and remain stable during the second year, while in a high inflation environment, transmission is close to zero during the first year and then increases in the second year. However, the degree of transmission of the shock to core inflation is low such that the evolution shown by headline inflation in both states is mainly triggered by the response of energy prices.

With respect to oil supply shocks, we also observe a more direct transmission to headline inflation in high inflationary environments, although the differences are less pronounced than in the case of aggregate demand shocks. With core inflation, transmission is slightly positive in high inflation environments, while in low inflation environments, the transmission is reversed after a slightly positive transmission in the first months, becoming negative in the longer term.

Finally, oil-specific demand shocks initially show a lower transmission in high inflation environments, although transmission is similar in the long run because of greater persistence in the inflation response in high inflation environments, compared to low inflation environments. This higher persistence is partially a consequence of a higher transmission of the shocks to core inflation in a high inflation environment, which shows the existence of higher indirect effects.

This finding, which is contrary to what theory predicts, may be the consequence of failing to account for asymmetries between positive and negative shocks such that the results may conceal the existence of a greater asymmetry in high inflationary environments, as predicted by the theoretical results in Ball and Mankiw (1994). In the next section, we empirically explore the existence of such sign asymmetries.

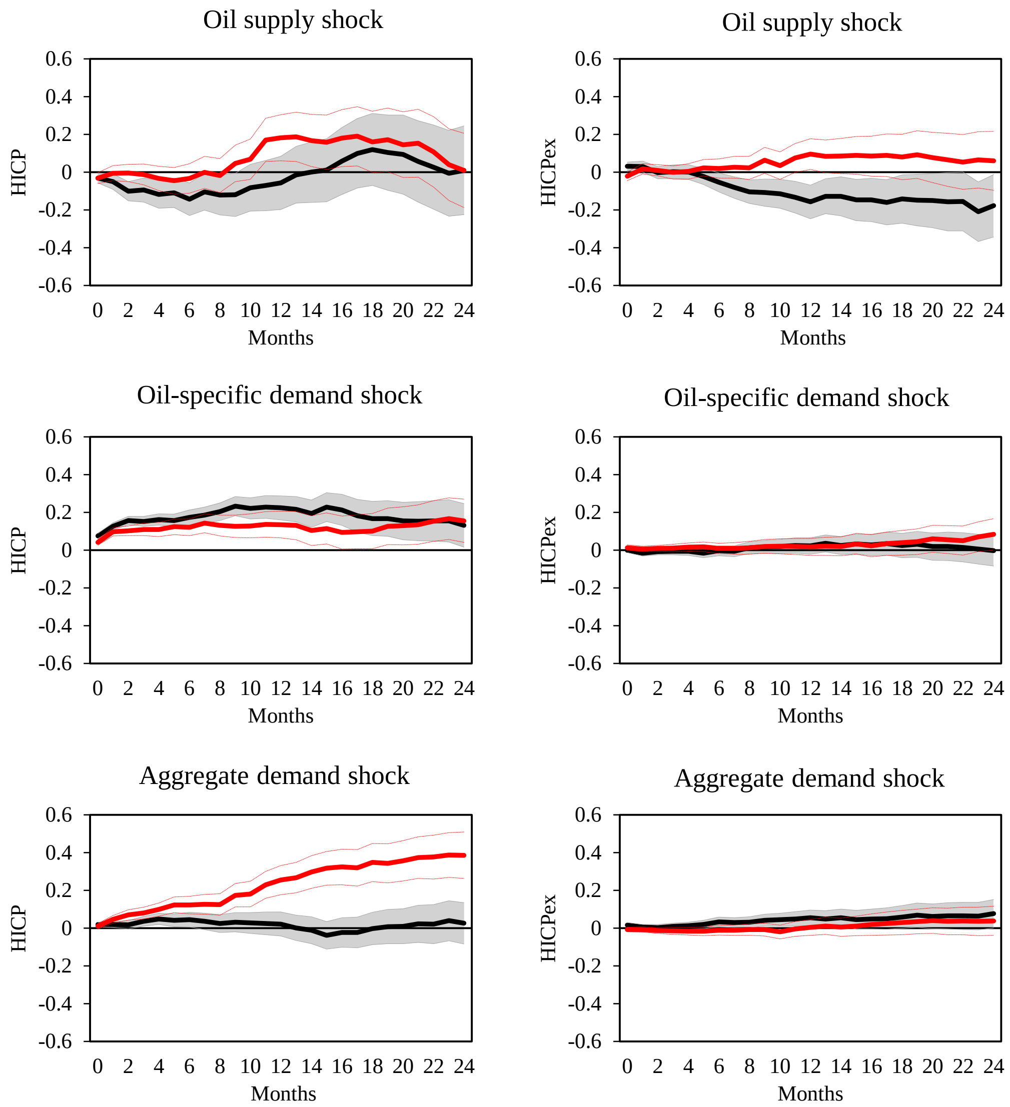

Fig. 4. Cumulative response of headline inflation (column 1) and core inflation (column 2) to the three structural oil shocks in the state-dependent model. *Notes*: Figures show the cumulative effect on inflation of a one standard deviation shock. The black line denotes the response of inflation in a low inflation environment. The red line denotes the response of inflation in a high inflation environment. Shaded areas denote 90% confidence intervals.

3.3. Asymmetry in the transmission of oil price shocks

The results presented in the previous section are obtained under the assumption that the response of inflation to oil price shocks is symmetric. In this section, we relax this assumption, estimating the model in equation (4) by distinguishing between positive shocks (which increase oil prices) and negative shocks (which reduce oil prices). Results are shown in Figures 5 and 6 and are summarized in Tables 1 and 2 for headline inflation and core inflation, respectively.

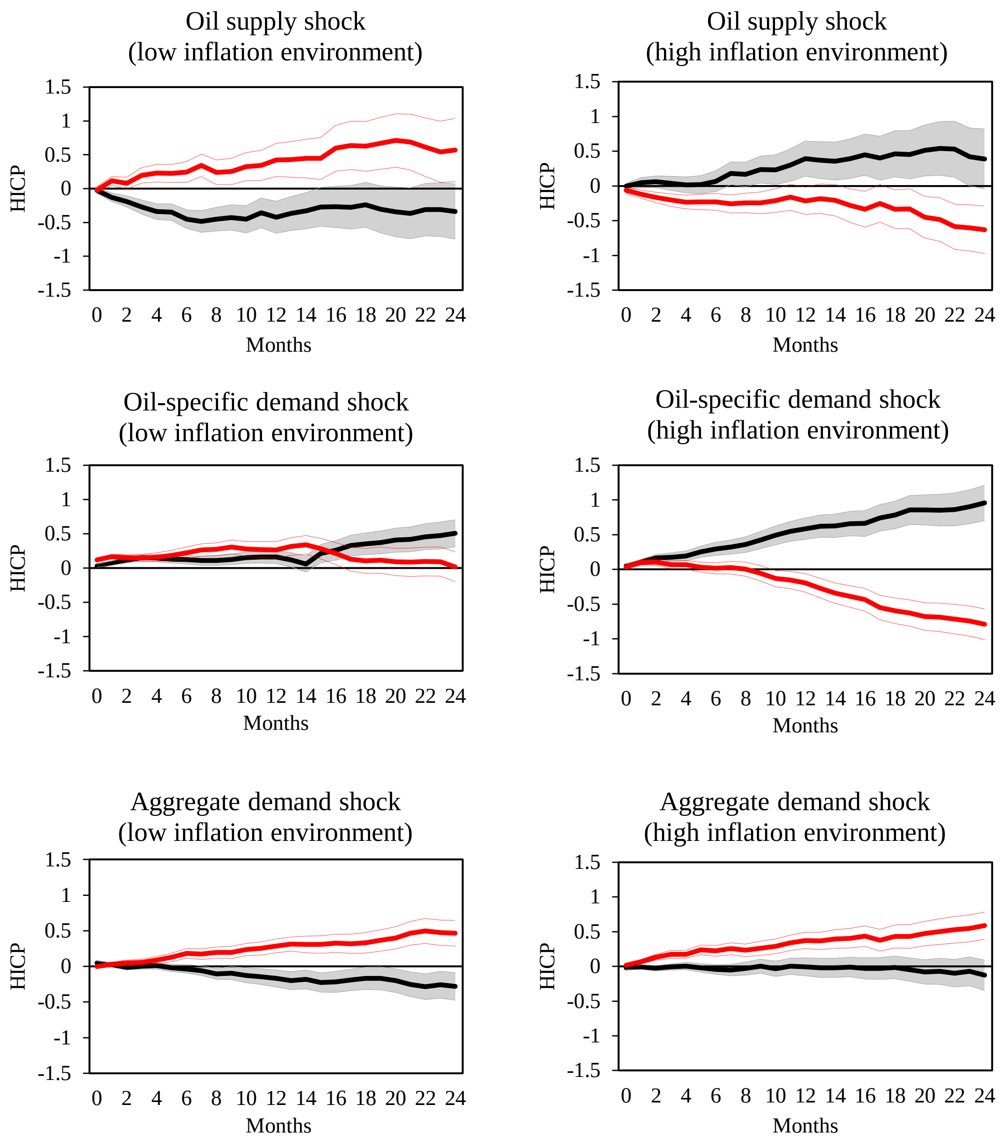

Fig. 5. Cumulative response of headline inflation to the three types of structural oil shocks in a low inflation environment (column 1) and in a high inflation environment (column 2). *Notes*: Figures show the cumulative effect on inflation of a one standard deviation shock. The black line denotes the response of inflation to a positive shock. The red line denotes the response of inflation to a negative shock. Shaded areas denote 90% confidence intervals.

These results show the importance of distinguishing between positive and negative shocks in analyzing their transmission to inflation and the role played by the inflation environment in which they occur. For supply shocks, we find that the direction of the asymmetry changes depending on the inflation environment. In a low inflation environment, a negative shock, that is, an increase in oil production that causes oil prices to fall, triggers a drop in inflation, while a positive shock shows a U-shaped response, with an initial drop in inflation followed by a small increase after six months, although its cumulative effect remains negative. In contrast, in high inflation environments, positive shocks have a greater impact on inflation, while negative shocks do not generate a decline in inflation but rather an increase in the long run. These results, which are in line with the asymmetry generated by the existence of positive trend inflation (Tsiddon, 1993; Ball and Mankiw, 1994), reflect the reaction of core inflation such that in high inflation environments, indirect effects play an important role in the response of inflation to the shocks. In contrast, in a low inflation environment, the response of core inflation is more muted and does not show any significant asymmetry.

State	Sign	Positive			Negative			Difference by shock		
	Shock	Oil supply shock	Oil-specific demand shock	Agg. demand shock	Oil supply shock	Oil-specific demand shock	Agg. demand shock	Oil supply shock	Oil-specific demand shock	Agg. demand shock
Low inflation	Max impact (%)	−0.03	0.51	0.05	0.71	0.34	0.50	−0.74	0.17	−0.45
	Impact after 12 months (%)	−0.42	0.16	−0.17	0.42	0.27	0.29	−0.85	−0.11	−0.46
	Impact after 24 months (%)	−0.34	0.51	−0.28	0.57	0.02	0.46	−0.91	0.49	−0.75
High inflation	Max impact (%)	0.54	0.96	0.00	−0.07	0.10	0.59	0.60	0.85	−0.58
	Impact after 12 months (%)	0.39	0.59	0.00	−0.21	−0.19	0.37	0.61	0.78	−0.38
	Impact after 24 months (%)	0.39	0.96	−0.13	−0.63	−0.79	0.59	1.02	1.75	−0.71
Difference by state	Max impact (%)	0.57	0.45	−0.04	−0.78	−0.23	0.09			
	Impact after 12 months (%)	0.82	0.43	0.17	−0.64	−0.46	0.09			
	Impact after 24 months (%)	0.73	0.45	0.15	−1.20	−0.81	0.12			

Notes: The cumulative impact represents the % change in HICP generated by a one standard deviation shock, estimated using the model in equation (4) and including the shocks as defined in equation (6).

Table 1. Summary of the transmission of structural oil price shocks to headline inflation.

For oil-specific demand shocks, the results are in line with what the theory predicts (Tsiddon, 1993; Ball and Mankiw, 1994), with asymmetry higher in a high inflation environment. In a low inflation environment, transmission of both positive and negative shocks is similar, although positive shocks are more persistent, while negative shocks revert at the end of the horizon. However, in high inflation environments, the transmission of positive shocks is higher and more persistent, while negative shocks, after an initial drop in inflation, are reversed, and the cumulative effect is a higher price level. These findings are in line with previous studies such as An et al. (2014) who found that positive shocks have a greater impact on inflation in the US than negative shocks, although comparability is limited as their study does not distinguish between the source of the shock or inflation environment in which it is generated. Finally, indirect effects are negligible in low inflation environments, while core inflation shows a similar transmission as headline inflation in high inflation environments, albeit to a lesser extent.

It is important to note that when we allow for the existence of asymmetric responses to positive and negative shocks, the counterintuitive results seen in Figure 4 that show oil-specific demand shocks have a higher transmission in low inflation environments disappear, in line with theoretical predictions. In other words, the lower transmission of these shocks in high inflation environments shown in Figure 4 is caused by the low transmission of negative oil-specific demand shocks, which turns negative, offsetting the higher transmission shown by positive shocks in high inflation environments. This proves the need to consider the existence of asymmetry in the response to these shocks; when the asymmetry is ignored, the results vary significantly as they average the responses of two different shocks (positive and negative shocks) whose level and rate of transmission differ.

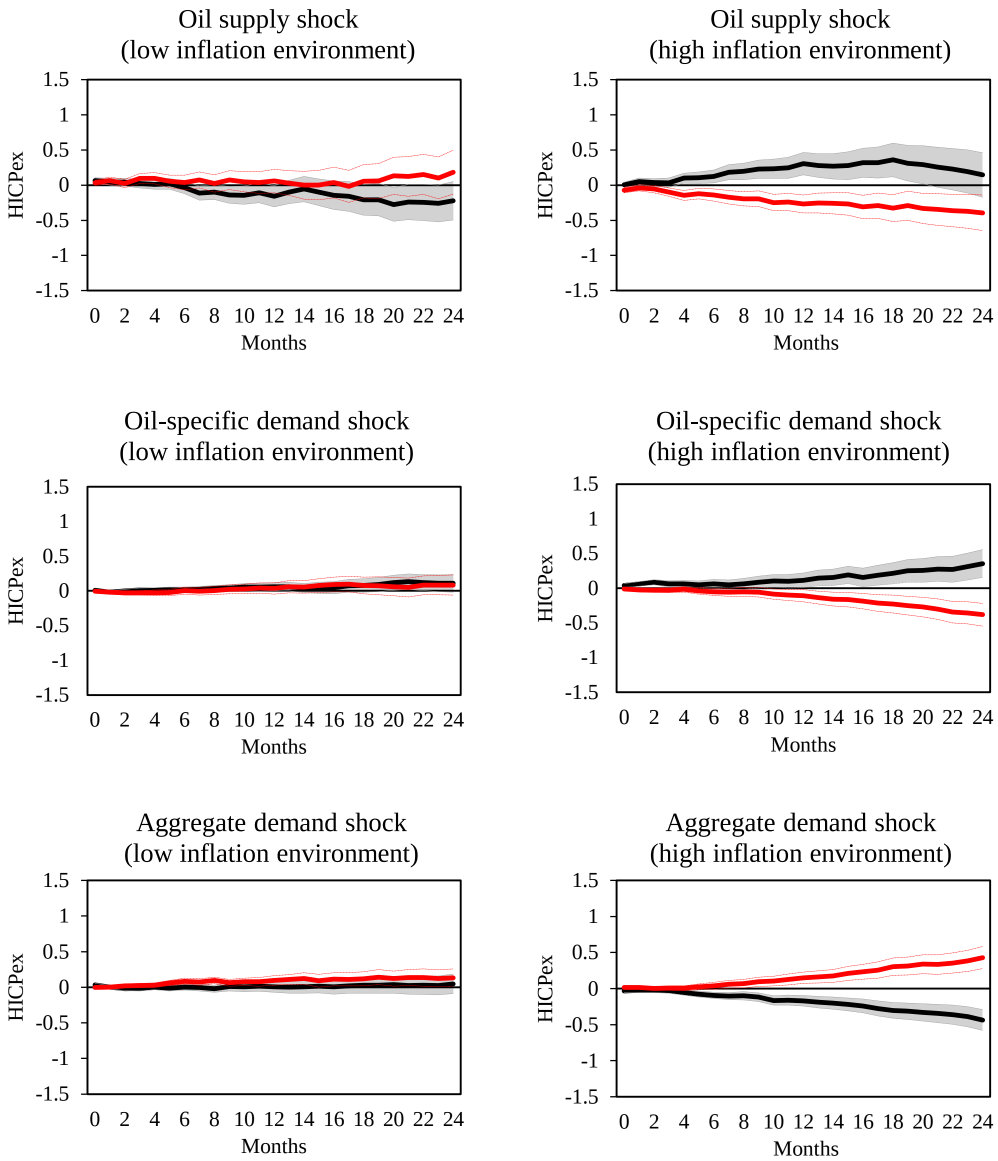

Fig. 6. Cumulative response of core inflation to the three types of oil shocks in a low inflation environment (column 1) and a high inflation environment (column 2). *Notes*: Figures show the cumulative effect on inflation of a one standard deviation shock. The black line denotes the response of inflation to a positive shock. The red line denotes the response of inflation to a negative shock. Shaded areas denote 90% confidence intervals.

Aggregate demand shocks show a different pattern, compared to the two other shocks as in both states, a persistent drop in inflation is seen after a negative shock, while positive shocks have a minor effect and even show a negative cumulative effect in low inflationary environments. Regarding transmission to core inflation, in an environment of low inflation, transmission is insignificant, while in high inflation environments, negative shocks trigger a significant drop in core inflation, and positive shocks also eventually produce a negative cumulative effect.

Contrary to what we observe for the other types of shocks, these results are consistent with Evgenidis (2018) who found that in periods of high financial stress, negative oil price shocks have a greater impact on inflation than positive shocks in the eurozone and Donayre and Wilmot (2016) who show that negative shocks have a greater impact on inflation than positive shocks in periods of low economic growth.

State	Sign	Positive			Negative			Difference by shock		
	Shock	Oil supply shock	Oil-specific demand shock	Agg. demand shock	Oil supply shock	Oil-specific demand shock	Agg. demand shock	Oil supply shock	Oil-specific demand shock	Agg. demand shock
Low inflation	Max impact (%)	0.07	0.13	0.05	0.18	0.1	0.14	−0.12	0.03	−0.09
	Impact after 12 months (%)	−0.16	0.06	0.01	0.06	0.03	0.1	−0.22	0.03	−0.09
	Impact after 24 months (%)	−0.22	0.11	0.05	0.18	0.08	0.13	−0.41	0.02	−0.08
High inflation	Max impact (%)	0.36	0.36	−0.02	−0.04	−0.01	0.43	0.4	0.37	−0.45
	Impact after 12 months (%)	0.31	0.11	−0.17	−0.27	−0.11	0.15	0.57	0.22	−0.32
	Impact after 24 months (%)	0.15	0.36	−0.44	−0.39	−0.38	0.43	0.54	0.74	−0.86
Difference by state	Max impact (%)	0.29	0.22	−0.07	−0.22	−0.11	0.29			
	Impact after 12 months (%)	0.46	0.05	−0.18	−0.33	−0.14	0.05			
	Impact after 24 months (%)	0.37	0.25	−0.48	−0.58	−0.47	0.3			

Notes: The cumulative impact represents the % change in the HICPex generated by a one standard deviation shock, estimated using the model in equation (4) and including the shocks as defined in equation (6).

Table 2. Summary of the transmission of structural oil price shocks to core inflation.

Further, it is important to emphasize the differences in the response of inflation to oil-specific demand shocks versus aggregate demand shocks. In a high inflation environment, negative aggregate demand shocks trigger a persistent drop in inflation, while oil-specific demand shocks, after an initial drop in inflation, cause price levels to increase such that the cumulative impact is higher inflation in the long run. One possible explanation for this is the transmission mechanisms of these shocks to the output. A negative aggregate demand shock reduces the price of oil and triggers a decline in global economic activity; this can be translated into a decline in domestic economic activity in the eurozone. On the other hand, a negative oil-specific demand shock, perhaps caused by precautionary or speculative actions, sparks the opposite response in terms of production (Kilian, 2009; Peersman and Van Robays, 2009); in other words, a lower cost of oil has a positive effect on production, so that, in an environment of high inflation, that translates into greater pressures on prices. The long-term effect is an increase in both headline and core inflation.

4. Robustness

In this section, we test the robustness of the results obtained thus far to the following: (i) the method used to identify exogenous oil price shocks; (ii) the choice of the speed of transition between regimes, determined by the parameter γ; (iii) the choice of the state variable $z_{i,t-1}$ used to define the inflationary environment; and (iv) the method used to define the transition between states or inflation environments.

4.1. Alternative identification of oil price shocks

In the baseline model, we identify oil price shocks using an exclusion restriction with a recursive structure, following the identification strategy in Kilian (2009). However, in studies of the oil market, oil price shocks are often identified via sign restrictions. To determine whether our results are robust to the identification method, we follow the strategy in Kilian and Murphy (2014) who distinguish between flow supply, flow demand, and speculative demand shocks. To do so, we extend the model in Kilian (2009) by adding a variable that represents changes in OECD crude oil inventories[4]. Following Kilian and Murphy (2014), we use sign restrictions in the contemporary response of the variables to these different types of shocks, as shown in Table 3.

We impose two additional restrictions. First, we include dynamic restrictions on the response of oil production, global economic activity, and the price of oil to maintain the sign imposed on the contemporary response for 12 months after a flow supply shock. Second, the impact price elasticity of oil supply is restricted to be less than or equal to 0.25, while the impact price elasticity of oil demand is restricted to be between 0 and −0.80 (see Kilian and Murphy, 2014).

	Flow supply shock	Flow demand shock	Speculative demand shock
Oil production	-	+	+
Real activity	-	+	-
Price of oil	+	+	+
Inventories			+

Source: Kilian and Murphy (2014). *Notes*: All shocks are normalized to imply an increase in the price of oil.

Table 3. Sign restrictions on the contemporary impact responses in the SVAR model.

The results, shown in Appendix B, are in line with those obtained in the baseline model. Specifically, flow demand shocks are equivalent to aggregate demand shocks, while speculative demand shocks are equivalent to oil-specific demand shocks. This demonstrates that the conclusions obtained from our baseline results are robust to the method of identifying oil price shocks.

4.2. Speed of regime switching

In our baseline model, the parameter that determines the speed of transition between states is set to $\gamma = 3$, following Tenreyro and Thwaites (2016). To test the sensitivity of our results to the value of this parameter, we re-estimate the model in equation (4), setting γ to 1.5 and 6 and, thereby, allowing the speed of transition to be lower and higher than in the baseline model, respectively. Results are provided in Appendix C and show that in both scenarios, the results are in line with those found in the baseline model.

4.3. State variable

In the baseline model, we employ standardized core inflation as the state variable. The choice of core inflation is motivated by the fact that it better represents the true inflation environment than headline inflation as it is not exposed to the volatility of energy and food prices.

[4] Since data on OECD crude oil inventories are not available, Kilian and Murphy (2014) calculated the ratio of oil and petroleum product inventories between the OECD and the US and multiplied US crude oil inventories by this ratio.

However, other studies (Sekine and Tsuruga, 2018; Cheikh and Zaied, 2020; Sekine, 2020) have used headline inflation as the state variable. In order to check the robustness of the model to this specification, we substitute core inflation with headline inflation as the state variable. In general, these results (shown in Appendix D) do not differ from those obtained in the baseline model, allowing us to conclude that the baseline results are robust to the choice of the state variable.

4.4. Definition of the transition between states

In this section, we test the robustness of our baseline findings to an alternative approach to determining the economy's current inflation environment (high or low). To do so, we extend the linear model to a threshold state-dependent model (Ahmed and Cassou, 2016; Ramey and Zubairy, 2018; Ahmed and Cassou, 2021), represented in the following equation:

$$p_{i,t+h} - p_{i,t-1} = \alpha_{i,h} + D_{i,t-1}\left[\sum_{l=1}^{12} \mu_{H,l}^{h}(p_{i,t-i} - p_{i,t-1-i}) + \beta_{H}^{h} Shock_{a,t} + \sum_{l=0}^{12} \theta_{H,l}^{h}\, Control_{i,t-l}\right] + (1 - D_{i,t-1})\left[\sum_{l=1}^{12} \mu_{L,l}^{h}(p_{i,t-i} - p_{i,t-1-i}) + \beta_{L}^{h} Shock_{a,t} + \sum_{l=0}^{12} \theta_{L,l}^{h}\, Control_{i,t-l}\right] + \epsilon_{i,t+h} \quad (7)$$

where $D_{i,t-1} \in \{0,1\}$ is a dummy variable that represents the inflation environment and is defined as follows:

$$D_{i,t-1} = \begin{cases} 1 \; if \; \pi_{i,t-1} > \bar{\pi}_i \\ 0 \; if \; \pi_{i,t-1} \leq \bar{\pi}_i \end{cases} \quad (8)$$

where $\pi_{i,t-1}$ is the lagged core inflation of country i, and $\bar{\pi}_i$ is the average core inflation over the period studied. Therefore, when the lagged core inflation is higher than the country's average over the period, $D_{i,t-1}$ takes a value of 1, indicating that the economy is in a high inflation environment; when the lagged core inflation is below the country's average, the economy is in a low inflation environment, with $D_{i,t-1}$ taking a value of 0. This method differs from the approach used in equation (4) as it does not assume a smooth transition between inflation regimes or environments but rather that the transition occurs when the state variable exceeds the threshold value.

The results, displayed in Appendix E, do not show any significant differences with respect to the baseline model, confirming the robustness of our findings.

5. Discussion of the results

The results presented in this study show that when analyzing the effect of oil price shocks on inflation, it is essential to consider both the inflationary environment in which they occur and the sign of the shocks, as the consequences of the shocks differ depending on these factors.

When we analyze oil price shocks originating from the oil market itself, that is, oil supply and oil-specific demand shocks, the results are in line with theoretical predictions. In high inflation environments, positive shocks, that is, those that increase the price of oil, are transmitted to inflation to a greater extent than negative shocks, producing indirect effects reflected in an increase in core inflation. This relationship is consistent with the theoretical model in Taylor (2000), which argues that in an environment of higher inflation, firms have expectations of higher future inflation and greater persistence of oil price shocks and, thus, transmit these higher costs to their prices to a greater degree. Furthermore, our results show that the degree of transmission of negative price shocks is greater in low inflation environments, while in high inflation environments, that transmission is very low. This is in line with the theoretical prediction in Ball and Mankiw (1994) who show that the frequency of price increases because changes in costs grows with higher trend inflation, while the frequency of price reductions decline, leading to greater asymmetry. These results with respect to the frequency of price changes have been empirically supported at the microeconomic level for Mexico (Gagnon, 2009), Argentina (Alvarez et al., 2019), the eurozone, and the US (Dhyne et al., 2006).

Moreover, our results for aggregate demand shocks show a reaction pattern for both headline and core inflation that differs from the pattern found for the other type of shocks. In both low and high inflation environments, we find a high degree of asymmetry between positive and negative shocks. Slumps in global economic activity trigger a persistent decline in consumer prices, while increases in global economic activity have a very low level of transmission to inflation and even show a negative cumulative impact in a low inflation environment. One possible explanation for the reduced impact of positive aggregate demand shocks is a greater impact of monetary policies that respond to demand pressure in the economy, which would be reflected in the negative transmission seen in core inflation in our estimates and offset the inflationary effect of the energy component. Another possible explanation could be an asymmetric impact of global economic activity on domestic economies within the eurozone, whereby an increase in global economic activity does not necessarily result in higher domestic economic activity, whereas a downturn in global economic activity triggers a decline in domestic demand and, therefore, a drop in consumer prices in the eurozone.

Other empirical studies have found evidence of negative asymmetry, such as Evgenidis (2018) who shows that in periods of high financial stress, negative shocks have a greater deflationary effect than the inflationary effect of positive shocks in the eurozone. Donayre and Wilmot (2016) found that negative oil price shocks in Canada have a greater transmission to inflation than positive shocks, especially in periods of low economic growth. Our results imply that periods of declining global economic activity, such as the global financial crisis of 2008 or the decline in economic activity caused by the slowdown in China's economy in 2014–2015, would have triggered greater deflationary pressure than the inflationary pressures generated during periods of booming global economic activity, such as during the period from 2006 to 2007.

Another important finding is the pattern of transmission of oil price shocks to core inflation. Our results show that in a low inflation environment, the transmission is negligible for all types of shocks, while transmission is significant in high inflation environments, with an inflationary effect from shocks originating in the oil market itself. These findings are relevant for monetary policy, as in a context of low inflation such as the one the eurozone has experienced since the global financial crisis, the inflationary effects of oil price shocks are small and transitory and do not trigger the indirect effects that force a central bank to tighten monetary policies to counter inflationary pressures. These considerations should be considered by central bank authorities, especially given that the trade-off between controlling inflation or stabilizing output that oil price shocks represent is reduced in an environment of low inflation.

By way of an example, in July 2008, just prior to the start of the global financial crisis, the ECB raised interest rates by 25 basis points in reaction to a rise in the price of oil that was attributed to increased oil demand. Monetary policy was consistent with what was predictable according to a linear model. However, this policy action would not have been consistent with the results of a model that accounts for the current inflation environment and the direction of the shock. This illustrates the practical implications for pursuing a detailed analysis of the transmission of oil price shocks to inflation in determining effective monetary policy.

6. Conclusions

This study analyzes the transmission of oil price shocks to inflation using a state-dependent model. Distinguishing between three types of oil price shocks (oil supply, oil-specific demand, and aggregate demand shocks), the model conditions the response of inflation to the inflation environment in which shocks occur and the direction of the shocks themselves, producing a comprehensive study of the transmission of oil price shocks to inflation.

The results show that the inflation environment in which shocks take place is a key determinant when analyzing whether and how those shocks are transmitted to inflation, as it affects both the degree of transmission and the asymmetry between positive and negative shocks. The transmission of oil price shocks differs depending on the current inflation environment and on the direction of the shocks, and those differences vary among the different types of shocks. The shocks generated in the oil market itself, that is, oil supply and oil-specific demand shocks, show a greater inflationary effect in periods of high inflation, while negative shocks have a higher deflationary impact in a low inflation environment, in line with the results predicted in theoretical models (Ball and Mankiw, 1994; Taylor, 2000). However, aggregate demand shocks, that is, those caused by variations in global economic activity, show an asymmetry that holds in both states; negative shocks generate a persistent decline in inflation, whereas positive shocks are barely transmitted. This last finding implies that the deflationary risk posed by negative aggregate demand shocks is higher than the inflationary risk of positive aggregate demand shocks. This is particularly relevant in low inflation environments, where the risk of deflation is higher and monetary policy must react in order to prevent the economy from sinking into a deflationary spiral. In high inflation environments, these findings are less relevant for monetary policy as the inflationary risk of positive shocks is low, while the decline in inflation caused by negative aggregate demand shocks can offset the inflationary pressures that emerge in a high inflation environment, thus allowing a central bank to accommodate these shocks and avoid tightening its monetary policy.

Another important finding is that the transmission of oil price shocks to core inflation, which represents the indirect effects of oil price shocks, is negligible in a low inflation environment but significant in a high inflation environment. This implies that monetary policy authorities, whose inflation target focuses on the medium-term dynamics of core inflation (ECB, 2011) should not be concerned by the inflationary effect of these shocks when the macroeconomic environment is characterized by low inflation. In contrast, in a high inflation environment, the transmission of shocks, especially those originating from the oil market itself, are substantially transmitted to core inflation; in this situation, positive shocks generate inflationary pressures that the central bank must take into account when establishing its monetary policy.

The main implication of these results is that when deciding how to react to oil price shocks, a central bank must consider the current inflation environment to design an optimal monetary policy as the extent to which inflation reacts to oil price shocks depends to a great extent on the inflation setting in which the shocks occur.

Further, our results show certain counterintuitive behaviors that call for future research on their possible causes. This is especially relevant in the case of aggregate demand shocks as inflation shows little response to positive shocks, contrary to what is expected by economic theory. However, this finding highlights the importance of taking into account all the factors that interact when analyzing oil price shocks, such as the inflation environment as well as the source and direction of the shock itself.

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