Global Oil Shocks and the Euro Area. An Empirical Model-Based Analysis*

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Abstract

We assess the impact of oil shocks on euro area macroeconomic variables by estimating with Bayesian methods a new-Keynesian small open economy model. Oil price is determined according to supply and demand conditions in the world oil market. We get the following results. First, the impact of an increase in the price of oil depends upon the underlying source of variation. When the driver of higher oil prices is the increase in the aggregate demand in the trade partners of the euro area, both euro area GDP and CPI inflation increase. To the opposite, negative oil supply shocks and positive worldwide oil-specific demand shocks have stagflationary effects on the euro area economy. Second, a positive aggregate demand shock in euro area trade partners tends to generate a trade balance surplus and an oil trade deficit in the euro area. To the opposite, unanticipated increases in the oil-demand specific and unanticipated oil supply disruptions cause a trade balance deficit in the euro area. Third, oil price shocks have a large and immediate effect on the fuel component of euro area CPI and muted impact on the non-fuel component of euro area CPI and euro area GDP. Fourth, the increase in the price of oil during the 2000s did not induce stagflationary effects on the euro area economy because it was associated with positive aggregate demand shocks in the main trade partners of the euro area. A similar reason (the drop in foreign aggregate demand) contributes to explain the recent simultaneous drop in oil prices, euro area GDP and inflation (in particular its fuel component).

JEL codes: C11, C51, E32, F41.

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1 Introduction

The wide swing in the oil prices in the recent years have strongly renewed the need of assessing the macroeconomic effects of oil shocks. Even if oil represents a relatively small share of the overall consumption basket and production costs in industrialized countries, it crucially affects households and firms’ decisions for several reasons. First, the oil price is rather volatile and hence its fluctuations have a relative large impact on domestic and international relative prices and inflation rates. Second, oil and non-oil goods are hardly substitutable. This feature is itself an amplifying factor of the relative price of oil, as wide changes in the latter are needed for a given change in the allocation of aggregate demand between oil and non-oil goods. Third, industrialized countries are net importers of oil, so they are affected by the wealth effect associated with the changes in the international relative price of oil.

Several theoretical and empirical contributions have analyzed the implications of oil shocks and their propagation mechanism to consumption and investment decisions by households and firms. Moreover, more recent contributions have emphasized the need of identifying the underlying (demand and supply) fundamental sources of changes in oil prices, as the implied macroeconomic effects can be rather different.1

So far the analysis has mainly focused on the effects on the U.S. economy. To the opposite, the analysis of the euro area has remained relatively underdeveloped, except few contributions (see later).

In this paper we try to fill the gap by assessing the macroeconomic effects of oil shocks on the euro area economy. Our contribution consists in developing and estimating a small open economy DSGE model of the euro area that explicitly differentiates between oil and non-oil goods. Similarly to other contributions on oil and macroeconomy, we assume that the price of crude oil is determined in the world oil market. We formalize the oil market in a rather stylized way but, at the same time, we try to disentangle and estimate the different sources of changes in oil prices that are relevant from an euro area perspective. Specifically, we assume that the oil supply follows an exogenous process, while oil demand depends upon the degree of economic activities in the euro area and in the euro area trade partners and upon an exogenous residual variable. The latter captures shocks that do not affect directly aggregate demand in the euro area or in the euro area trade partners, such as aggregate demand shocks in the rest of the world

1See Barsky and Kilian (2004), Kilian (2008a, 2009).
and oil-specific demand shocks due to speculative or precautionary reasons.\textsuperscript{2}

Under this approach, aggregate demand shocks in the euro are trade partners would affect the euro area economy through two channels: a traditional direct trade channel and an “oil price” channel. Instead, shocks to the residual component of oil demand (called “oil-specific demand shocks” in the rest of the paper) would affect the euro area only through changes in the international relative price of oil.

Consistently with empirical evidence on the euro area, we assume that crude oil is imported from the rest of the world and sold to domestic households (for consumption purposes) and firms (as intermediate good in the production function). Moreover, we assume there is an (exogenous) time-varying wedge between the price of crude oil (paid at the border) and the price of fuel (paid by consumers and firms). The wedge is a shortcut for catching the presence of (value added and excise) taxes, refining and distribution margins in the fuel price.\textsuperscript{3} Other features of the model are standard and in line with the new-Keynesian small open economy model of Adolfson et al. (2007).

Households in the small economy consume and invest in physical capital and in two riskless bonds, denominated in domestic and rest of the world’s currency, respectively. We assume that nominal wages and prices are sticky and subject to indexation. As a consequence, there is a nontrivial role for monetary policy, that is set according to a standard Taylor rule. For international trade variables, we make the following assumptions. First there is (possibly different) home bias in consumption and investment. Second, firms are specialized in the production of a tradable intermediate good and set prices in the currency of the destination market (local currency pricing assumption). A similar assumption holds for firms in the rest of the world producing non-oil goods. For crude oil, instead, we assume that the international law of one price holds. Third, as said above, a riskless bond is internationally traded. So international financial markets are incomplete, implying the existence of a cross-country wealth effect associated with changes in international relative prices, in particular in the price of oil. Finally, an uncovered interest parity links the (domestic and rest of the world) interest rate differential to the expected bilateral nominal exchange rate. Finally, the model is estimated on euro area and rest of the world data with Bayesian methods.

Our results are as follows.

\textsuperscript{2}This is consistent with Lutz Kilian’s claim on the need to distinguish across the various (demand and supply) sources of oil and energy price changes for properly assess the macroeconomic effects of the changes themselves. See Kilian (2008b).

\textsuperscript{3}For an analysis of the role of the refining and distribution margins, see Kilian (2008a, 2010).
First, the impact of an increase in the price of oil depends upon the underlying source of variation. When the driver of higher oil prices is the increase in the aggregate demand in the trade partners of the euro area, both euro area GDP and CPI inflation increase. To the opposite, negative oil supply shocks and positive worldwide oil-specific demand shocks have stagflationary effects on the euro area economy.\(^4\) Second, a positive aggregate demand shock in euro area trade partners tends to generate in the euro area a trade balance surplus and an oil trade deficit. To the opposite, unanticipated increases in the oil-demand specific and unanticipated oil supply disruptions cause a trade balance deficit, as the oil trade deficit more than compensates for the non-oil trade surplus driven by the drop in euro area demand.\(^5\) Third, oil price shocks have a large and quick effect on the price of the fuel component of euro area CPI and muted impact on the non-fuel component of euro area CPI and euro area GDP. Fourth, the increase in the price of oil during the 2000s has not induced stagflationary effects on the euro area economy because it was associated with positive aggregate demand shocks in the main trade partners of the euro area. A similar reason (the drop in world aggregate demand) contributes to explain the recent simultaneous drop in oil prices, euro area GDP and inflation (in particular its fuel component).

Our paper is related to other contributions that exploit DSGE models to assess the impact of oil on macroeconomic variables.

For the US, Bodenstein et al. (unpublished) use a large scale two-country open economy DSGE model to assess the impact of different oil shocks on the US trade balance under alternative assumptions on the strength of the wealth effect associated with changes in the relative prices of oil. Nakov and Pescatori (2009) estimate a DSGE model using US data to assess the contribution of oil shocks to the great moderation. They find that oil related effects explain around a third of the decrease in the inflation volatility.\(^6\) Blanchard and Riggi (2009), building on Blanchard and Gali (2007), find for the US that the vanishing correlation between oil prices and the business cycle is the result of important structural changes (such as the weakening of unions and the anchoring of medium-run inflation expectations) modifying the transmission mechanism of oil

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\(^4\)Lippi and Nobili (2009) estimate a structural VAR using US data. As in our case, they find that negative oil supply shock reduces US output, whereas a positive oil demand shock has a positive effect on GDP.

\(^5\)Killian, Rebucci and Spatafora (2009) provide estimates of the effects of demand and supply shocks in the global crude oil market on several measures of oil exporters' and oil importers' external balances. They show that the effect of oil demand and supply shocks on the merchandise trade balance and the current account, depending on the source of the shock and critically on the response of the non-oil trade balance. They also find that valuation effects associated with capital gains or capital losses on asset holdings abroad as well have an important role in shaping the effect of oil shocks on trade balance. Our contribution abstracts from valuations effects, but not from wealth effects associated with market incompleteness, as we assume that only a riskless bond is internationally traded.

\(^6\)See also Nakov and Pesctori (2010) for a welfare analysis of alternative oil shocks.
shocks of similar sources and magnitude.

For the euro area, Christoffel et al. (2008) estimate with Bayesian methods a small open economy of the euro area. They extend the model by introducing bridge equations for HICP excluding energy and HICP energy, the latter measuring the direct impact of changes in oil prices on the HICP, as well as a number of other macroeconomic variables. Differently from them, we make oil and fuel prices fully endogenous and determined in general equilibrium by the interaction of demand and supply curves in the various markets. Jacquinot et al. (2009) use a calibrated large scale open economy DSGE model to assess the impact of oil price shocks on euro area inflation. Consistently with their approach, we distinguish across the various sources of oil price changes. Differently from them, we estimate the model with Bayesian methods. Sanchez (2008) analyze oil price shocks by appropriately modifying the model by Smets and Weuters (2003). Differently from that contribution, we consider the open economy dimension of the euro area and distinguish between oil demand and supply shocks. Finally, given the available sample period (1995-2007) we do not consider issues related to the impact of structural changes in the economy on the relationship between oil and macroeconomic variables.

The rest of the paper is organized as follows. Next section reports the model setup. Section three describes the estimation procedure. Section four reports the results, consisting in the estimates, the impulse response analysis, the forecast error variance decomposition, the historical decomposition and the sensitivity analysis. Section five concludes.

2 The Model

We develop a standard small open economy model, similar to recent contributions by Adolfson et al. (2007) and Christoffel et al. (2008). Differently from them, we include the world market for crude oil and a fuel sector in the small open economy. In what follows, we refer to the small economy as “Home”, to the rest of the world as “Foreign”.

Home households maximize an intertemporal utility function by choosing consumption and leisure. Consumption and investment are final nontradable goods. Consumption good, produced by domestic firms under perfect competition, is a basket of two bundles, fuel and non-fuel. The non-fuel bundle is composed by domestic and imported bundles of intermediate non-fuel goods. The investment basket includes domestic and imported non-fuel intermediate goods only. Home

Adolfson et al. (2007) build on the work of Christiano, Eichenbaum and Evans (2005) and extend their DSGE model using an open economy framework. See also Justiniano and Preston (in press).
non-fuel intermediate goods are produced by firms under monopolistic competition according to a constant elasticity of substitution (CES) technology in labor, capital and fuel. They are sold domestically and abroad. Firms in the intermediate sector are price-setter. We assume that the local currency pricing assumption holds for non-oil goods, as firms set prices in the currency of the destination market (Home or Foreign). As such, pass-through of exchange rate into import and export prices is incomplete in the short-run.

The fuel bundle is a homogeneous good produced by Home firms using crude oil as the only input of a linear production function. Firms producing fuel act under perfect competition. They buy crude oil in the world market and then sell fuel domestically to households and to firms producing non-fuel intermediate goods.

The price of crude oil is set in the world market. World demand is composed by Home and Foreign demand. The latter depends on the relative price of oil and aggregate demand, which is assumed to be exogenous. The oil price is set in currency of rest of the world (we assume it is the US dollar) and is the same in both the euro area and the rest of the world, once corrected for nominal exchange rate fluctuations. So the law of one price holds for the crude oil price (there is no international price discrimination). The fuel price in the Home country is equal to the sum of the crude oil price, refining margins, distribution margins and (value added and excise) taxes. The margins and taxes are captured in a rather stylized but tractable way by a time-varying term (wedge) between the crude oil price paid at the border and the fuel price paid by households and firms in the Home country.

Financial markets are incomplete, as there is a riskless bond denominated in domestic currency which is traded in the small economy and a riskless bond denominated in the Foreign currency that is traded internationally. As such, an uncovered interest parity holds for Home households, that links the differential between Home and Foreign interest rates to the expected nominal exchange rate depreciation. The model includes nominal and real frictions useful to fit data. Specifically, habit in consumption, sticky prices and wages, price and wage indexation, adjustment costs on investment, imports, fuel consumption. Finally, the Home monetary policy is set according to a standard Taylor rule.

2.1 Firms

In this section we initially illustrate the Home fuel sector. Subsequently, we describe the sectors producing non-fuel final and intermediate goods.
The Fuel sector

We assume that firms in the Home fuel sector act under perfect competition. They import crude oil $O_t$ and transform it into liquid fuel $FU_t$ according to a simple linear technology ($FU_t = O_t$). Firms then make fuel available to domestic firms in the final consumption goods sector and to firms producing the Home (non-fuel) intermediate good.\(^8\) The (US dollar) price of crude oil, $P^{O,*}_t$, is determined in the world market (see section below). We assume that the law of one price holds at the border. The implied crude oil price in Home currency is:

$$P^O_t = S_t P^{O,*}_t$$

where $S$ is the nominal exchange rate (number of Home currency units per unit of Foreign currency). We assume there is a time-varying wedge \(\eta_t\) between the border price of crude oil and the consumer price of fuel $P^FU_t$. As such, the fuel price can be written as:

$$P^FU_t = P^O_t + \eta^FU_t$$

The wedge $\eta^FU_t$ is a proxy that implicitly captures the presence of taxes, refinement and distribution margins in the (consumer) price of fuel. The adopted framework is consistent with the empirical evidence on oil price pass-through in fuel price for European countries, which is complete and quick. Moreover, it is consistent with the fact that in European countries taxes and margins constitute a large share, around 80 percent, of fuel prices.\(^9\) We assume that the time-varying component of the wedge $\eta^FU_t$ follows an exogenous (log-linear) autoregressive process:\(^10\)

$$\hat{\eta}^FU_t = \rho_{\eta^FU} \hat{\eta}^FU_{t-1} + \hat{\epsilon}_{\eta^FU, t}, \quad \hat{\epsilon}_{\eta^FU, t} \overset{iid}{\sim} N(0, \sigma^2_{\eta^FU})$$ (1)

Our choice of assuming a simple exogenous process for the margins and taxes guarantees the tractability of the model.

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\(^8\)So firms sell fuel only domestically.

\(^9\)See European Central Bank (2010).

\(^10\)A hat denotes log-deviation from the corresponding steady-state level: $\hat{X}_t = \ln X_t - \ln \bar{X}$. 

Sectors producing the final goods

Firms in the final goods sector produce three different types of goods under perfect competition. One type is used for private consumption, the other for investment and the other one for public sector’s consumption.

The private consumption bundle is produced accordingly to a CES function of non-fuel basket $C_{V,t}$ and fuel $FU_{C,t}$:

$$C_t = \left[ (1 - a_{FU_C})^{\frac{1}{\eta}} C_{V,t}^{\frac{\eta}{\eta-1}} + a_{FU_C}^{\frac{1}{\eta}} ((1 - \Gamma_{FU_C} (FU_{C,t}/C_t; \epsilon_{FU_C}^t)) FU_{C,t})^{\frac{\eta}{\eta-1}} \right]^{\frac{\eta-1}{\eta}}$$

(2)

where $a_{FU_C} (0 < a_{FU_C} < 1)$ is the share of fuel in the bundle and $\rho > 0$ measures the long-run elasticity of substitution between fuel, $FU_{C,t}$, and non-fuel consumption, $C_{V,t}$. As said, we assume that fuel $FU_{C,t}$ is a homogeneous good. The final good firm pays the cost $\Gamma_{FU_C} (FU_{C,t}/C_t)$ when changing the amount of fuel in producing the consumption bundle:

$$\Gamma_{FU_C} (FU_{C,t}/C_t) \equiv \frac{\gamma_{FU_C}}{2} \left( \frac{FU_{C,t}/C_t}{FU_{C,t-1}/C_{t-1}} - 1 \right)^2$$

(3)

where $\gamma_{FU_C} > 0$. As such, we distinguish between short and long run fuel consumption elasticity to changes in the relative prices, as existing evidence suggests that in the short run the fuel share is rather unresponsive to changes in the relative prices. The term $\epsilon_{FU_C}^t$ represents a fuel demand shock. We assume that it follows a (log-linear) AR(1) process:

$$\epsilon_{FU_C}^t = \rho_{FU_C} \epsilon_{FU_C}^{t-1} + \xi_{FU_C,t}, \quad \xi_{FU_C,t} \sim iid \sim N(0, \sigma_{FU_C}^2)$$

(4)

The bundle $C_{V,t}$ consists of non-fuel domestically produced goods ($C_H$) and imported goods ($C_F$):

$$C_{V,t} = \left[ a_{HC}^{\frac{1}{\eta}} C_{HC}^{\frac{\eta}{\eta-1}} + (1 - a_{HC})^{\frac{1}{\eta}} ((1 - \Gamma_{C_F} (C_{F,t}/C_t; \epsilon_{C_F}^t)) C_{F,t})^{\frac{\eta}{\eta-1}} \right]^{\frac{\eta-1}{\eta}}$$

(5)

where the parameter $a_{HC} (0 < a_{HC} < 1)$ is the share of domestic goods in the bundle and $\eta > 0$ is the elasticity of substitution between domestic and imported goods. Consumption goods $C_H$ and $C_F$ are composite baskets of a continuum of, respectively, differentiated non-fuel domestic ($h$) and non-fuel imported ($f$) intermediate goods, each supplied by a different firm. The term $\Gamma_{C_F} (C_{F,t}/C_t; \epsilon_{C_F}^t)$ is a non-oil import adjustment cost similar to (??). The term $\epsilon_{C_F}^t$ represents a non-oil import demand shock. We assume that it follows a (log-linear) AR(1) process:
\begin{equation}
\hat{\epsilon}_t^r = \rho_r \epsilon_{t-1}^r + \hat{\epsilon}_r, \quad \hat{\epsilon}_r \sim i.d. N(0, \sigma_r^2)
\end{equation}

Consumption \(C_H\) and \(C_F\) are produced according to the following functions, respectively:

\begin{equation}
C_{H,t} = \left[ \int_0^n C_{H,t}(h) \frac{\theta_{H,t}^{n-1}}{\theta_{H,t}^{n-1}} \, dh \right]^{\theta_{H,t}^{n-1}} \quad \text{and} \quad C_{F,t} = \left[ \int_1^n C_{F,t}(f) \frac{\theta_{F,t}^{n-1}}{\theta_{F,t}^{n-1}} \, df \right]^{\theta_{F,t}^{n-1}},
\end{equation}

where \(1 < \theta_{H,t}, \theta_{F,t} < \infty\) are the time-varying elasticity of substitution among non-oil domestic and non-oil imported brands, respectively. The parameter \(n\) is the size of the Home economy (the size of the rest of the world is \(1 - n\)). Each of the elasticities \(\theta_{H,t}, \theta_{F,t}\) is distributed according to the following log-linear stationary autoregressive stochastic process:

\begin{equation}
\hat{\theta}_{i,t} = \rho_{\theta_i} \hat{\theta}_{i,t-1} + \hat{\epsilon}_{\theta_i,t}, \quad \hat{\epsilon}_{\theta_i,t} \sim i.d. N(0, \sigma_{\theta_i}^2), i = H, F
\end{equation}

The production of investment goods \(I\) is isomorphic to that of non-fuel consumption (??). We allow for (possibly) different import intensities (so for investment we have shares \(a_{HI}\) and \(1 - a_{HI}\), with \(0 < a_{HI} < 1\), adjustment cost on non-oil imports, \(\Gamma_{I_F}(I_{F,t}/I_t)\), while the elasticity of substitution between domestic and imported bundles (\(\eta\)) and across varieties in each bundle (\(\theta_{H,t}, \theta_{F,t}\)) are the same as those in the corresponding consumption bundles.

For the public expenditure, we assume it is fully biased towards domestic non-fuel varieties. The implied basket is:

\begin{equation}
G_t = \left[ \int_0^n G_{H,t}(h) \frac{\theta_{H,t}^{n-1}}{\theta_{H,t}^{n-1}} \, dh \right]^{\theta_{H,t}^{n-1}},
\end{equation}

\begin{itemize}
\item[11] We assume that the size of the country is equal to the number of domestic firms in each sector and domestic households.
\item[12] Specifically:
\end{itemize}

\begin{equation}
I_t = \left[ \frac{1}{a_{HI}} \frac{n-1}{a_{HI}^n} + (1 - a_{HI}) \frac{1}{\Gamma_{I_F}(I_{F,t}/I_t)} \right]^{\frac{1}{\theta_{HI}}} \quad \text{and:}
\end{equation}

\begin{equation}
I_{H,t} = \left[ \int_0^n I_{H,t}(h) \frac{\theta_{H,t}^{n-1}}{\theta_{H,t}^{n-1}} \, dh \right]^{\theta_{H,t}^{n-1}}, \quad I_{F,t} = \left[ \int_1^n I_{F,t}(f) \frac{\theta_{F,t}^{n-1}}{\theta_{F,t}^{n-1}} \, df \right]^{\theta_{F,t}^{n-1}}.
\end{equation}
Sectors producing non-fuel intermediate goods

The production function for the generic intermediate good \( h \) is:

\[
Y_{H,t}(h) = \left[ \frac{1}{1 - a_{FU,Y}} V_t(h) \frac{\xi_Y - 1}{\xi_Y} + a_{FU,Y} \left( 1 - \Gamma_{FU,Y} \left( \frac{FU_{Y,t}(h)}{Y_{H,t}(h)}, \epsilon_t^{FU,Y,t} \right) \right) \right] ^{\frac{\xi_Y - 1}{\xi_Y}} \tag{12}
\]

where the variable \( FU_{Y,t}(h) \) represents fuel, bought from the domestic fuel sector, the variable \( V_t(h) \) is the value added input and \( a_{FU,Y} \) is the weight of fuel in the production. The parameter \( \xi_Y > 0 \) measures the long run elasticity of substitution between value added and fuel. The term \( \Gamma_{FU,Y} \left( \frac{FU_{Y,t}(h)}{Y_{H,t}(h)}, \epsilon_t^{FU,Y,t} \right) \) represents a fuel demand adjustment cost similar to equation (??). The term \( \epsilon_t^{FU,Y,t} \) is a shock to the fuel demand. We assume that it follows a process similar to equation (??). The value added input is defined as:

\[
V_t(h) = \epsilon_t \left[ (1 - a_L) \frac{\xi_V - 1}{\xi_V} K_{t-1}(h) + a_L \left( z_t L_t(h) \right) \right] ^{\frac{\xi_V - 1}{\xi_V}} \tag{13}
\]

where the variable \( K_{t-1}(h) \) is the physical capital, rented from domestic households in a competitive market, and \( L_t(h) \) is labor, supplied by domestic households under monopolistic competition (see below and next section). The parameter \( \xi_V > 0 \) measures the elasticity of substitution between capital and labor. The parameter \( a_L \) is the weight of labor in the production of the value added. The variable \( z_t \) is a unit-root labor-augmenting technology shock capturing world productivity. It is common to all firms in the Home and rest of the world. The variable \( \epsilon_t \) is a domestic stationary technology shock, common to all Home firms. The growth rate of the unit-root technology follows a log-linear stationary autoregressive process:

\[
\hat{\mu}_{z,t} = \rho_z \hat{\mu}_{z,t-1} + \hat{\epsilon}_{\mu_Z,t}, \quad \hat{\epsilon}_{\mu_Z,t} \overset{iid}{\sim} N(0, \sigma^2_{\mu_Z}) \tag{14}
\]

where:

\[
\hat{\mu}_{z,t} \equiv \frac{z_t}{z_{t-1}} - 1 \tag{15}
\]

Similarly, the stationary technology process is:

\[
\hat{\epsilon}_t = \rho_{\epsilon} \hat{\epsilon}_{t-1} + \hat{\epsilon}_{\epsilon,t}, \quad \hat{\epsilon}_{\epsilon,t} \overset{iid}{\sim} N(0, \sigma^2_{\epsilon}) \tag{16}
\]
The variable $L(h)$ is a composite of a continuum of differentiated labor inputs, each supplied by a different domestic household $J$ under monopolistic competition:

$$L_t(h) = \left[ \int_0^\infty L_t(j) \frac{\theta_{L,t}^{-1}}{\theta_{L,t} - 1} dj \right]^{\theta_{L,t}^{-1}}$$

(17)

where $1 < \theta_{L,t} < \infty$ is the time-varying elasticity of substitution between labor varieties, which is distributed accordingly to the following log-linear autoregressive process:

$$\dot{\theta}_{L,t} = \rho \theta_{L,t-1} + \xi_{\theta_{L,t-1}} \sim i.i.d. N(0, \sigma_{\theta_{L}}^2)$$

Each firm $h$ in the intermediate sector minimizes its production costs by optimally choosing the amount of inputs given the above technology constraints and the corresponding prices (the gross nominal rental rate of capital $R^K_t$, the nominal wage rate $W_t$ and the price $P^F_U$ of fuel).

Each non-fuel intermediate good is sold domestically and abroad subject to market-specific cost of adjusting prices à la Rotemberg (1982).\(^{13}\) As such, nominal prices are sticky in the currency of the destination market (local currency pricing assumption) and the exchange rate pass-through into export prices is incomplete in the short run.\(^{14}\) In any period, each intermediate firm can reoptimize the price in the Home and Foreign country, $P_{H,t}(h)$ and $P^*_{H,t}(h)$ respectively, subject to quadratic adjustment costs in the form of a CES basket of all goods produced in the same sector of the economy ($Y_{H,t}$ and $Y^*_{H,t}$, respectively):

$$AC_{H,t}(h) \equiv \frac{\kappa_H}{2} \left( \frac{P_{H,t}(h)}{P_{H,t-1}(h)} - 1 \right)^2 Y_{H,t}$$

(18)

$$AC^*_{H,t}(h) \equiv \frac{\kappa^*_H}{2} \left( \frac{P^*_{H,t}(h)}{P^*_{H,t-1}(h)} - 1 \right)^2 Y^*_{H,t}$$

(19)

where $\kappa_H, \kappa^*_H \geq 0$ are adjustment cost parameters. The parameters $0 \leq \alpha_H, \alpha^*_H \leq 1$ measure the degree of indexation, respectively in the Home and Foreign economy. Specifically, we assume $(1 - \alpha_H)$ measures the degree of indexation to the current period central bank time-varying (gross) consumer price inflation target ($\bar{\pi}_t$) and $\alpha_H$ to last period’s sector-specific inflation rate $\pi^H_{H,t-1} (\pi^*_{H,t} \equiv P^H_{H,t}/P^H_{H,t-1})$. A similar interpretation holds for $(1 - \alpha^*_H)$ and $\alpha^*_H$\(^{15}\). Profits of

\(^{13}\)Adolfson et al. (2007) use a variant of the Calvo (1983) model.

\(^{14}\)See also Smets and Wouters (2002).

\(^{15}\)As we do not introduce a monetary authority in the rest of the world, $\pi^*_t$ should be considered as a shock that captures medium and long-run components of Foreign inflation and allows to improve the capacity of the
intermediate firms are rebated lump-sum to domestic households.

In the symmetric equilibrium, the profit maximization problem of Home intermediate firms yields two standard log-linearized market-specific Phillips curves holding in the Home and Foreign markets, respectively:

\[ \hat{\pi}_H, t = \alpha_H \hat{\pi}_H, t - (1 - \alpha_H) \hat{\pi}_t \]

\[ = \beta \pi^{ss} E_t \left( \hat{\pi}_H, t+1 - \alpha_H \hat{\pi}_H, t - (1 - \alpha_H) \hat{\pi}_{t+1} \right) - \left( \theta_H - 1 \right) \hat{\pi}_H, t + \left( \theta_H - 1 \right) \hat{\pi}_H, t - (1 - \alpha_H) \hat{\bar{\pi}}_t \]

\[ \hat{\pi}_H, t - \alpha_H \pi^{ss}_H, t - (1 - \alpha_H) \hat{\pi}_t^{*} \]

\[ = \beta \pi^{ss} E_t \left( \hat{\pi}_H, t+1 - \alpha_H \hat{\pi}_H, t - (1 - \alpha_H) \hat{\pi}_{t+1}^{*} \right) - \left( \theta_H - 1 \right) \hat{\pi}_H, t + \left( \theta_H - 1 \right) \hat{\pi}_H, t - (1 - \alpha_H) \hat{\bar{\pi}}^{*}_t \]

where \( \beta \) is the discount factor of the Home representative household (see next sections for more details), \( \pi^{ss} \) is the steady state gross consumer price inflation rate (we assume it is the same for the both Home and Foreign country), \( \hat{\pi}_H, t \) (\( \hat{\pi}_H, t^{*} \)) is the relative price of the Home tradable in the Home (Foreign) market, \( \hat{\rmc}_t \) is the real marginal cost and \( \hat{\rmr}_t \) is the real exchange rate, defined (in levels) as the ratio of consumption prices expressed in the same currency:

\[ RER_t = \frac{S_t P^*_t}{P_t} \]

where \( S_t \) is the Home nominal exchange rate (number of Home currency units per unit of Foreign currency) and \( P_t \) (\( P^*_t \)) is the Home (Foreign) consumption-based price level. The term \( \hat{\theta}_H, t \) represents the markup shock affecting the supply of goods in the Home market (see equation ??). Similarly, the term \( \hat{\theta}_H, t^{*} \) represents a markup shock affecting Home export supply. It is distributed as an AR(1) process:

\[ \hat{\theta}_H, t^{*} = \rho \theta_H \hat{\theta}_H, t^{*} - 1 + \epsilon_{\theta_H, t}^{*}, \epsilon_{\theta_H, t}^{*} \sim i.i.d. N(0, \sigma_{\theta_H}^2) \]

model to fit the data.

13
2.2 Households

There is a continuum \((0 \leq j \leq n)\) of households that maximize expected utility subject to a standard flow budget constraint. The preferences of household \(j\) are given by:

\[
E_t \left[ \sum_{k=0}^{\infty} \beta^k \left( C_t^{C,j} \log (C_t^{C,j} - bC_t^{C,j-1}) - \frac{L_t^{L,j}}{1+\sigma_L} (L_t^{C,j})^{1+\sigma_L} \right) \right]
\]

(24)

where \(\beta\) denotes the discount factor, \(C_t^{C,j}\) and \(L_t^{L,j}\) are respectively the \(j\)-th household’s levels of consumption and labor supply, each of them subject to a preference shock, \(\xi^C\) and \(\xi^L\) respectively. The parameter \(b\) \((0 \leq b \leq 1)\) measures the degree of external habit formation in consumption \((C\) is the consumption level of the Home representative household), while \(1/\sigma_L\) is the labor Frisch elasticity. Each of the two shocks is distributed according to the following autoregressive process:

\[
\hat{\xi}_t^i = \rho \hat{\xi}_{t-1}^i + \hat{\xi}_{t-1}^i, \quad \hat{\xi}_{t-1}^i \sim N(0, \sigma^2_{\xi^i}) \]

where \(i = C, L\)

Home households can save in Home and Foreign riskless bonds, respectively \(B_{H,t}^{R}\) and \(B_{F,t}^{R}\) as well as in physical capital \(K_t\). Home bonds are denominated in Home currency and are traded only domestically, while Foreign bonds are denominated in Foreign currency and are traded between Home households and the rest of the world. The resulting budget constraint is:

\[
B_{H,t}^{R} (j) + S_t B_{F,t}^{R} (j) - B_{H,t-1}^{R} (j) R_{t-1}^{R,P} - S_t B_{F,t-1}^{R} (j) R_{t-1}^{R,P} \Phi \left( a_{t-1}, \phi_{t-1} \right)
\]

\[
= W_t (j) N_t (j) + \left( R_{K,t}^{R,P} K_{t}^{R,P} (j) + \Pi_t \right)
\]

\[
+ T_t (j) - P_{C,t} C_t (j) - P_{I,t} I_t (j) - \Gamma W (j)
\]

where \(R_t\) and \(R_{t}^{*}\) are respectively the gross nominal interest rates on Home and Foreign bonds.

The term \(\epsilon_{t-1}^{R,P}\) represents a risk premium shock on the Home bond, distributed according to a standard log-linear AR(1) process:

\[
\hat{\epsilon}_t^{R,P} = \rho_{\epsilon} \hat{\epsilon}_{t-1}^{R,P} + \hat{\epsilon}_{t-1}^{R,P}, \quad \epsilon_{t-1}^{R,P} \sim N(0, \sigma^2_{\epsilon^{R,P}})
\]

(25)

The term \(\Phi \left( a_{t-1}, \phi_{t-1} \right)\) is a premium that depends on the net foreign asset position of the home economy \((a, see below). It ensures a well-defined steady-state. The variable \(\Pi_t\) represents total profits from ownership of domestic firms. We assume they are equally distributed across
households. The variable $T_t(j)$ represents net lump-sum taxes. The households can invest ($I_t$) in additional physical capital ($K_t$) undertaking a quadratic adjustment cost. The implied capital accumulation equation is:

$$K_t(j) = (1 - \delta) K_{t-1}(j) + \left(1 - \frac{\gamma_t}{2} \left(\frac{\Upsilon_t I_t(j)}{I_{t-1}(j)} - 1\right)\right) I_t(j)$$

(26)

where $\gamma_t > 0$ is a parameter, $0 < \delta < 1$ is the depreciation rate and the term $\Upsilon_t$ is a shock that follows a stationary autoregressive investment-specific technology. In log-linear terms it is equal to:

$$\hat{\Upsilon}_t = \rho \Upsilon_{t-1} + \hat{\varepsilon}_{\Upsilon,t}, \quad \hat{\varepsilon}_{\Upsilon,t} \overset{iid}{\sim} N(0, \sigma_{\Upsilon}^2)$$

(27)

Finally, each household is a monopolistic supplier of a differentiated labor service. She chooses her wage given labor demand by domestic firms and subject to Rotemberg-type wage adjustment costs $\Gamma_W$, whose functional form is:

$$\Gamma_W(j) \equiv \frac{\kappa_W}{2} \left(\frac{W_t(j)}{\pi_W W_{t-1}(j)} - 1\right)^2 L_t$$

(28)

where $\kappa_W \geq 0$ is the wage adjustment cost parameter, $\alpha_W$ ($0 \leq \alpha_W \leq 1$) is a parameter that measures indexation to the gross wage inflation rate in the previous period ($\pi_{W,t} \equiv W_t/W_{t-1}$) and to the current inflation target of the central bank, while $L$ is the bundle of labor varieties.

From the two first order conditions with respect to the two bond positions, $B_{H,t}(j)$ and $B_{F,t}(j)$, we get a modified uncovered interest parity condition. The latter links the interest rate differential, comprehensive of the domestic premium $\epsilon_{t-1}^{RP}$ and the premium $\Phi\left(a_{t-1}, \tilde{\phi}_{t-1}\right)$ on the holdings of Foreign bond, to next period expected exchange rate change. The premium $\Phi\left(a_{t}, \tilde{\phi}_{t}\right)$ is given by:

$$\Phi\left(a_{t}, \tilde{\phi}_{t}\right) = \exp\left(-\tilde{\phi}_{t} (a_t - \bar{a}) + \tilde{\phi}_t\right)$$

(29)

where $a_t \equiv S_t B_{F,t}/(P_t z_t)$ is the net foreign asset position (divided by the Home consumption deflator and the stochastic technology trend) and $\tilde{\phi}_t$ is a shock to the external risk premium.\[16\]

---

16See Benigno (2009) and Schmitt-Grohé and Uribe (2001). The cost implies that domestic households are charged a premium over the foreign interest rate $R^*_t$ if the net foreign asset position of the country is negative, and receive a lower remuneration if the net foreign asset position is positive.
The (log-linearized) shock is distributed as follows:

\[ \hat{\phi}_t = \rho \hat{\phi}_{t-1} + \hat{\varepsilon}_{\phi,t}, \quad \hat{\varepsilon}_{\phi,t} \overset{iid}{\sim} N(0, \sigma_{\phi}^2) \] (30)

2.3 Central bank

The monetary policy specification is in line with Smets and Weurers (2003). We assume that the central bank follows an augmented Taylor interest rate feedback rule characterized by the response of the nominal rate \( R_t \) to its lagged value, to the gap between lagged gross consumer price inflation \( \pi_{t-1} / \pi_{t-1} \) and targeted inflation \( \hat{\pi}_t \), to the gap between contemporaneous (detrended) output \( Y_t \) and its steady state value, to changes in inflation \( \Delta\pi_t \equiv \pi_t / \pi_{t-1} \) and to output growth \( \Delta Y_t \equiv Y_t / Y_{t-1} \). In log-linearized terms we have:

\[ \hat{R}_t = \rho_R \hat{R}_{t-1} + (1 - \rho_R) \left( \hat{\pi}_t + r_\pi (\hat{\pi}_{t-1} - \hat{\pi}_t) + r_y \hat{y}_t \right) \]

\[ + r_{\Delta\pi} \Delta\hat{\pi}_t + r_{\Delta\hat{y}} \Delta\hat{y}_t + \hat{\varepsilon}_{R,t} \] (31)

where \( \varepsilon_{R,t} \) is an uncorrelated monetary policy shock and \( \hat{\pi}_t \) is a shock to the monetary authority inflation target. They are respectively distributed as:

\[ \hat{\varepsilon}_{R,t} \overset{iid}{\sim} N(0, \sigma_{\hat{R}}^2) \] (32)

\[ \hat{\pi}_t = \rho_{\pi} \hat{\pi}_{t-1} + \hat{\varepsilon}_{\pi,t}, \quad \hat{\varepsilon}_{\pi,t} \overset{iid}{\sim} N(0, \sigma_{\pi}^2) \] (33)

2.4 Fiscal Policy

We assume that the Home fiscal authority simply buys domestic intermediate non-fuel goods. Purchases \( (G_t) \) are financed by lump-sum taxes \( (T_t) \) paid by domestic households. The implied budget constraint:

\[ P_{H,t} G_t = T_t \] (34)

We assume that the stationary components of government purchases expressed in real terms (deflated by domestic consumer prices), \( g \), follows the log-linear AR(1) process:

\[ \hat{g}_t = \rho_g \hat{g}_{t-1} + \hat{\varepsilon}_{g,t}, \quad \hat{\varepsilon}_{g,t} \overset{iid}{\sim} N(0, \sigma_g^2) \] (35)
2.5 Rest of the World Economy

The setup of the Foreign economy is stylized to get a parsimonious model. For oil market, we assume oil supply $Y^S_{O,t}$ is exogenous. It follows a log-linear AR(1) process:

$$\tilde{y}^S_{O,t} = \rho_{\tilde{y}^S_{O,t}} \tilde{y}^S_{O,t-1} + \tilde{\varepsilon}^S_{O,t}, \quad \tilde{\varepsilon}^S_{O,t} \sim \text{iid} N(0, \sigma^2_{\tilde{y}^S_{O,t}}) \quad (36)$$

The rest of the world demand for oil $Y^D_{O,t}^*$ is a function of the relative price of crude oil, aggregate demand in euro area’s main trade partners and a “residual” shock:

$$Y^D_{O,t}^* = \gamma^*_{OIL,t} a^*_{OIL} \left( \frac{P^*_{OIL}}{P^*_t} \right)^{-\rho} AD_t^* \quad (37)$$

where the parameter $a^*_{OIL} \ (0 \leq a^*_{OIL} \leq 1)$ is the share of oil in euro area trade partners’ aggregate demand bundle, $\rho > 0$ is the elasticity of substitution between oil and other goods (we assume it is the same as in the Home economy), $P^*_t$ is the price deflator and $AD_t^*$ is the aggregate demand.

The shock $\gamma^*_{OIL,t}$ captures oil demand shocks that are not related to aggregate demand in main euro area trade partners. We define these shocks as “oil-specific” to the crude oil market (as such, they are not related to changes in aggregate demand neither in the euro area nor in its main trade partners), consistently with Kilian (2009). Oil-market-specific demand shocks can be thought as shocks to the precautionary demand for crude oil, to speculative demand or to aggregate demand shocks in countries that are not main trade partners of the euro area. We assume that $\gamma^*_{OIL,t}$ and the aggregate demand $AD_t^*$ are exogenous. They follow standard AR(1) log-linear processes, respectively:

$$\tilde{AD}_t^* = \rho_{AD_t^*} \tilde{AD}_t^*_{t-1} + \tilde{\varepsilon}_{AD_t^*}, \quad \tilde{\varepsilon}_{AD_t^*} \sim \text{iid} N(0, \sigma^2_{AD_t^*}) \quad (38)$$

$$\tilde{\gamma}^*_{OIL,t} = \rho_{\gamma^*_{OIL,t}} \tilde{\gamma}^*_{OIL,t-1} + \tilde{\varepsilon}_{\gamma^*_{OIL,t}}, \quad \tilde{\varepsilon}_{\gamma^*_{OIL,t}} \sim \text{iid} N(0, \sigma^2_{\gamma^*_{OIL,t}}) \quad (39)$$

World oil demand ($Y^D_{O,t}^{W}$) is the sum of Home ($Y^D_{O,t}^{H}$) and rest of the world demand ($Y^D_{O,t}^*$):

$$Y^D_{O,t}^{W} = Y^D_{O,t}^{H} + Y^D_{O,t}^* \quad (40)$$

where $Y^D_{O,t}^{H}$ is:

$$Y^D_{O,t}^{H} = nFU_{C,t} + nFU_{Y,t} \quad (41)$$
Euro area exports depend on their relative price \( P_H^* / P_t^* \) and rest of the world aggregate demand \( AD_t^\ast \):

\[
Y_{H,t}^\ast = a_H^* \left( \frac{P_H^*}{P_t^*} \right)^{-\eta} AD_t^\ast
\] (42)

where \( a_H^* \) is the share of Home exports in the Foreign aggregate demand bundle and \( \eta > 0 \) is the elasticity of substitution between Home exports and other goods.

For the supply of non-oil goods produced in the Foreign country and imported by the Home economy, we assume that the local currency pricing assumption holds. As for the Home intermediate goods, we assume that in any period, each intermediate Foreign firm can reoptimize its prices in the Home and Foreign country, \( P_{F,t}^\ast (f) \) and \( P_{F,t}^\ast (f) \) respectively, subject to quadratic adjustment costs in the form of a CES basket of all goods produced in the same sector of the economy (\( Y_{F,t} \) and \( Y_{F,t}^\ast \), respectively):

\[
AC_{F,t} (f) \equiv \frac{\kappa_F}{2} \left( \frac{P_{F,t}^\ast (f)}{\pi_{F,t}^\ast \bar{p}_{t}^{1-\alpha_F}} - 1 \right)^2 Y_{F,t}
\] (43)

\[
AC_{F,t}^\ast (f) \equiv \frac{\kappa_F^\ast}{2} \left( \frac{P_{F,t}^\ast (f)}{(\pi_{F,t}^\ast \bar{p}_{t}^{1-\alpha_F})^\ast} - 1 \right)^2 Y_{F,t}^\ast
\] (44)

where \( \kappa_F, \kappa_F^\ast \geq 0 \) are adjustment cost parameters, \( \alpha_F \) and \( 1 - \alpha_F \) measure the indexation to previous period’s sector-specific inflation and current period Home inflation target, respectively. Similar interpretations hold for \( \alpha_F^\ast \) and \( 1 - \alpha_F^\ast \). As such, there is a Phillips curve, holding in the Home market. Its log-linearized form is:\(^{17}\)

\[
\kappa_F \hat{\pi}_{F,t} - \alpha_F \kappa_F \hat{\pi}_{F,t-1} - (1 - \alpha_F) \kappa_F \hat{\pi}_{F,t} = \kappa_F \beta \pi_{ss} \hat{\pi}_{F,t+1} - \alpha_F \kappa_F \beta \pi_{ss} \hat{\pi}_{F,t} - \frac{\theta_F - 1}{\hat{p}_{F,t}} \hat{p}_{F,t} - (\theta_F - 1) \hat{r}_{\text{ret}} + \hat{\theta}_{F,t}
\]

The markup shock \( \hat{\theta}_{F,t} \) follows an AR(1) log-linear process:

\[
\hat{\theta}_{F,t} = \rho_{\theta_F} \hat{\theta}_{F,t-1} + \hat{\epsilon}_{\theta_F,t}, \quad \hat{\epsilon}_{\theta_F,t} \sim N(0, \sigma_{\theta_F}^2)
\] (45)

\(^{17}\)As we do not explicitly consider the production process in the rest of the world, the foreign Phillips curves do not include real marginal costs. The latter are catched by the markup shocks.
Similarly, the Phillips curve in the rest of the world is:

\[
\kappa_F^* \hat{\pi}_t^* - \alpha_F^* \kappa_F^* \hat{\pi}_{t-1}^* - (1 - \alpha_F^*) \kappa_F^* \hat{\pi}_t^* = \kappa_F^* \beta \pi_{ss} \hat{\pi}_{t+1}^* - \alpha_F^* \kappa_F^* \beta \pi_{ss} \hat{\pi}_{t+1}^*
\]

\[
- (1 - \alpha_F^*) \kappa_F^* \beta \pi_{ss} \hat{\pi}_{t+1}^*
\]

\[
+ \hat{\theta}_{F,t}^*
\]

where \( \hat{\pi}_t^* \) is a shock aiming at capturing long-run trend in inflation rate and is \( \hat{\theta}_{F,t}^* \) a markup shock. Each shock follows an AR(1) process, respectively:

\[
\hat{\pi}_t^* = \rho_{\pi.t} \hat{\pi}_{t-1}^* + \hat{\epsilon}_{\pi.t} \sim N(0, \sigma_{\pi.t}^2)
\]

\[
\hat{\theta}_{F,t}^* = \rho_{\theta.t} \hat{\theta}_{F,t-1}^* + \hat{\epsilon}_{\theta.t} \sim N(0, \sigma_{\theta.t}^2)
\]

For the rest of the world nominal interest rate \( R_t^* \), we assume it is exogenous and follows an AR(1) process:

\[
\hat{R}_t^* = \rho_{R.t} \hat{R}_{t-1}^* + \hat{\epsilon}_{R.t} \sim N(0, \sigma_{R.t}^2)
\]

The above assumptions contribute to fit the real exchange rate dynamics.

### 2.6 The trade balance of the Home economy

The Home trade balance is obtained by consolidating the private sector (households and firms) aggregate budget constraint and the government budget constraint. Assuming that a symmetric equilibrium holds (so that there is a representative household and a representative firm in each production sector), the resulting trade balance is:

\[
TB_t = nS_t B_{F,t} - nS_t B_{F,t-1} R_{t-1}^* \Phi \left( a_{t-1}, \phi_{t-1} \right)
\]

\[
= nP_H Y_H,t + nS_t P_H^* Y_H^*,t - nP_I C_t - nP_I t I_t - P_H G_t
\]

\[
- nP_{FU,t} Y_{FU,t}
\]

\[
= nS_t P_H^* Y_H^*,t - (1 - n) P_{FU,t} Y_{FU,t} - P_{FU,t}^{O,D,H}
\]

The first equality expresses the trade balance as the sum of the change in and the interest payment on the net foreign asset position (\( R^* \) is the gross nominal interest rate). The second equality is the difference between total aggregate revenues from production and total aggregate expenditures. The term \( nP_{FU,t} Y_{FU,t} \) represents expenditure for fuel as input in the production of
Home non-fuel goods. It is evaluated at the border price of crude oil, expressed in Home currency. Finally, the third equality is net exports, expressed in domestic currency. The term $P_t Y_{O,t}^{D,H}$ is the value of the total amount of oil imports, used as intermediate good in the production of the final consumption good and as input in the production function of Home non-fuel tradable goods.

The overall trade balance can be split in non-oil and oil trade balance. The first is equal to the difference between Home export and non-oil imports:

$$TB_t^{NO} = n S_t P_{H,t}^* Y_{H,t}^* - (1 - n) P_{F,t} Y_{F,t}$$

(49)

The oil trade balance simply corresponds to the value of oil imports, as the Home country does not export oil products:

$$TB_t^O = -P_t^O Y_{O,t}^{D,H}$$

(50)

Finally, we define the Home non-oil terms of trade as the ratio of non-oil import-to-export prices, both expressed in Home currency:

$$TOT_t \equiv \frac{P_{F,t}}{S_t P_{H,t}^*}$$

(51)

where $P_{F,t}$ and $P_{H,t}^*$ are respectively the prices of Home non-oil imports and Home exports expressed in the currency of the correspondent destination market.\(^\text{18}\)

### 3 Estimation

In what follows we describe the data, the calibrated parameters and the prior distributions of estimated parameters. We solve the model by log-linearizing the equations around the model’s steady state. We estimate the model with Bayesian methods using euro area quarterly data. The Bayesian approach implies that the posterior distributions of the estimated parameters is obtained by updating the information in the prior distributions with the information in the data.\(^\text{19}\)

\(^\text{18}\)An increase (decrease) in the value of $TOT$ represents a deterioration (improvement) of Home terms of trade.\(^\text{19}\)For a comprehensive discussion on the Bayesian estimation of DSGE models, see Lubik and Schorfheide (2005). For a discussion of the implementation of Bayesian methods, see Geweke (1999) and Gelman et al. (2004).
3.1 Data

We use quarterly euro area data for the period 1995:1–2007:4 to estimate the model. We are forced to start from 1995 as data for fuel are not available for the previous years. We do not include the years 2008 and 2009 to avoid breaks in the structural relationships related to the global financial crisis. We match twenty variables. For the euro area (the Home country): employment, government consumption, real exchange rate, GDP, consumption, investment, the HICP deflator, the GDP deflator, the investment deflator, wage, exports, imports, the deflator of fuel-liquid fuel-lubricants (fuel from now on), the deflator of the ex-fuel component of HICP, the short term interest rate. For the rest of the world (Foreign) economy: the aggregate demand, the consumption deflator, the short term interest rate. For the international oil market: the crude oil price and oil supply.

All data are from the Area Wide Model (AWM) data set, except for the Foreign interest rate, the fuel price, the HICP deflator net of fuel, oil supply and hours worked.\textsuperscript{20} For the Foreign interest rate, we use the effective Fed funds rate as a proxy. Data of fuel and HICP net of fuel are from Eurostat. Data of global oil supply are from OECD-International Energy Agency. For hours worked we use employment from AWM data set. We model the link between hours and employment using a Calvo-rigidity equation:\textsuperscript{21}

\[
\dot{E}_t = \frac{\beta}{1 + \beta} E_t [\dot{E}_{t+1}] + \frac{1}{1 + \beta} \dot{E}_{t-1} + \frac{(1 - \beta \xi_E) (1 - \xi_E)}{(1 + \beta) \xi_E} (\dot{L}_t - \dot{E}_t) \tag{52}
\]

where \(1 - \xi_E\) is the fraction of firms that can adjust the (log-linear) level of employment \(\dot{E}\) to the preferred amount of total labor input \(\dot{L}\).

In the AWM data set export and import series include both intra- and extra-area trade and there is no series on aggregate hours worked. The exchange rate is the ECB’s official effective exchange rate for the 12 main trading partners of the Euro area.\textsuperscript{22}

The assumption of non stationary technology shock implies a common stochastic trend in the real variables. We make them stationary by using first log-differences. Similarly, we take first difference of GDP deflator, consumer prices, ex-fuel consumer prices, nominal wage, foreign prices.

We remove a linear trend from the employment, the public consumption expenditure, the oil

\textsuperscript{20}For details on the AWM dataset see Fagan et al. (2005).
\textsuperscript{21}See Smets and Wouters (2003).
\textsuperscript{22}See Adolfson et al. (2007).
supply, the rest of the world demand. We also remove an excessive trend of import and export (with respect to output) series, to make the correspondent shares stationary.\textsuperscript{23}

Employment, public expenditure, the real exchange rate, the real price of oil and the real price of fuel are measured as percentage deviations around the mean. The real price of oil is the US dollar price of oil deflated by the Foreign price index. The real price of fuel is the euro price deflated by the euro consumer price index.

\subsection*{3.2 Calibrated parameters}

We calibrate parameters to match the sample mean of observed variables and those that are weakly identified. Values are in line with Adolfson et al. (2007), Christoffel et al. (2008), Jacquinot et al. (2009) and ECB (2010).

In Table 1 we report the calibrated parameters. In Table 2 the implied steady state values of main variables.

We calibrate the weight of labor, $a_L$, in the production function of the value added to 0.48 (so the weight of capital is 0.52). We set the weight of fuel in the production function of intermediate goods, $a_{FU_Y}$, to 0.03 (consistently with a share of fuel in the production cost equal to 4 percent), the long-run elasticity of substitution between fuel and non-fuel inputs to 0.5, the elasticity of substitution between capital and labor to 0.75. As such, oil and other inputs are hardly substitutable.

For the consumption basket, we set the weight of fuel to 0.03, so that the share of fuel in the consumption basket is equal to 4.0 percent. Moreover, we set the steady state value of $\eta_{FU}^{P_{FU}}$ (the share of the fuel price absorbed by distribution margin, refinement margin and oil taxes) equal to 0.8. This value is consistent with existing evidence on the shares of refining margin, distribution margin and (value added and excise) taxes in the euro area consumer price of fuel. The long-run elasticity of substitution between non-fuel and fuel is equal to 0.2. As in the case of the production of intermediate goods, oil and other goods are hardly substitutable. We calibrate the weight of imported non oil good to 0.2. The long-run elasticity of substitution between domestic and imported non oil goods is 1.1.

For the investment basket, we calibrate the weight of imported good to 0.3. The long-run elasticity of substitution between domestic and imported goods is the same as that of the consumption basket (1.1).

\textsuperscript{23}The data treatment is similar to Adolfson et al. (2007) and Christoffel et al. (2008).
We set the (steady-state) elasticity of substitution across brands \((\theta_H, \theta_F, \theta^*_H, \theta^*_F)\) to 6, the elasticity of substitution across labor varieties, \(\theta_L\), to 4.33. They imply steady state markup values equal to 1.2 and 1.3, respectively.

For households’ preferences, we calibrate the discount factor \(\beta\) to 0.9996, consistently with an annualized equilibrium nominal interest rate of 4.0 percent (the sample mean). The inverse of the labor supply elasticity, \(\sigma^L\), is set to 2. The depreciation rate \(\delta\) of physical capital to 0.025.

The calibration allows us to roughly match all the ratios reported in Table 2. Home consumption, investment and government consumption as a ratio to Home GDP are respectively equal to 58, 20 and 22 percent. The non-oil import content of consumption and investment spending is respectively 10 and 6 percent as a ratio to GDP. The oil imports amount to 0.01 percent of Home GDP. We set the steady state net foreign asset position to zero, implying that both trade balance and current account are equal to zero. We assume that the steady state growth rate of the world economy is 2.00 percent per annum. For the monetary authority, we assume its long-run annualized gross inflation objective \(\bar{\pi}\) is 1.9 percent.

### 3.3 Prior distributions of the estimated parameters

We report in Table 3 the prior distribution of the estimated parameters (first fourth columns from the left hand side). The location of the prior distribution corresponds to a large extent to that in Adolfson et al. (2007). Parameters bounded between 0 and 1 are distributed according to a beta (\(B\) in the table) distribution (habit persistence \(b\), indexation parameters \(\alpha\) and coefficients of shock autocorrelation \(\rho\)). Positive parameter have an inverse gamma (\(G\)) distribution (wage and price stickiness parameters \(\kappa\), adjustment costs \(\gamma\), standard deviations of the shocks \(\sigma\)). Finally unbounded parameters are distributed according to the normal (\(N\)) distribution (the interest rate response to output growth in the Taylor rule \(\rho_{\Delta y}\)).

Investment adjustment coefficient has a mean of 3.0 and a standard deviation equal to 1.5. For the monetary policy rule, the prior mean on the the lagged interest rate coefficient is set to 0.8, those on inflation and inflation growth coefficients respectively to 1.7 and 0.3. Finally, the coefficient responding to output (deviation from steady state) is calibrated to zero, while the prior mean of the coefficient responding to output growth is set to 0.0625. For nominal rigidities, we set the prior mean of wages and prices of Home as well Foreign intermediate goods to 250 (if converted in Calvo 1983 terms, it implies an average contract duration equal to about 4 quarters). The standard deviation is set to 60, implying that the prior distributions are rather loose. For
imports and exports, we set the prior mean to 10 (in Calvo terms, it corresponds to a contract
duration of 2 quarters), so that the exchange rate pass-through into import and export prices is
rather quick. We set the standard deviation to 2.5. The implicit assumption of relatively flexible
import and export prices is consistent with estimates by Adolfson et al. (2007), that suggest 2–3
quarters stickiness in these sectors. Finally, we set the mean values of the indexation parameters
to 0.5 (standard deviation equal to 0.1) and that of the adjustment costs on oil imports, non-oil
imports and exports to 2.0. All the autocorrelated shocks have an autoregressive coefficient set
to 0.75. Innovations to all shocks are assumed to be white noise with standard deviation having
mean set to 0.1 percent.

4 Results

In what follows we report the estimated values of the parameters, and some results from analysis
performed on the basis of those estimates. In particular, we show the responses of the main
euro area variables to shocks that directly hit the oil market and report the contribution of these
shocks to the variance and historical path of euro area variables.

4.1 Posterior distributions of the estimated parameters

We estimate the posterior distributions of the parameters using the Metropolis–Hastings algo-
rum with 200,000 iterations. The joint posterior distribution of all estimated parameters is
obtained in two steps. First, the posterior mode and an approximate covariance matrix, based
on the inverse Hessian matrix evaluated at the mode, is obtained by numerical optimization
on the log posterior density. Second, the posterior distribution is explored by generating draws
using the Metropolis–Hastings algorithm. The proposal distribution is taken to be the multivari-
ate normal density centered at the previous draw with a covariance matrix proportional to the
inverse Hessian at the posterior mode.24 The results are reported in Table 3, where we show the
posterior mode of all the parameters, along with the approximate posterior standard deviation,
as well as the mean of the posterior distribution, along with the 5th and 95th percentiles.

The degree of habit formation in consumption and the investment adjustment cost parameter
are in line with the corresponding values reported in Adolfson et al. (2007). The posterior
mean of habit parameter is 0.72, that of investment adjustment cost is 8.44. For nominal price

rigidities, we find that the degree of domestic price stickiness is equal to be 0.88 in Calvo (1983) terms, in line with the findings by Smets and Wouters (2003, 2005), Christoffel et al. (2008) and Adolfson et al. (2007). The implied average contract duration is 8 quarters. We estimate a similar value for the degree of price stickiness in the rest of the world. High price stickiness allows, to some extent, to simultaneously fit the volatile real exchange rate and the relatively stable price indices, a result that is well known in the international business cycle literature.

Nominal wages are sticky as well. The implied duration in Calvo terms is equal to 10 quarters. The estimated value is higher than those reported by Adolfson et al. (2007) and Christoffel et al. (2008). The likely reason is that high sticky wages contribute to stabilize marginal costs and prices in correspondence of volatile oil prices. For indexation parameters, we find that they are rather low. This is a finding common to the other contributions (e.g. Adolfson et al. 2007). The posterior mode of the persistence parameters are generally lower than those reported Smets and Wouters (2003, 2005) and in line with Adolfson et al. (2007), that explain the result in terms of the inclusion of the unit-root technology shock and of the open economy aspects of the model.25

Figure 1 shows the data and the benchmark model’s Kalman filtered one-sided estimates of the observed variables, computed at the posterior mode of the estimated parameters. The in-sample fit of the model is satisfactory, as we fit all the observables rather well.

4.2 Impulse response Functions

In this section we perform the impulse response analysis to assess how the main Home macroeconomic variables react to shocks affecting the oil market, i.e. the global oil supply shock, the rest of the world aggregate demand shock, and demand shocks that are specific to the crude oil market.

Oil supply shock

We assess the impact of an exogenous reduction in the global oil production that induces a 10 percent increase in the international real (expressed in foreign consumption terms) price of oil on impact.

We report in Figure 2 the results.26 The CPI inflation increases on impact, up to 0.2 annu-

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25Adolfson et al. (2007) finds lower numbers than those reported by Smets and Wouters (2003, 2005) for the autocorrelation of shocks. They explain the result to the inclusion of the unit-root technology shock and to the open economy aspects of the models, two features that characterize our framework as well.

26All figures in this section report the mean (solid line) and the 90 percent equal-tail uncertainty bands. The results are based on 5,000 draws from the posterior distribution of the model’s parameters.
alized percentage points, and then quickly falls. The initial increase is mainly driven by its fuel component, as the pass-through of the price of oil into the price of fuel is quick and complete. The non-fuel component increases as well, albeit to a much lower extent. The increase in the production costs is transmitted only gradually to final goods prices due to the high estimated nominal price rigidities of Home goods (whose share in the consumption bundle is relatively high). Given the increase in the consumer price inflation, the monetary authority rises the policy rate, albeit slightly. Households’ consumption suffers a negative wealth effect associated with higher oil price. Investment decreases as well, in the usual hump-shaped and persistent matter. Overall, there is a rather small reduction in the euro area output, to -0.05 percent. Results for CPI and output are in line with those reported by ECB (2010) and Jacquinot et al. (2009). Looking at the trade balance, lower Home aggregate demand implies a decrease in non-oil import, which partially offsets the increase in the value of oil imports. The overall trade balance deteriorates by about 0.1 percentage points of GDP. After 10 quarters, the trade deficit shifts into a small surplus, as the price of oil decreases and the amount of exports increases. The latter are favored by the Home exchange rate depreciation, that makes Home export cheaper than foreign non-oil goods. Finally, as said, the exchange rate depreciates so as to guarantee the equilibrium in the goods and bonds’ markets. Results are qualitatively in line with those reported by Kilian et al. (2009).

Rest of the world oil-specific demand shock

We now show the effects of an oil price rise generated by a demand shock that is specific to the oil market (as, such it does not affect the aggregate demand in the main trade partners of the euro area). We calibrate the shock to get an increase in the international relative price of oil equal to 10 percent on impact. We report the results in Figure 3. Qualitatively, the effects are similar to those of a negative oil supply shock. The shock induces higher CPI inflation through the increase in the price of fuel. The negative wealth effect induces households to reduce consumption and investment. As such aggregate demand and GDP decrease as well. The monetary authority raises the nominal interest, given the relatively high weight of the CPI inflation in the monetary policy rule. Quantitatively, the effects of the shocks on real variables are slightly more persistent than those induced by a negative supply shock of the same size. The reason is that the oil-specific demand shock is estimated to be more persistent. As such, the related negative wealth effect is stronger. The Home GDP decreases by -0.1 percent, and stays below the baseline for a longer
time than in the case of a oil supply shock. The same is true for consumption and investment. For the trade balance, the initial deterioration (-0.1 percent of GDP) is roughly equivalent to the one experienced under the oil supply shock, but in this case the balance shifts to surplus later (13 vs 10 quarters). The reductions in non-oil imports and in the volume of oil imports partially compensate for the increase in the value of oil imports.

**Foreign aggregate demand shock**

We report in Figure 4 the effects of a positive shock to the foreign aggregate demand (RW demand shock, in the following) that increases the international oil price by 10 percent on impact. The Home CPI inflation increases up to the peak of 0.2 annualized percentage points on impact. The increase is mainly driven by its fuel component. The non-fuel component does not substantially change, as nominal rigidities are relatively high and firms end up absorbing almost entirely the increase in production costs driven by higher fuel prices. Results are in line with those reported by ECB (2010) and Jacquinot et al. (2009). Differently from the oil supply and oil-specific demand shocks, the positive RW demand shock has a positive effect on euro area exports and GDP. The latter increases up to 0.33 percent on impact. Home consumption gradually increases, albeit to a lower extent than Home GDP as households smooth consumption by lending abroad. Investment in physical capital increases, so as to sustain the increase in the level of production. The trade balance improves (up to 0.22 percent, as a ratio to domestic output), driven by higher export that more than counterbalances the increase in non-oil import (due to higher aggregate demand). As such, the non-oil trade balance surplus more than compensates for the increase in the value of oil imports, driven by the higher price of oil. The euro area real exchange rate appreciates, as demand for euro area goods increases, partially offsetting the increase in (US dollar) oil prices and, hence, limiting the increase in fuel prices (that are set in euro currency). Consistently with the increase in inflation and the economic activity, the monetary authority rises the policy rate.

The RW demand shock affects euro area dynamics in two ways: directly, as it increases the export of the area, and indirectly, via its impact on oil demand and hence oil price. To isolate this latter indirect effect, in Figure 5 we show responses from an economy in which oil demand is not affected by RW demand. Comparing results from Figure 4 and Figure 5, we can evaluate the quantitative importance of the oil channel in transmitting external demand shocks to the euro area. Looking at Figure 5, inflation is now barely affected by the shock, as the fuel price
decreases instead of increasing, pushed down by the real exchange rate appreciation (that reduces the price of oil in euro). The increase in consumption is slightly larger and more frontloaded, as households are not affected by the negative wealth effect associated with the higher oil price. As such, euro area output increases slightly more, up to 0.35 percent. Higher consumption drives up oil and non-oil imports. For oil imports, now quantities increase. The related value (expressed in terms of euro) does not greatly change, because of the real exchange rate appreciation. As such, the overall trade balance improves to a larger extent (0.29 percent, as a ratio to domestic output). Overall, the two sets of results suggest that the “oil price channel” of the RW demand shock mainly affects euro area inflation. To the opposite, oil prices changes driven by this shock do not greatly change real variables other than oil imports.

4.3 Forecast error variance decomposition

Table 4,5,6 decompose the forecast error variances of the main euro area variables into components attributable to the shocks perturbing the model over short (1 and 4-quarter) and medium-term (40-quarter) horizons, respectively. We report values obtained using the posterior mode. We group the shocks as follows: technology (Tech), monetary policy (Mon Pol), euro area demand (Dem), markup (Mkps), rest of the world (RW), fuel margin (Fuel Mkp), oil supply (Oil sup), oil-specific demand (Oil dem), foreign aggregate demand (RW dem).

Moreover, we include the contribution of measurement errors (ME) used in the estimation process, which it is always rather low.

The impact of oil supply shocks and oil-specific demand shocks on the Home GDP, consumption, investment and (real) amount of exports and imports is rather low. The impact on consumption fluctuations is higher than that on other GDP components. The reason is that oil shocks directly affect consumption through its oil component, while they affect investment only indirectly, through changes in the relative prices and, as a consequence, allocations of the available resources (the oil component of the investment basket is zero). The GDP and its component are mainly explained by a combination of preference and technology shocks, in line with

\[27\text{Following Christoffel et al.}(2008), the technology group includes the permanent technology shock, the tran-}
\[\text{sitory technology shock and the investment-specific technology shock. The monetary group is represented by the}
\[\text{innovation to interest rate and the inflation target shock. The euro area demand group includes the preference}
\[\text{shock, shocks to the external risk premium, domestic risk premium, government consumption and import demand.}
\[\text{The markup group consists of the wage markup, the domestic price markup and the import price markup shocks.}
\[\text{The rest of the world consists of shocks to euro area export markup, foreign markup, inflation and interest rate.}
\[\text{The fuel margin group is the shock to the fuel distribution margin. The oil supply group is the shock to the}
\[\text{international supply of oil. The oil demand group is the oil-specific demand shock. Finally, the foreign aggregate}
\[\text{demand group comprises the shock to foreign aggregate demand and to preferences for euro area exported goods.}
\[28\]
evidence provided by Christoffel et al. (2008).

For Home inflation rates, oil shocks explain close to 5 percent of the CPI in the short run and 3 percent in the long run. If we also take into account of shocks to fuel margins, oil-related shock explain around 26 percent of CPI inflation in the short run. In particular, the shocks to oil supply, oil specific demand and to the Home margin on fuel explain almost completely the fuel component of the CPI. Oil specific demand provides the largest contribution, while oil supply and euro area foreign demand shocks provide small contributions. The decomposition is similar to that of the international relative price of oil, as the pass-through into fuel prices of changes in the crude oil price is quick and complete. The oil-related shocks’ contribution to the non-fuel component fluctuations of CPI is muted. The component is mainly explained by a combination of shocks to markup, uncovered interest parity and inflation target.

Overall, our results suggest that oil shocks affect mainly the CPI inflation rate and the consumption component of GDP. The main impact is through the fuel component of the two variables. The impact is immediate and rather similar across all horizons, as the short-run pass-through of change in crude oil prices into fuel prices is complete. Oil shocks also indirectly affect, to some extent, the investment component of GDP.

4.4 Historical decomposition

We show the contribution of shocks to the historical fluctuations in real output growth, CPI inflation, fuel component of CPI inflation and oil price since 1997 up to 2009 (third quarter). We group the shocks in the same way as for the forecast error variance decomposition.28

According to Figure 6, the impact on GDP of oil supply and oil-specific demand shocks have been rather muted. As reported also by Christoffel et al. (2008), the stronger real GDP growth in 1999 and 2000 is mainly due to favorable markup and demand shocks, which offset the overall negative contribution of technology shocks. For the 2001-2008 period, the oil contributions are overall tiny and negative, as the oil price spikes in correspondence of positive oil-specific demand

28We newly report them here for the convenience of the reader. The technology group includes the permanent technology shock, the transitory technology shock and the investment-specific technology shock. The monetary group is represented by the innovation to interest rate and the inflation target shock. The euro area demand group includes the preference shock, shocks to the external risk premium, domestic risk premium, government consumption and import demand. The markup group consists of the wage markup, the domestic price markup and the import price markup shocks. The rest of the world consists of shocks to euro area export markup, foreign markup, inflation and interest rate. The fuel margin group is the shock to the fuel distribution margin. The oil supply group is the shock to the international supply of oil. The oil demand group is the oil-specific demand shock. Finally, the foreign aggregate demand group comprises the shock to foreign aggregate demand and to preferences for euro area exported goods.
shocks and tight oil supply. The decline in euro area domestic demand contributions is the main source of slower real GDP growth in the period. Going to the more recent period, oil supply and demand-specific shocks continue to play a limited role in the decline of GDP growth from the second half of 2008. Foreign aggregate demand, instead, plays a much more crucial role. In fact, lower Foreign activity has a direct negative effect on GDP, via the contraction of exports, but a partially offsetting positive effect via the decrease in oil prices. In correspondence of the through of GDP, oil-specific demand shocks give a positive contribution, as the oil price reaches a minimum value.

We report the CPI historical decomposition in Figure 7. Oil-specific demand shocks contribute negatively to inflation during the 1997-2000 and 2001-2002 periods, when the oil price decreases. The same shocks turned to positive contributions during the 2004-2008 period. Foreign demand shocks follows a similar path. The decline in inflation from the second half of 2008 is due to the negative contribution of domestic demand and the decreasing contribution of Foreign aggregate demand. As in the case of GDP, Foreign aggregate demand has a direct and an indirect impact on inflation. The former is due to low demand for euro area tradables (that affect the ex fuel component of CPI, not reported), the latter to low demand for crude oil and more favorable supply conditions, that induce a decline in the fuel prices.

We show in Figure 8 that the fuel component of euro area CPI inflation essentially mirrors the path of (the level of) oil international relative price, reported in Figure 9. This is consistent with the quick and complete pass-through of oil price changes in the price of fuel. The increase over time of the international relative price of oil is mainly explained by the increase in oil-specific demand contribution (which goes from negative to positive) and, to a less extent, by the increase in the contribution of higher Foreign aggregate demand. These contributions are only partially offset by favorable, albeit decreasing, oil supply shocks during the 2001-2007 period. From 2008, the drop in the relative price of oil is due to the negative contribution of Foreign aggregate demand shocks and oil-specific demand.

4.5 Sensitivity Analysis

In what follows we show the role of key parameters in the transmission of oil supply shocks. We initially consider higher fuel share in the consumption basket. Subsequently, we assume a rather high value (close to one) for the persistence of the oil supply shock. Finally, we assume a higher value of the elasticity of substitution between non-fuel and fuel goods.
Higher fuel share in the consumption basket

Figure 10 shows the responses to a 10 percent oil price hike induced by a negative oil supply shock under two alternative calibrations of the fuel share in the consumption bundle. In the benchmark case it is calibrated to 4 percent, in the alternative calibration to 6 percent. Under the new calibration, the euro area GDP decreases slightly more than in the benchmark scenario (to 0.08 percent and 0.05 percent, respectively). Similarly, annualized CPI inflation increases up to 0.4 percent (0.2 percent in the benchmark). As the share of fuel is higher, households income and, hence, demand are more strongly affected by the increase in the price of oil. Non-oil imports decrease to a larger extent, following the larger drop in consumption and investment, while the value of oil imports is hardly affected, as it is mainly driven by the wide change in the international price of oil.

Higher persistence of the oil supply shock

Figure 11 shows responses of the euro area to a 10 percent permanent rise in the relative price of oil driven by a negative oil supply shock. The bigger negative wealth effect associated with the higher persistence implies a stronger decrease in Home real variables. Home GDP now decreases to a bigger extent than in the benchmark case (−0.14 against −0.05). Similarly, consumption and investment decrease to a bigger extent. Moreover, real variables persistence increase. After 20 periods, GDP deviation from baseline is equal to −0.1 percent. The Home CPI inflation increases is the same as in the benchmark case. For the trade balance, its deterioration is lower. The reason is the stronger exchange rate depreciation, that contributes to shift world’s demand towards Home tradables (the high pass-through into export and import prices is relatively quick, as the corresponding nominal rigidities are estimated to be rather low). For the same reason, the non-oil trade balance quickly shifts towards surplus.

Higher elasticity of substitution

Figure 12 shows the responses to a 10 percent oil price hike induced by a negative oil supply shock under two alternative calibrations of the elasticity of substitution between fuel and non-fuel goods. In the benchmark case it is calibrated to 0.2. In the alternative scenario, to 5. Moreover, we set to zero the short-run adjustment costs of fuel in the consumption basket. As

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29 The autoregressive coefficient of the shock is set to 0.999.
such, there is not anymore a difference between short-run and long-run elasticity.\textsuperscript{30} Increasing the high elasticity case does not greatly affect GDP, consumption and investment. Oil imports are affected relatively more, as households substitute more easily non-fuel goods to fuel. As such, the core component of inflation increases relatively more, inducing a slightly larger increase in the overall CPI index. For the same reason, oil imports and non-oil imports respectively decrease and increase relatively more, driving initially the non-oil trade balance towards deficit. The extra-impact on the overall trade balance (compared to the case of low elasticity) is however nil.

5 Conclusions

In this paper we have empirically analyzed the macroeconomic effects of oil price shocks in the euro area by estimating a small open economy DSGE model. We have assumed that the oil price is endogenously determined by oil demand and supply shocks in the global oil market. According to our results, the euro area GDP and CPI inflation increase when the higher oil price is due to an increase in world aggregate demand. Global oil supply shocks, instead, induce stagflationary effects on the euro area economy. Overall, results point out the need of identifying the (demand and supply) shocks that drives the changes in oil prices, to fully and correctly assess the impact of these changes on macroeconomic variables.

Our contribution can be improved along several dimensions. First, by inserting microfoundations of the supply of oil. One possibility is to follow Nakov and Pescatori (2009, 2010), that endogenize OPEC decisions. Taking a different but complementary route, taking into account the role of oil inventories could be relevant for clearly distinguish between precautionary demand and supply. Finally, we have not fully specified the refining and distribution margins. As such, we cannot fully capture the role of refining and distribution sector for the propagation of oil supply and demand shocks. Moreover, we do not explicitly formalize value added and excise taxes, that could have relevant implications for relative prices and, hence, welfare and optimal policy. We leave these issues for future research.

\textsuperscript{30}To get the same fuel share in consumption (3 per cent) across the two calibrations, we opportunely change the weight of fuel in the consumption basket. Moreover, we modify the elasticity of substitution between fuel and non-fuel goods only in the Home country, while in the rest of the world we continue to set it equal to 0.15.
References


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<td>Dom. risk premium</td>
<td>$\rho_{RP}$</td>
<td>B</td>
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<tr>
<td>External risk premium</td>
<td>$\rho_o$</td>
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<tr>
<td>Price markup: domestic</td>
<td>$\rho_{\theta_H}$</td>
<td>B</td>
</tr>
<tr>
<td>Price markup: export</td>
<td>$\rho_{\theta^*_H}$</td>
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### Table 3. Prior and Posterior Mean of the Parameters (continued)

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<th>Prior std</th>
<th>Prior mode</th>
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<th>Posterior median</th>
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<th>95%</th>
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<td>Price markup: import</td>
<td>$\rho_{\theta F}$</td>
<td>B 0.75</td>
<td>0.15</td>
<td>0.987</td>
<td>0.990</td>
<td>0.990</td>
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<td>Wage markup</td>
<td>$\rho_{\theta L}$</td>
<td>B 0.75</td>
<td>0.15</td>
<td>0.367</td>
<td>0.512</td>
<td>0.499</td>
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<td>Inflation target</td>
<td>$\rho_{\bar{\pi}}$</td>
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<td>0.688</td>
<td>0.740</td>
<td>0.740</td>
<td>0.675</td>
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<td>Ex-oil Import</td>
<td>$\rho$</td>
<td>B 0.75</td>
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<td>0.683</td>
<td>0.711</td>
<td>0.719</td>
<td>0.598</td>
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<td>0.751</td>
<td>0.724</td>
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<td>0.993</td>
<td>0.986</td>
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<td>0.989</td>
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<td>0.923</td>
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<td>0.924</td>
<td>0.926</td>
<td>0.894</td>
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<td>0.886</td>
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<td>0.134</td>
<td>0.131</td>
<td>0.097</td>
<td>0.185</td>
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</table>

**Standard deviations**

| Transitory techn.  | $\sigma_{\epsilon}$ | G 0.001 | 0.1 | 0.002 | 0.002 | 0.002 | 0.002 | 0.003 |
| Inv.-spec. tech.    | $\sigma_{\epsilon}$ | G 0.001 | 0.1 | 0.036 | 0.063 | 0.055 | 0.033 | 0.101 |
| Permanent tech.     | $\sigma_{\mu}$     | G 0.001 | 0.1 | 0.009 | 0.009 | 0.008 | 0.007 | 0.011 |
| Monetary policy     | $\sigma_{R}$       | G 0.001 | 0.1 | 0.000 | 0.000 | 0.000 | 0.000 | 0.001 |
| Preferences         | $\sigma_{C}$       | G 0.001 | 0.1 | 0.011 | 0.016 | 0.015 | 0.012 | 0.019 |
| Public exp.         | $\sigma_{\epsilon}$| G 0.001 | 0.1 | 0.003 | 0.003 | 0.003 | 0.003 | 0.004 |
| Dom. risk premium   | $\sigma_{\epsilon P}$ | G 0.001 | 0.1 | 0.001 | 0.001 | 0.001 | 0.000 | 0.001 |
| External risk premium| $\sigma_{\epsilon}$ | G 0.001 | 0.1 | 0.001 | 0.001 | 0.001 | 0.001 | 0.001 |
| Price markup: domestic| $\sigma_{\epsilon H}$ | G 0.001 | 0.1 | 0.129 | 0.205 | 0.202 | 0.159 | 0.261 |
| Price markup: export | $\sigma_{\epsilon H}$ | G 0.001 | 0.1 | 0.469 | 0.460 | 0.446 | 0.362 | 0.607 |
| Price markup: import | $\sigma_{\epsilon H}$ | G 0.001 | 0.1 | 0.183 | 0.176 | 0.176 | 0.147 | 0.202 |
| Wage markup         | $\sigma_{\epsilon L}$ | G 0.001 | 0.1 | 0.102 | 0.103 | 0.102 | 0.078 | 0.129 |
| Inflation target    | $\sigma_{\epsilon}$ | G 0.001 | 0.1 | 0.003 | 0.003 | 0.003 | 0.003 | 0.004 |
| Ex-oil Import       | $\sigma_{\epsilon F}$ | G 0.001 | 0.1 | 0.024 | 0.021 | 0.020 | 0.017 | 0.028 |
| Fuel import: firms  | $\sigma_{\epsilon F U}$ | G 0.001 | 0.1 | 0.078 | 0.074 | 0.074 | 0.059 | 0.088 |
| Fuel import: cons.  | $\sigma_{\epsilon F U}$ | G 0.001 | 0.1 | 0.001 | 0.001 | 0.001 | 0.001 | 0.001 |
| Fuel margin         | $\sigma_{\epsilon F U}$ | G 0.001 | 0.1 | 0.012 | 0.014 | 0.014 | 0.011 | 0.019 |
| Export preference   | $\sigma_{\epsilon H^*}$ | G 0.001 | 0.1 | 0.025 | 0.026 | 0.025 | 0.021 | 0.031 |
| Aggregate demand: foreign| $\sigma_{\epsilon H^*}$ | G 0.001 | 0.1 | 0.003 | 0.003 | 0.003 | 0.003 | 0.004 |
| Oil-spec. dem       | $\sigma_{\gamma D I L}$ | G 0.001 | 0.1 | 0.026 | 0.026 | 0.026 | 0.022 | 0.031 |
| Oil supply          | $\sigma_{\epsilon S O}$ | G 0.001 | 0.1 | 0.010 | 0.010 | 0.010 | 0.008 | 0.012 |
| Price markup: foreign| $\sigma_{\epsilon F}$ | G 0.001 | 0.1 | 0.001 | 0.001 | 0.001 | 0.000 | 0.001 |
| Interest rate: foreign| $\sigma_{R^*}$ | G 0.001 | 0.1 | 0.001 | 0.001 | 0.001 | 0.001 | 0.001 |
| Inflation: foreign  | $\sigma_{\epsilon}$ | G 0.001 | 0.1 | 0.003 | 0.003 | 0.003 | 0.003 | 0.003 |
|---------------------|------|-----------|------|-----|---------------------|------|----------|----------|---------|----|
| GDP                 | 53.2 | 0.1       | 3.5  | 118 | 124                 | 1.6  | 0.0      | 0.3      | 17.0    | 0.0 |
| Consumption         | 23.1 | 0.7       | 23.7 | 333 | 2.2                 | 10.2 | 0.1      | 1.7      | 4.7     | 0.5 |
| Investment          | 64.7 | 0.2       | 1.2  | 233 | 2.6                 | 2.2  | 0.0      | 0.4      | 5.3     | 0.1 |
| Export              | 18.7 | 0.0       | 0.0  | 1.0 | 47.6                | 0.0  | 0.0      | 0.0      | 32.6    | 0.0 |
| Import              | 4.9  | 0.0       | 1.4  | 61.1| 7.6                 | 1.1  | 0.0      | 0.3      | 20.3    | 3.3 |
| Interest rate       | 12.1 | 23.4      | 18.5 | 10.1| 4.2                 | 24.6 | 0.7      | 3.9      | 2.4     | 0.0 |
| GDP Deflator        | 17.0 | 11.4      | 0.2  | 21.1| 46.7                | 0.0  | 0.0      | 0.0      | 2.1     | 1.4 |
| CPI                 | 11.4 | 28.3      | 14.4 | 11.0| 1.6                 | 24.6 | 0.6      | 3.9      | 0.1     | 4.0 |
| CPI ex fuel         | 16.0 | 392.2     | 20.4 | 16.1| 1.9                 | 0.4  | 0.0      | 0.0      | 0.3     | 5.6 |
| CPI fuel rel. price | 0.0  | 0.0       | 0.0  | 12  | 0.4                 | 10.0 | 1.1      | 73.2     | 1.4     | 2.7 |
| Oil internat. rel. price | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 128 | 84.1 | 1.1 | 2.0 |
| Real eff exch       | 1.5  | 0.5       | 1.8  | 488 | 18.0                | 0.5  | 0.0      | 0.0      | 28.9    | 0.0 |
### Table 5. Forecast Error Variance Decomposition (4-quarter horizon)

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<td>3.8</td>
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<td>162</td>
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<td>78.0</td>
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<td>0.1</td>
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<td>0.0</td>
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<td>36.4</td>
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Figure 1: Data (thick) and one-sided predicted values from the model (thin).
Figure 2: Responses to a negative oil supply shock

Horizontal axes: quarters. Vertical axes: percentage deviations from the baseline, except for inflation and interest rates (annualized percentage-point deviations). GDP and its components are reported in real terms.

Diagram showing the responses of various economic indicators to a negative oil supply shock, including:
- Oil (internal) price
- CPI inflation
- CPI fuel inflation
- CPI excluding fuel inflation
- Nominal interest rate
- GDP
- Consumption
- Investment
- Export
- Terms of trade (excluding oil)
- Real exchange rate
- Oil import (volume)
- Oil import (value)
- Trade balance
- Non-oil trade balance

Source: Text from the document.
Figure 3: Responses to a positive oil-specific demand shock

Horizontal axis: quarters. Vertical axis: percentage deviations from the baseline, except for inflation and interest rates (annualized percentage-point deviations), and the trade balance (as a ratio to GDP, percentage-point deviations). GDP and its components are reported in real terms.
Figure 4: Responses to a positive foreign aggregate demand shock.

Horizontal axis: quarters. Vertical axis: percentage deviations from the baseline, except for inflation and interest rates (annualized percentage-point deviations), and the trade balance (as a ratio to GDP, percentage-point deviations). GDP and its components are reported in real terms.
Figure 5: Responses to a positive foreign aggregate demand shock that does not affect the price of oil

Horizontal axis: quarters. Vertical axis: percentage deviations from the baseline, except for inflation and interest rates (annualized percentage-point deviations), and the trade balance (as a ratio to GDP, percentage-point deviations). GDP and its components are reported in real terms.
Each colored bar shows how that group of shocks contributes to the absolute deviation from steady-state (expressed in percentage points) of the GDP growth rate in a given quarter.
Each colored bar shows how that group of shocks contributes to the absolute deviation from steady-state (expressed in percentage points) of the yearly inflation rate in a given quarter.
Each colored bar shows how that group of shocks contributes to the absolute deviation from steady-state (expressed in percentage points) of the fuel inflation rate in a given quarter.
Figure 9: Historical decomposition of international relative price of oil

Each colored bar shows how that group of shocks contributes to the absolute deviation from steady-state (expressed in percentage points) of the oil price in a given quarter.
Figure 10: Responses to a negative oil supply shock. High fuel weight in consumption.

Horizontal axis: quarters. Vertical axis: percentage deviations from the baseline, except for inflation and interest rates (annualized percentage-point deviations), and the trade balance (as a ratio to GDP, percentage-point deviations). GDP and its components are reported in real terms. Blue line: baseline calibration. Red dotted line: high fuel weight.
Figure 11: Responses to a negative oil supply shock. Permanent oil supply shock

Horizontal axis: quarters. Vertical axis: percentage deviations from the baseline, except for inflation and interest rates (annualized percentage-point deviations), and the trade balance (as a ratio to GDP, percentage-point deviations). GDP and its components are reported in real terms. Blue line: baseline calibration. Red dotted line: permanent shock.
Figure 12: Responses to a negative oil supply shock. High fuel elasticity

Horizontal axis: quarters. Vertical axis: percentage deviations from the baseline (annualized percentage-point deviations), except for inflation and interest rates (annualized percentage-point deviations). GDP and its components are reported in real terms. Blue line: baseline calibration. Red dotted line: high elasticity.