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Energy Prices and Business Cycles: Lessons from a Simulated Small Open Economy Model

by
Torsten Schmidt* and Tobias Zimmermann

Despite energy price hikes in recent years, growth rates turned out to be high in most industrialised countries. This pattern starkly contrasts the adverse effects that energy price shocks exerted on growth in the 1970s and 1980s. This study investigates whether a reduction in the energy cost share or different sources of energy price hikes are responsible for this divergence. By adding an exogenous two-variable VAR to a new open economy model for Germany, both energy prices and global economic activity are specified to be independent from domestic variables but assumed to influence each other. We show that it is sensible to calibrate the model in accordance with long-run fluctuations in important, observable, structural parameters and VAR coefficients on a period by period basis. Increases in energy prices and in global output serve as supply side and demand side shocks respectively. Our results suggest that the effects of recent energy price hikes have been different from past experiences because they were demand driven. Therefore, supply driven energy price increases could still be an important source of business cycle fluctuations.

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* Corresponding author: Torsten Schmidt, Deputy Division Chief, Growth and Cycles Research Programme, Rhine-Westphalia Institute for Economic Research, Hohenzollernstraße 1-3, 45128, Essen, Germany, e-mail: torsten.schmidt@rwi-essen.de.

1. Introduction

Energy prices rose dramatically between 2004 and 2008, while during the same period, economic growth remained high in most energy importing countries. This suggests that the current effects of energy price hikes are different from those experienced in the 1970s and early 1980s. In general, there are two candidate explanations for this phenomenon. First, the difference could be caused primarily by a change in the economic structure, in particular a reduction of the energy cost share. In this case, the effects of supply driven energy price shocks would be reduced permanently. Second, it is likely that recent energy price increases have been demand driven to a large extent, as a reflection of a soaring world economy. Thus, the favourable stance of the world economy might have offset the adverse effects of more costly energy. Due to the simultaneous occurrence of macroeconomic phenomena, the relative importance of these two candidate explanations can only be addressed sensibly in terms of stylised economic models rather than by a close examination of the data.

By simulating a new open economy (NOE) model for the German economy, we analyse these two explanations more elaborately in this paper. In the model, the size of the energy cost share determines the strength of adverse supply effects of energy price hikes. Due to the importance of this variable for our simulations, we extract the underlying trend of this and other important variables, and use them to change the calibration of the model for each period. Moreover, we allow shocks to energy prices and to the global economy to be interdependent by adding a two-variable VAR for energy prices and global GDP to the NOE model. Changes in the persistency of the shocks and the relation between them are captured by varying the relevant parameters each period according to estimates derived from a 40-period rolling window.

Two different types of energy price shocks are considered each period: supply driven energy price shocks, simulated by an innovation to energy prices; and demand driven energy price movements, simulated by an innovation to global output. The results of our simulations suggest that energy prices are still an important source of business cycle fluctuations in Germany. Except for the 1990s, energy price shocks still display substantial negative effects if they are supply driven. Hence, the source of the shock has a great impact. Moreover, only the simulated responses to a global economy shock resemble the evolution of energy prices and important domestic variables during the recent episodes of rising energy prices. Consequently, it appears that the effects of recent energy price hikes have only been moderate because, to a large extent, they were demand driven.

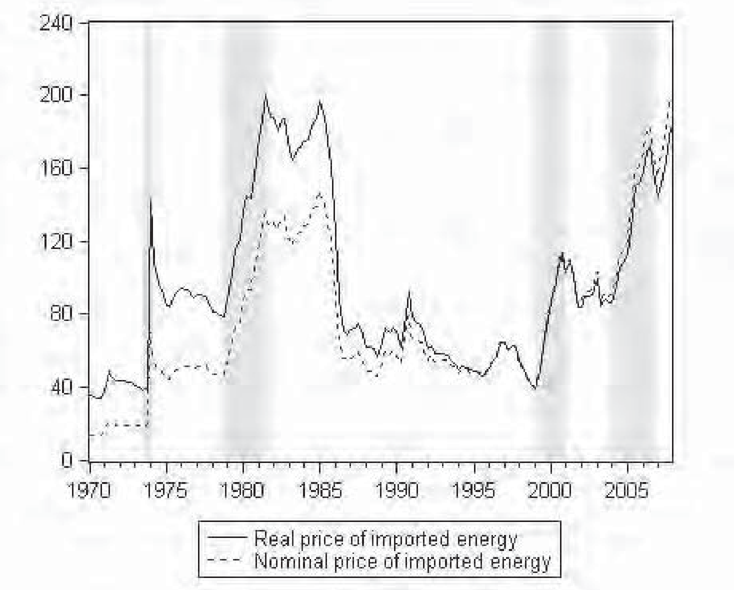
Our results contribute to the ongoing discussion on whether the effects of oil price shocks have changed since the early 1970s. In favour of non-fundamental changes, Hamilton (1996) stresses that the effects of energy price increases are still the same as in the 1970s if one concentrates on dramatic oil price increases. In line with our approach, Barsky and Kilian (2004), Kilian (2009) and Peersman and Van Robays (2009) claims that the energy price shocks in the 1970s and early 1980s were exogenous supply shocks caused by political events while the recent energy price hike was caused by excess demand, in particular related to increasing economic activity in transition economies such as China and India. In contrast, other authors argue that the energy intensity of production has been reduced by industrial countries since the 1970s (*e.g.* Blanchard, Gali, 2007; Sanchez, 2008). This is in line with the empirical finding that energy price increases foster energy saving, technological change (Frondel, Schmidt, 2002, 2006). Moreover, a trend towards more flexible real wages has tended to lead to smaller responses of real output and inflation to an energy price shock. Finally, it is argued that the conduct of monetary policy is important for the propagation of oil price shocks (Bernake, Gertler, Watson, 1996; Leduc, Sill, 2004). Changes in the response of monetary policy to oil price shocks may also lead to different effects on the real economic activity.

The outline of the paper is as follows: in section two we describe some stylised facts concerning important economic variables; in section three we describe the model, the calibration and the solution methodology; section four presents the simulation results; section five summarises and concludes.

2. Basic facts

In this section we identify important energy price shocks and characterise the evolution of important macroeconomic variables in Germany during these episodes. It is shown that real variables evolve quite differently, whereas the magnitudes of the price increases are quite similar. Figure 1 visualises the developments of the nominal and the real price of imported energy. The price series is the price index of imported energy provided by the Federal Statistical Office, normalised to 100 for the year 2000. Since 1970, there have been four big jumps in real energy prices. The first jump in the energy price index occurred in 1974 from 40 to 140. The second increase from 80 to 160 started in 1979. The increase of energy prices after 1999 also proceeded in two steps. In the first step, energy prices jumped from 40 to 100 and eased to 90 in 2002. The second increase started in 2004 and in 2007 reached the level of 1981.

Figure 1. **Energy shock episodes**



Note: To obtain the real series, the nominal price index of imported energy (2000 = 100) is deflated by the GDP deflator.
Source: Federal Statistical Office.

The movements of the price for imported energy sources during these four episodes of rising energy prices are characterised in Table 1. The first line shows the change of the real energy price index. During the first energy shock episode, the real energy price increased by more than 130% and nearly doubled again between 1978:Q4 and 1981:Q3. The increase in the third period also exceeded 100%. Compared with these figures, the increase in energy prices during the fourth episode seems relatively moderate, albeit still substantial. Correspondingly, Table 1 also reports the development of important macroeconomic variables during these episodes. Following Blanchard and Gali (2007), we compare the cumulated growth rates of GDP and exports of the eight subsequent quarters after the first oil price increase with the trend growth measured as the growth rate of the eight quarters preceding the oil price shock. For inflation and interest rates, we compare the eight quarter averages before and after the first quarter of the oil price shock. For example, the eight quarter growth rate of GDP in the first episode was 7.4 percentage points below the growth rate of the eight quarters before the oil price shock.

The figures in Table 1 therefore highlight that the first two energy price shock episodes were accompanied by a substantial loss in GDP, while in the third and fourth episodes there was a gain. Except for the first episode, when there was a loss, exports increased faster in periods of energy price shocks. However, the gains in exports were substantially higher in the two most recent episodes than had previously been the case. There is also a slight change in the development of inflation. While inflation rates were even lower after the first oil price shock, they increased after the other oil price shocks but at different magnitudes. During the second oil price shock, the average inflation rate over eight quarters was 5.5 percentage points higher than before the shock, but only 1.3 and 1.5 percentage points higher during the third and fourth shock, respectively. It is therefore not surprising that the interest rate increased to a lesser extent during the more recent energy price shocks. It is also shown that monetary policy even lowered interest rates during the first energy shock episode. These stylised facts for Germany are approximately in line with the empirical findings of Peersman and Van Robays (2009). For the sample from 1986 to 2008 which captures oil price shock episodes 3 and 4, they find small positive effects of oil price increases on GDP and stronger positive effects on exports. In addition, the authors find relatively strong positive effects on consumer prices. The explanation is that oil prices shocks lead to higher nominal wages. This aggravates the direct oil price effect on consumer prices and mitigates the effect on domestic demand. However, this focus on second-round effects neglects the response of exports to an oil price shock. In the following sections we therefore analyse whether raising oil prices caused by an increasing global demand are able to explain the response of exports and other stylised facts.

Table 1. **Changes in selected macroeconomic variables during energy shock episodes**

	Episode 1: 1973:Q3-1974:Q1	Episode 2: 1978:Q4-1981:Q3	Episode 3: 1999:Q1-2000:Q4	Episode 4: 2004:Q1-2006:Q3
Real energy prices	132	94	106	48
GDP	–7.4	–1.2	2.9	0.7
Exports	–10.6	3.4	31.3	8.9
Inflation	–0.3	5.5	1.3	1.5
Interest rate	–2.5	1.5	0.7	0.5

3. Model simulations

To explore the reasons why similar increases in energy prices have apparently exerted quite different effects on the German economy, we use a new open economy (NOE) model in the style of McCallum and Nelson (1999). Like Kamps and Pierdzioch (2002), the model considers that energy is not only used for productive purposes, but is also consumed. We also include investment and physical capital in our model to account for substitution effects between energy and capital in the production function. Another important feature of this model is that the shock processes of energy prices and world economic activity are modelled as a VAR(1) to account for interdependencies of these shocks. Germany is therefore treated as a small open economy, *i.e.* the stance of the global economy and the real price of imported energy sources are exogenous shocks. By using a structural model, the effects of a lower energy cost share can be identified. However, after presenting the model setup, we show that the energy cost share in Germany exhibits long-run fluctuations. The same is true for the relation between energy prices and world GDP growth. To capture these trends, a time-varying calibration of the model is proposed. According to this concept, the effects of each of these two shocks have to be calculated separately for each period.

3.1. Model setup

In this section we describe the building blocks of the NOE model.[1] In this model energy (*IM*) as well as labour (*N*) and capital (*K*) is utilised to produce domestic output (*Y*) with a CES production technology:

$$Y_t = A_t \left(\alpha IM_t^{\rho} + \phi K_t^{\rho} + \gamma N_t^{\rho} \right)^{\frac{1}{\rho}} \tag{1}$$

The capital stock (*K*) accumulates according to

$$K_{t+1} = (1-\delta) K_t + IVX_t - C(IVX_t) \tag{2}$$

where *IVX* is private investment and *C*(*IVX*) are adjustment costs. Following Casares and McCallum (2000) we define:

$$C(IVX_t) = \psi IVX_t^{\eta}$$

It is also considered that energy is consumed by private households. The representative household maximises:

$$E_t \sum_{j=0}^{\infty} \beta^j \exp(v_t) \left(\frac{\sigma}{\sigma - 1} \right) \left(\frac{CX_t}{CX_{t-1}^{h}} \right)^{\frac{(\sigma-1)}{\sigma}} + (1-\gamma)^{-1} \left(\frac{M_t}{P_t^{CX}} \right)^{(1-\gamma)} \tag{3}$$

where v is a preference shock and M / P^{CX} are real money balances. *CX* is the household consumption good comprised of domestically (*C*) and foreign (IM^C) produced consumption goods (Kamps, Pierdzioch, 2002). For simplicity we assume that energy is the only imported consumption good.

$$CX_t = \omega^{\omega} (1-\omega)^{1-\omega} C_t^{\omega} \left(IM_t^C \right)^{1-\omega}$$

and C is a CES consumption basket:

$$C_t = \left(\int_0^1 C_t(j)^{\frac{(\theta-1)}{\theta}} dj \right)^{\frac{\theta}{(\theta-1)}} .$$

In addition, the price index of the household's overall consumption (P^{CX}) is a weighted average of the prices of domestically (P^{C}) and foreign (P^{IMC}) produced goods. In this model the import price is identical to the price of oil.

$$P_t^{CX} = \left(P_t^{C}\right)^{\omega}\left(P_t^{IMC}\right)^{1-\omega} \tag{4}$$

Demand for the domestically produced consumption good is given by

$$C_t = \omega\left(\frac{P_t^{C}}{P_t^{CX}}\right)^{-1} CX_t \tag{5}$$

and for imported consumption goods:

$$IM_t^{C} = \left(1-\omega\right)\left(\frac{P_t^{IMC}}{P_t^{CX}}\right)^{-1} CX_t \tag{6}$$

The household's budget constraint is given by

$$\begin{aligned}&\frac{P_t}{P_t^{CX}}Y_t - CX_t + \frac{W_t}{P_t^{CX}}N_t^{S} - \frac{W_t}{P_t^{CX}}N_t + TR_t - \frac{M_t}{P_t^{CX}} + \frac{M_{t-1}}{P_t^{CX}} - \frac{B_{t+1}}{1+r_t} + B_t\\ &-Q_t IM_t - \frac{Q_t B_{t+1}^{*}}{\left(1+\kappa\right)\left(1+r_t^{*}\right)} + Q_t B_t^{*} - K_{t+1} + \left(1-\delta\right)K_t - \psi IVX_t^{\eta} = 0\end{aligned} \tag{7}$$

where W is the wage and *B* and *B** denotes the quantity of domestic and foreign bonds, respectively. TR is the amount of government transfers. κ is a risk premium on interest rates, which is endogenous in this model (Schmidt-Grohe, Uribe, 2003):

$$\kappa_t = \left(\frac{S_t B_t^{*}}{P_t^{CX} Y_t}\right)^{\varphi}. \tag{8}$$

The real exchange rate Q is defined as:

$$Q_t \equiv \frac{S_t P_t^{CX*}}{P_t^{CX}} \tag{9}$$

where S is the nominal exchange rate.

Households maximise (3) under the constraint (7) with respect to $CX_t, M_t P_t^{A}, B_{t+1}, B_{t+1}^{*}, N_t, IM_t$ and K_{t+1}. From the first order conditions we get the following set of equations:

$$exp\left(\nu_t\right)CX_t^{\frac{-1}{\sigma}}\left(\frac{1}{CX_{t-1}^{h}}\right)^{\frac{\sigma-1}{\sigma}} - \beta h E_t\, exp\left(\nu_{t+1}\right)CX_{t+1}^{\frac{\sigma-1}{\sigma}}\, CX_t^{\frac{h-\sigma h-\sigma}{\sigma}} = \lambda_t \tag{10}$$

$$\lambda_t\left(1+r_t\right)^{-1} = \beta\lambda_{t+1} \tag{11}$$

$$\psi\eta IVX_t^{\eta-1} = \frac{\theta}{\theta-1}\phi A_{t+1}^{\rho}\left[\frac{Y_{t+1}}{K_{t+1}}\right]^{1-\rho} - \delta - r_t + \left(1-\delta\right)\psi\,\eta\, IVX_{t+1}^{\eta-1} \tag{12}$$

$$\left(\frac{\lambda_t}{\zeta_t}Q_t\left(\frac{P_t^{IMO*}}{P_t^{CX*}}\right)\right)^{\frac{1}{1-\rho}} = \alpha^{\frac{1}{1-\rho}} A_t^{\frac{\rho}{1-\rho}}\frac{Y_t}{IM_t} \tag{13}$$

$$\left(1+r_t\right)\frac{P_{t+1}^{CX}}{P_t^{CX}} = E_t\frac{S_{t+1}}{S_t}\frac{P_{t+1}^{CX*}}{P_t^{CX*}}\left(1+\kappa_t\right)\left(1+r_t^{*}\right) \tag{14}$$

In addition, export demand (EX) is given by

$$EX_t = Q_t^{\tau} Y_t^{*b} \tag{15}$$

where Y* is foreign GDP and Q is the real exchange rate. The aggregate resource constraint in this model is:

$$Y_t = CX_t + IVX_t + EX_t - IM_t^{C} \tag{16}$$

To solve the model we linearise equations (1), (2), (4) – (6) and (8) – (16). From the linearised production function and import demand equation we derive equations for flexible output and import demand. Under flexible prices labour input equals one for all t and the price mark up is constant. Under flexible prices the linearised import demand equation is given by

$$i\overline{m}_t = \overline{y}_t - \frac{1}{1-\rho}\left(q_t - p_t^{IMO*} + p_t^{CX*} + \rho a_t\right) \tag{17}$$

By substituting (16) into the linearised production function we get:

$$\overline{y}_t = \Upsilon a_t - \Omega\left(q_t - p_t^{IMO*} + p_t^{CX*} + k_t\right) \tag{18}$$

with $\Omega = \left(\alpha \frac{1}{1-\rho}\left(\frac{I\overline{M}}{\overline{Y}}\right)^{\rho}\right) \Big/ \left(1-\alpha\left(\frac{I\overline{M}}{\overline{Y}}\right)^{\rho}\right)$ and $\Upsilon = 1/\left(1-\alpha\left(I\overline{M}/\overline{Y}\right)\right)+\Omega$.
The output gap (y^{gap}) is defined as the difference between actual and flexible price output $(\overline{y})$.

$$y_t^{gap} = y_t - \overline{y}_t\,. \tag{19}$$

We also use the definition of nominal interest rates:

$$R_t = r_t + p_{t+1}^{CX} - p_t^{CX} \tag{20}$$

Monetary policy is conducted according to the following rule:

$$R_t = \mu_0 + \mu_3 R_{t-1} + \left(1-\mu_3\right)\left[\mu_1 \Delta p_t^{CX} + \mu_2 y_t^{gap}\right] + \varepsilon_t \tag{21}$$

Because of certain monopoly power, each firm treats the price of its good as a choice variable while aggregate home and foreign price levels are taken as given. After setting the profit-maximising price, each firm produces whatever quantity of output is demanded. It is assumed that firms behave according to a price adjustment mechanism similar to the one introduced in Fuhrer and Moore (1995). This approach rationalises a reasonable degree of inertia in inflation dynamics. More precisely, it claims that inflation, measured as the change of the price index of domestically produced goods, is a function of the output gap and of the weighted average of lagged and expected inflation (Kamps, Pierdzioch, 2002)

$$\left(p_t^C - p_{t-1}^C\right) = 0.5\left(p_{t-1}^C - p_{t-2}^C\right) + \left(p_{t+1}^C - p_t^C\right) + \xi\, y_t^{gap} + \varepsilon_t^p \tag{22}$$

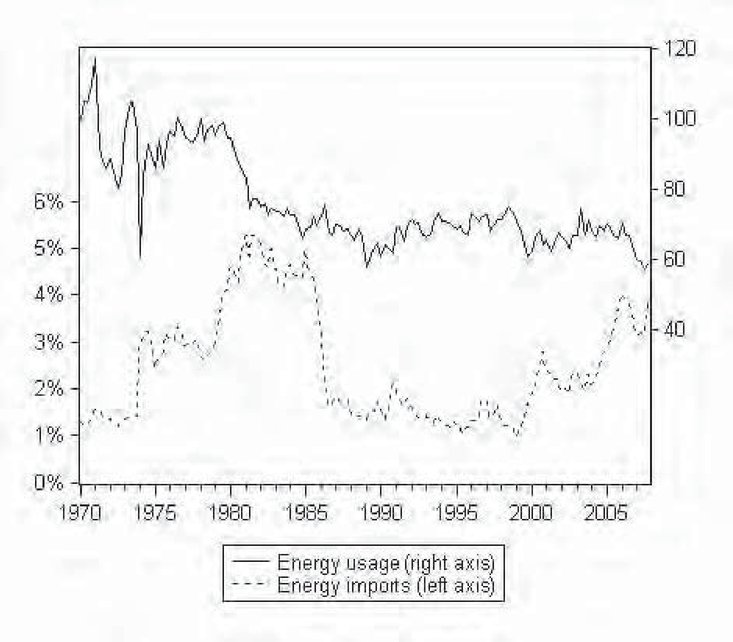
This establishes a system of 18 difference equations in the endogenous variables c_t, cx_t, ex_t, im_t^c, $i\overline{m}_t$, ivx_t, κ_t, p_t^c, p_t^{cx}, q_t, r_t, $R_t s_t$, y_t, $\overline{y}_t$, y_t^{gap}, λ_t, κ_t. In addition, we treat the energy price and all foreign variables as exogenous. While they influence the domestic variables, energy prices and the level of global economic activity are assumed to be intimately related. To capture these interactions, the shock processes are modelled as a VAR(1).

$$\begin{bmatrix} p_t^{IM^E} \\ y_t^* \end{bmatrix} = \begin{bmatrix} coef_{11} & coef_{12} \\ coef_{21} & coef_{22} \end{bmatrix} \begin{bmatrix} p_{t-1}^{IM^E} \\ y_{t-1}^* \end{bmatrix} + \begin{bmatrix} \varepsilon_t^{IM^E} \\ \varepsilon_t^{Y^*} \end{bmatrix} \tag{23}$$

3.2. Time varying calibration

In this section, the calibration of the model is discussed. In our approach the most important measure to assess the supply side effects of energy price hikes is the energy cost share e_Y^{SS}.[2] This structural parameter is influenced by non-cyclical variations in the physical amount of energy per output or GDP (in Figure 2 this measure is referred to as energy usage) as well as non-cyclical movements in energy prices that lead to different cost per unit of energy used. Figure 2 indicates that the energy usage shows a continuous downward trend whereas the economically more important variable energy cost share is mainly driven by long-run fluctuations in energy prices. The energy cost share exhibits trends and long-run fluctuations that are relatively strong compared with other structural

Figure 2. **Energy usage and energy imports in proportion to GDP**



Note: To calculate energy usage in proportion to GDP, nominal energy imports are deflated by the price index for imported energy and divided by real GDP. Since the scale of this measure is arbitrary, its value for 1970 is set to 100.
Source: Federal Statistical Office.

parameters of DSGE models, *e.g.* depending on the preferences of the economic agents in the respective economy.

Several papers (*e.g.* Blanchard, Gali, 2007; Schmidt, Zimmermann, 2005, 2007; Sanchez, 2008) distinguish two sub-periods to investigate the effects of price shocks in more and less energy intensive times. Obviously, the calibration of an era of low energy intensity from the end of the 1980s up to today does not seem to be suitable. Even if the amount of energy (in physical units) in relation to GDP has remained lower than in the 1970s and 1980s, the ongoing upward trend in energy prices since 2002 has pushed the energy cost share near to its previous peak of 1981.

Therefore, a calibration on the basis of sample averages does not seem to be appropriate for capturing cost trends adequately. Instead, the Hodrick Prescott (HP) filter is used to identify trends in the energy cost share. This trend is used for adapting the calibration of the model for each quarter of our sample. Thus, long-run fluctuations are employed for calibration purposes while the remaining fluctuations of the energy prices are interpreted as shocks. The identified cost trend suggests that from 2005 to 2008 the cost burden for the German economy was nearly as large as during the first half of the 1980s.

The same filter is applied to calibrate other parameters of the model, *e.g.* the export share, ex^{ss}, which is an indicator of openness and therefore, crucially determines the response of the domestic economy to world GDP shocks. This parameter shows an upward trend that becomes steeper after 1995.[3]

As introduced in the previous section, the model is exposed to two shocks variables that interact with each other. To derive the series of energy price and global economic activity shocks, both series are HP-filtered before estimation.[4] Since long-run trends in energy prices are already considered by the time-varying calibration of the structural parameters of the model, only the remaining fluctuations are interpreted as shocks. Moreover, it is considered that the relationship between the exogenous variables may also have changed. By estimating a rolling window VAR of 40 quarters over the period from 1970:Q1 to 2007:Q4, trends in the relationship between, and the persistency of, exogenous shocks are captured.[5]

The HP filtered trend of the rolling window coefficients are depicted in Figure 3. Each point in the graph represents a filtered coefficient of the VAR estimated for a 40 quarter sample. For example the first dot in Figure 3(a) is the autoregressive coefficient of the oil price estimated from the first quarter 1970 to the fourth quarter 1979. This coefficient is assigned to the first quarter of 1975 in the graph. It is evident that the magnitude of the coefficients exhibit substantial changes over time. For example the autoregressive coefficient of the oil price jumps to almost one in 1980:1 (sample 1976:1 to 1985:4) and remains relatively high in the following period. The coefficients that show how oil prices drive the global economy and *vice versa* are particularly interesting. Figure 3(b) shows that oil prices are strongly driven by global GDP in recent times. That is not surprising as the soaring demand from China and other Asian countries is often seen as a major reason for the step by step increase in oil prices from 2000 to 2008. It is more surprising that the link between global GDP and energy prices was relatively strong, also at the beginning of our sample, and showed a downward trend during the 1980s. Figure 3 therefore shows that the oil price hikes in the 1970s and early 1980s are at least partly driven by global economic activity and not only by supply cuts in the Middle East. Figure 3(c) confirms that the negative effects of energy price hikes on global economic activity were the strongest around 1980, became negligible as industrialised countries reduced their energy intensity and energy prices collapsed, and became stronger as energy intensive, booming, emerging markets became more powerful in the global economy and energy prices rose. By incorporating this changing structure in our model of a small open economy, we get a more complete picture of the internal and external structural changes that are responsible for the changing effects of energy price hikes over time.

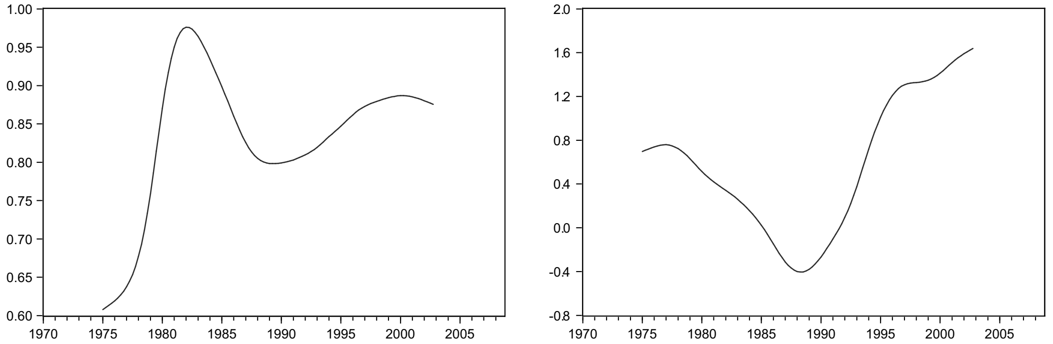
One disadvantage of the calibration set-up we conduct in our analyses is that the resulting DSGE simulation is not completely immune to the Lucas critique. The reason is that for each period, the model is solved as if the structural coefficients of the model were not changing, *i.e.* that economic agents do not take into account expectable shifts in the economic structure. We want to put forward two arguments related to that issue. First, the changes between succeeding periods are relatively small and economic agents discount future variables. Second, if several distinctive sub-periods were used, the argument would be the strongest at the beginning of one and the start of another distinctive sub-period. Despite this shortcoming of the model, we think that the use of real-time values for the steady state variables helps to improve the assessment of the economic effects of past oil price shocks.

For the other parameters of the model we use common values from the related literature. Most of these parameters are in line with McCallum and Nelson (1999) and Kamps and Pierdzioch (2002). In particular, we set the discount factor $\beta = 0.99$ but choose a slightly lower value for the habit formation parameter ($h = 0.6$) following Smets and Wouters (2003). In the export demand equation we set the elasticity of exports with respect to foreign demand (b) as well as the exchange rate elasticity of exports (τ) to 0.33. Following

Figure 3. **Time varying coefficients of the shock processes**

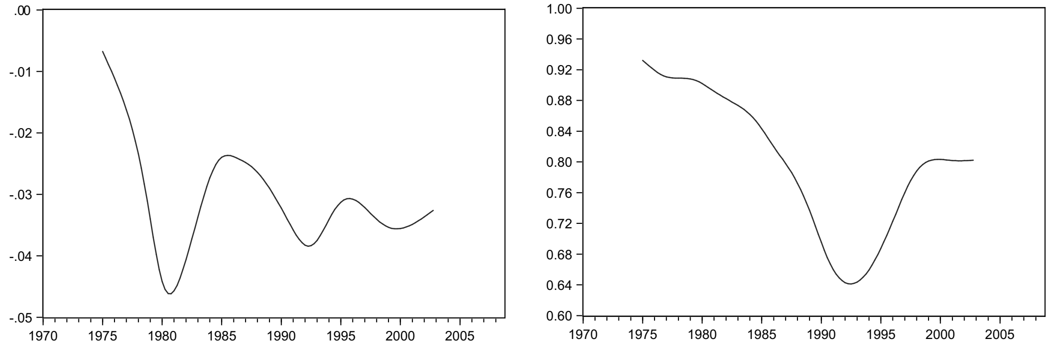
a) Coefficient of persistency in energy prices

b) Coefficient of the effects of global activity on energy prices



c) Coefficient of the effects of energy prices on global economic activity

d) Coefficient of persistency in global economic activity



Casares and McCallum (2000), we set the parameters of the adjustment cost function $\eta = 3.42$ and $\psi = 0.125$. We choose 0.025 as depreciation rate (δ). The output gap coefficient in the price setting equation (ξ) is set to 0.02 and the share of domestic produced consumption goods is 0.98. While capital is introduced in the production function, we use the same parameter values as Edenhofer *et al.* (2005). Therefore, we set the distribution parameters to $\alpha = 0.04$, $\phi = 0.3$ and $\gamma = 0.66$. We choose 0.25 for the substitution parameter ρ. We also differ from the benchmark calibration in McCallum and Nelson (1999) concerning preferences by assigning σ the conventional value of 0.5. The coefficient of the risk premium equation (φ) is set to –0.02 (Ambler *et al.*, 2004). For the parameters of the Taylor rule we set the interest rate smoothing parameter (μ_3) to 0.8, the inflation response parameter (μ_1) to 1.3 and the output gap response parameter (μ_2) to 0.25.

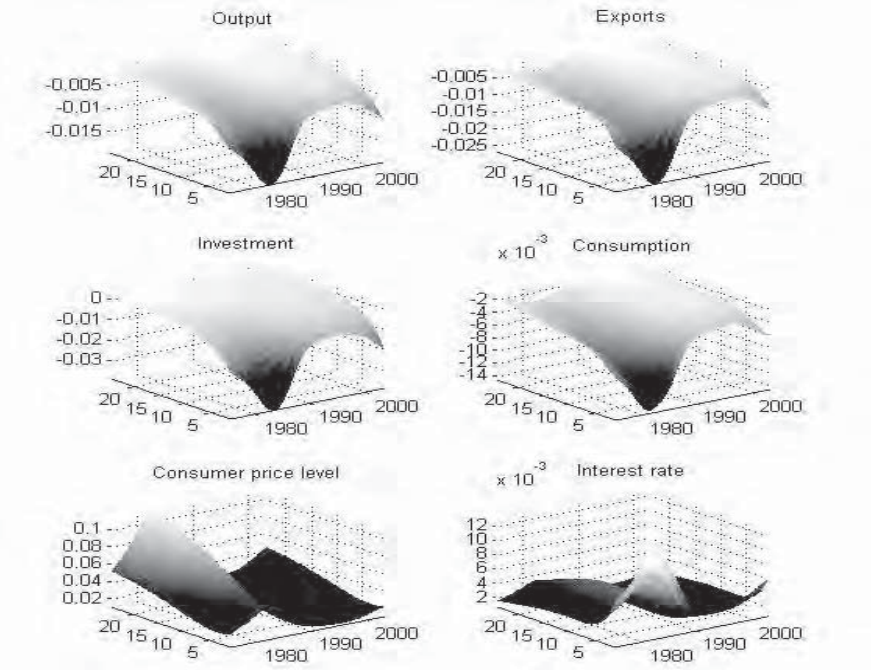
4. Simulation results

In this section, impulse response functions are presented, showing the reaction of the small open economy to exogenous global energy price and demand shocks. Due to the time varying calibration proposed above, the responses to shocks are different at each point in time. In the following, our graphs therefore differ from the conventional impulse response figures as a third dimension, representing the period for which a certain response is valid, is added.

To identify the source and the resulting effects of the recent oil price shock, we perform three simulation experiments. In the first experiment, we analyse the importance of structural changes in the German economy by changing the energy cost and the export share as well as the investment share and the GDP to capital ratio.[6] The parameters describing the persistency and the interaction between the exogenous variables remain unchanged and the effects of a pure energy cost shock are shown. In this case, shocks are assumed to be independent AR(1) processes, that are estimated over the whole sample. In both simulations that follow, we change the structural parameters of the economy as well as the coefficients of the shock processes. In the second experiment, we again simulate a pure energy price shock and in the third experiment, we simulate a shock to global economic activity. In the latter two experiments, both exogenous variables are interlinked by a VAR process: the stance of the global economy changes in the succeeding periods of an oil price shock and *vice versa*. This setup allows two different explanations for energy price hikes. Firstly, as previously carried out, an energy price increase is modelled as an exogenous initial innovation. However, contrary to the former case, this shock may be aggravated by global economic downswings. Secondly, energy prices are triggered by global output. This variant resembles a demand driven energy price increase. We present both simulations. Since the effects on the German economy are quite different, we can decide which of the two variants yields a plausible explanation for different shock episodes.

The results of the first simulation are plotted in Figure 4. The period at which the initial impulse of a 1% increase in energy prices hits the German economy is depicted on the *x*-axis. The *z*-axis represents the number of periods after the initial shock impulse. The vertical axis shows the amount of reaction that would take place if the model's parameters remained unchanged compared to the period where the initial shock impulse occurred. Impulse response functions are calculated from 1971:Q1 to 2006:Q4. It becomes evident that an exogenous energy price shock had the most pronounced effects in the early 1980s. During this time, an energy price shock triggers a substantial loss in GDP and its demand components as well as a strong increase in inflation and the nominal interest rate. These results are approximately in line with the stylised facts presented in Table 1. It is also demonstrated that supply side effects of energy price shocks had only small effects in

Figure 4. **Impulse response functions of the NOE model to a one unit energy price shock, constant shock coefficients**



the 1990s. However, even for this period, the model predicts a reduction of GDP and its components after an oil price shock. This is contrary to the empirical findings for the oil price shock episodes of 1999/2000 as well as of 2004/2006. Another interesting finding of this simulation exercise is that due to the upward trend in energy prices, the reaction of GDP at the end of the simulation sample (2006:Q4) became more pronounced than during the 1990s. The same is also true for investment, consumption, and exports but to a smaller extent for the price level, and the reaction of the monetary authority.

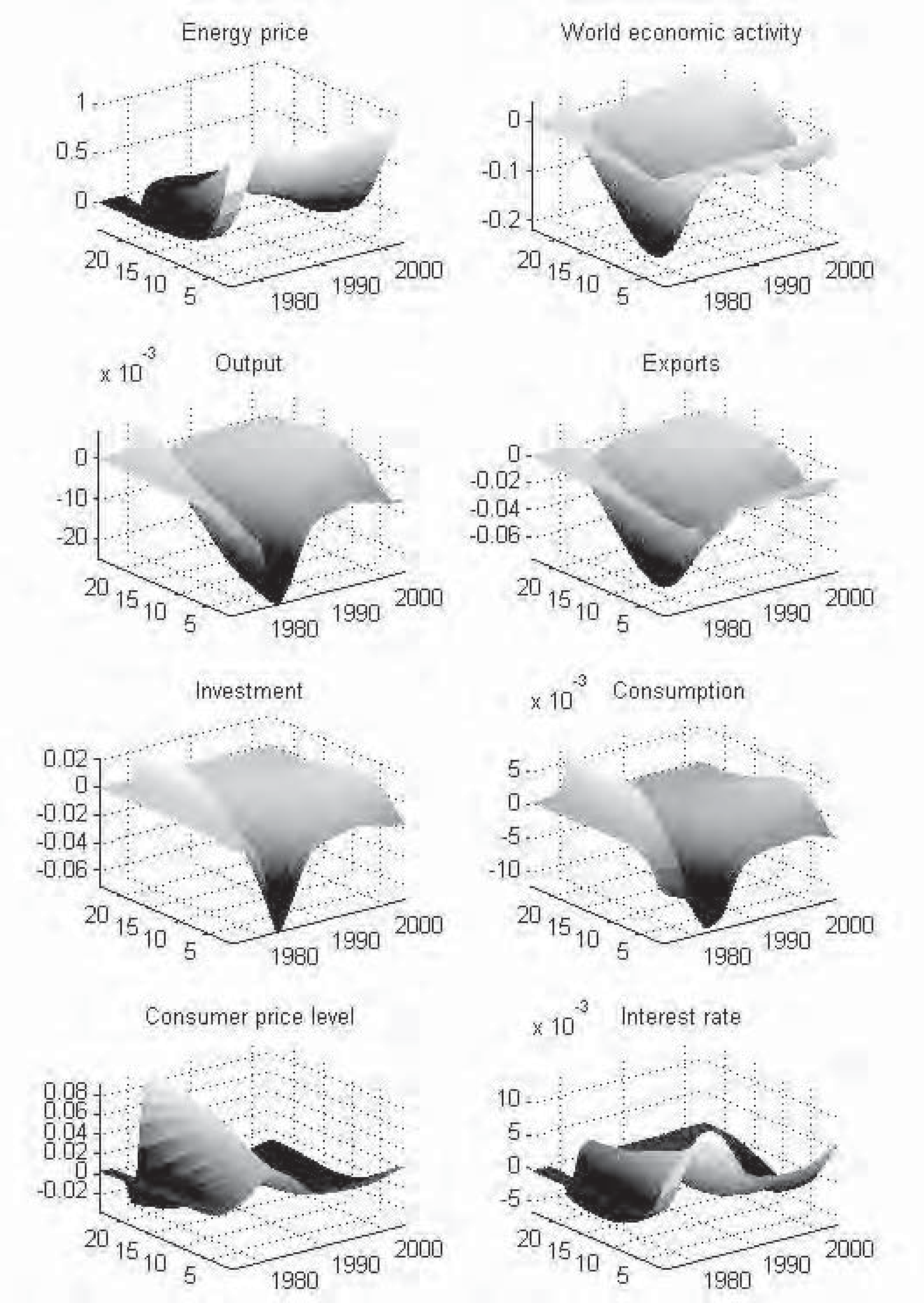
Note that the final simulation starts at the end of 2006 and therefore shows what, according to our model, was supposed to have happened when energy prices started to rise from the level of 2006. Due to the relatively high level of energy cost share at the end of 2006, the recent energy price shock should have had effects more in line with earlier shock episodes. These results suggest that the German economy had not reduced the energy intensity of production or the energy usage for consumption purposes sufficiently to prevent a trend reversal of the energy cost share. Consequently, energy importing countries had not become immune to supply side driven energy price hikes at the end of 2006.

So far, we have shown that the energy cost share is not able to explain why the effects of energy price shocks were severe in the 1970s and early 1980, but accompanied by high growth rates today. For a small export-oriented country such as Germany the source of the shock has a great impact. On the one hand, the negative effects of higher energy prices can be offset when they are accompanied or even triggered by a soaring world economy. On the other hand, the negative effects of higher energy prices can be reinforced when they are accompanied by a global recession.

In the following simulations, the energy prices and global output evolve independently from the German economy, but are allowed be interrelated. Since the VAR coefficients are estimated in a 40-period rolling window scheme, the first (latest) impulse response functions are available for 1975:1 (2002:Q4). Thus, the simulations cannot identify what the model would show for the period after 2006 when energy prices rose for another two years and collapsed as a consequence of the succeeding global economic recession. However, simulating shocks at the beginning of 2003 should reasonably explain the evolution of macroeconomic variables during the latest run-up period (2004:Q1-2006:Q3).

The results of our second simulation show what happens to important macroeconomic variables subsequent to a one unit energy price hike, when all time varying elements are included (Figure 5). In contrast to the former simulations, differences in the impulse functions are not only caused by trends in structural parameters but also by a changing persistency of energy prices themselves and changing effects on the global economy. At first, it becomes evident that the persistency of the energy price itself was exceptionally large at the beginning of the 1980s. Then, at the same time the estimated effects on the world economy increased. Thus, the adverse supply effects on the German output and exports were relatively persistent and heavily aggravated by a decrease in demand from abroad. This can be seen by comparing the magnitude of the responses to the ones which are depicted in Figure 4. As a consequence of the high energy price persistency during this time, the price level effects of energy price shocks are comparatively large from the beginning to the middle of the 1980s. These simulations are therefore useful to understand the first energy shock episodes because they not only reproduce the very large negative impact on domestic and worldwide aggregates, but also

Figure 5. **Impulse response functions of the NOE model to a one unit energy price shock, time varying shock coefficients**



a harsh monetary reaction can be explained although other important factors such as the credibility of the monetary authority remains unchanged. The persistency of the energy price itself, resulting in a harsh monetary policy reaction, and its strong negative impact on the world economy were key factors for the strong negative effect in the 1980s. The negative impact on the world economy is particularly important for export intensive small open economies such as Germany and heavily aggravates the pure adverse cost effects of energy price shocks.

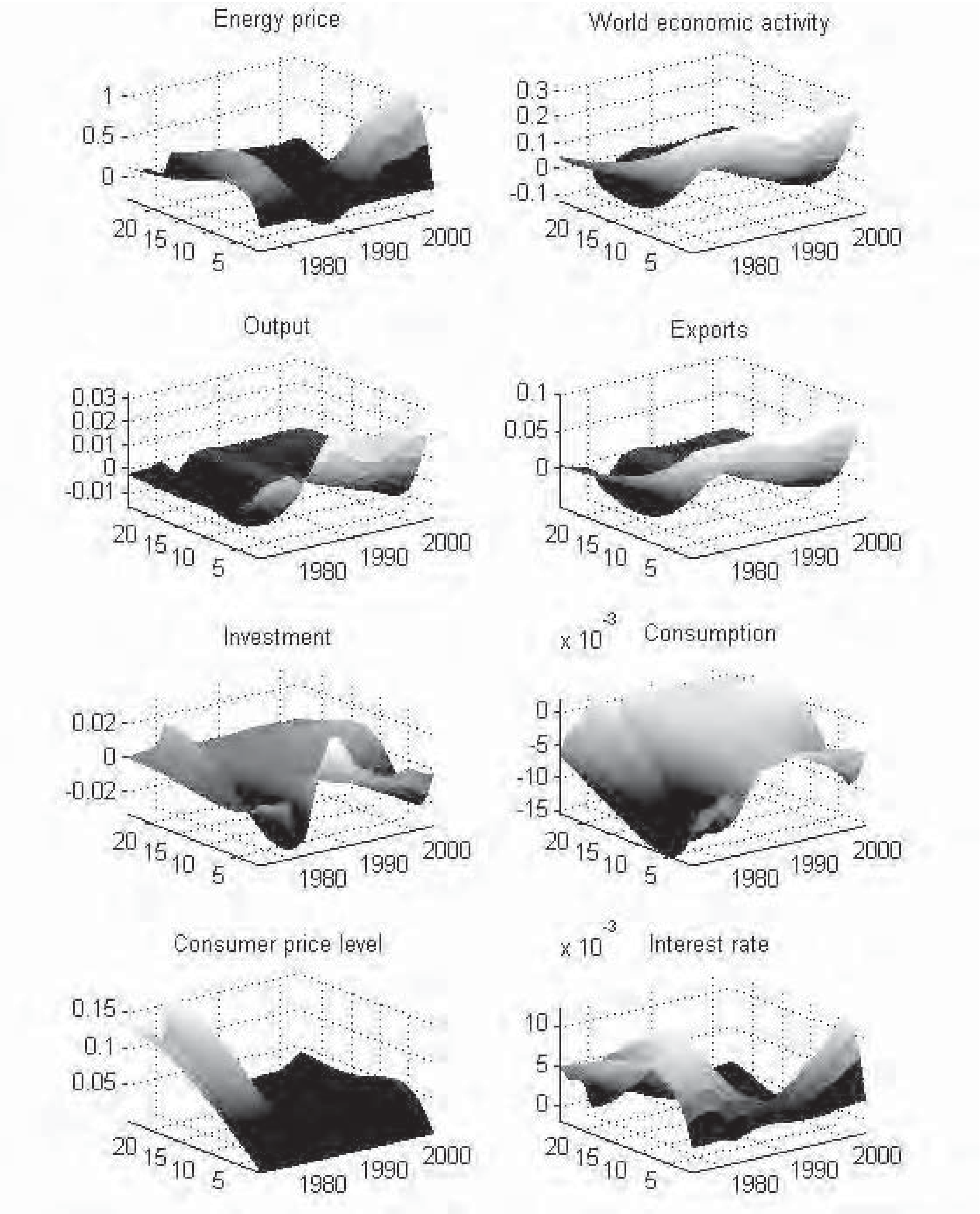
Even if the effects of energy prices were not strongly aggravated by a depressed global economy, our simulations so far show that supply driven energy price shocks cause negative effects on real and positive effects on nominal domestic variables, also in the recent run-up periods. Thus, these simulations are less appropriate to reproduce the recent facts, which suggest that energy price shocks have no substantial effects or are even accompanied by unusual high growth rates and moderate inflationary pressure at least up to 2008.

In our third simulation exercise, the model is therefore shocked by the same innovation to global output in each period. The simulations of the late 1980s and 1990s suggest that economic booms and energy prices exhibit a weak or even negative relationship, *i.e.* energy prices were not demand driven. Surprisingly, the simulations which are conducted for the time before 1980 show that, according to the model, the demand shock explanation is not completely implausible for previous major energy shock episodes. Contrary to recent shock episodes, the negative effects of higher energy prices which succeed economic booms strongly over-compensate the weak positive initial effects on exports and output. As observed in this period, the effects on these variables are therefore ultimately negative. However, there is strong evidence that energy supply was shortened prior to the earlier shock episodes. We conclude that the supply shock explanation plays at least a dominant role in the first energy shock episodes.

After the late 1990s, shocks to global output have been accompanied by increasing energy prices. Note that the magnitude of the innovations is chosen to cause approximately a one unit increase in energy prices, so that the energy price hikes in Figures 5and 6 are comparable for recent shock episodes. Figure 6 shows that domestic output and exports increase and the effects on the consumer price level are moderate, so that a minor reaction by the monetary authority follows. The final simulation, starting in 2002, matches what could be observed in Germany (and in other small energy importing countries) from this point in time to 2008: a booming world economy, rapidly increasing energy prices, an increase in domestic output and exports and moderate inflationary pressure.

However, compared to the stylised facts, the monetary policy reaction in the model during the recent oil price shock seems to be relatively strong causing a reduction in domestic consumption and investment. This highlights the importance of monetary policy reactions for the propagation of oil price shocks that is well documented in the literature (Bernanke *et al.* 1997, Leduc and Sill 2004). There is also some evidence for the US that shifts in the conduct of monetary policy contribute to the changes in the effects of oil price shocks (Herrera and Pesavento 2009). Empirical estimates for the monetary policy reaction functions of the Bundesbank and the ECB suggests that the same is true for Germany. By comparing estimated Taylor rules, Sauer and Sturm (2007) find that the ECB responds more to business cycle fluctuations than the Bundesbank. This offers a third explanation for the changing effects of oil price shocks.

Figure 6. **Impulse response functions of the NOE model to a global economy shock, time varying shock coefficients**



5. Conclusions

This paper contributes to the ongoing debate on the changing effects of energy price shocks. We illustrate that during the recent energy price shock episodes the inflation rate and the interest rate increased moderately compared to the 1970s and early 1980s, while up to 2008 GDP and exports showed unaltered or even higher growth rates following recent energy shock episodes.

We show that a permanent reduction of the energy cost share cannot be the dominant source for the different effects of energy price hikes on the German economy since it increased substantially from the late 1990s to the energy price peak of 2008. This upward trend in the energy cost share suggests that energy importing countries such as Germany have not generally become invulnerable to energy price shocks. In addition, due to this upward trend, a calibration of the energy cost share to sample averages is not useful to assess why the adverse supply effects of energy prices might change over time. Instead, we propose indentifying trends in observable, structural, parameters which change the calibration of our model each period. Using a time varying calibration also gives us the opportunity to consider the changing relation between energy prices and the global economy by estimating a rolling window scheme.

Simulations with an NOE model suggest that the source of an energy price shock plays the major role from the perspective of a small open economy. Supply driven energy price shocks can explain the stylised facts of the first shock episodes very well. Hereby, the succeeding worldwide economic downswing heavily aggravated the pure supply side effects. Moreover, since oil price increases were exceptionally persistent, even the harsh monetary reaction displayed by central banks in the early 1980s can be explained without referring to credibility problems or other special factors leading to a different monetary policy reaction function. Surprisingly, also the global demand shock view is not completely implausible as an explanation for the earlier shock episodes. During these times, the only weak, positive effects of shocks to global production on domestic output were strongly overcompensated by the strong, negative effects of succeeding energy price increases in our model.

On the contrary, the supply shock simulation does not yield a convincing explanation for recent energy price shocks and their consequences while a demand driven energy price hike is a convincing candidate explanation. A world economic boom has negligible effects on energy prices from the end of the 1980s to the new century, but a substantial increase in global energy prices is the consequence thereafter. Since both shocks compensate each other, the positive reaction of domestic production and exports match the stylised facts. What can be learned from our simulation for the future importance of energy prices for business cycles? On the one hand, if energy price movements continue to be demand driven for the main part, their effects will continue to be negligible for a small open economy. In this case two exogenous shocks will continue to compensate each other. On the other hand, if a new supply driven energy price hike takes place, leading to a high energy cost burden and a worldwide recession, the effects in small open energy importing economies might be even stronger due to the larger openness of the respective countries.

Whether such a scenario has been an important factor during the recent economic crisis cannot definitively be answered by our simulations. What was observed was a further increase in energy price between 2006 and 2008 and a succeeding global economic downturn which lead to deep export driven recessions in small open economies such as Germany. However, it is very likely that the major part of the global recession was caused by the recent financial crisis and not high energy prices, though both issues have been interlinked. We leave a precise assessment of the two factors for future research.

Notes

1. In what follows lower case letters denote logarithms of the corresponding upper-case variables. The only exception is r, which denotes the real interest rate.
2. Our model distinguishes between energy imports used for production and consumption purposes. To calculate the share of imported energy in total consumption, ω, we assume that 70% of the imported energy is spent on production while 30% is consumed by private households. This distribution is a very approximate estimate based on information from the Arbeitsgemeinschaft Energiebilanzen.
3. Note that the corresponding parameter c^{ss} is not calculated on the basis of the data. Since the model abstracts from saving and capital accumulation, all output beside exports is spent on consumption purposes. The parameter c^{ss} is therefore simply $1 - ex^{ss} - ivx^{ss}$.
4. A description of the data can be found in the Appendix.
5. In the rolling window regressions, the AIC as well as the SIC indicate that in the majority of cases the VAR(1) specification is appropriate. In addition, a flexible VAR specification leads to the problem that in some cases the DSGE model was not solvable. We therefore decided to use one lag for all samples.
6. In our simulations we do not account for all aspects of structural change that might be important for the economic effects of oil price shocks. For example, these effects also depend on the real exchange rate elasticity of exports. A higher elasticity would lead to stronger effects of oil price shocks on GDP. A comprehensive understanding of the effects of oil price shocks has to take these changes into account.

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APPENDIX

Data Description

GDP	Real Gross Domestic Product. Chain index. Seasonally adjusted by official source. National Accounts, Federal Statistical Office Germany.
Consumer price level	GDP, implicit Price Deflator. National Accounts, Federal Statistical Office Germany.
Consumption	Real private household consumption. Chain index. Seasonally adjusted by official source. National Accounts, Federal Statistical Office Germany.
Exports	Real exports. Chain index. Seasonally adjusted by official source. National Accounts, Federal Statistical Office Germany.
Real Energy imports	Nominal energy imports – GDP-deflated. Foreign trade statistics, Statistical Office Germany.
Real energy price	Imported energy price index 2000 = 100 – GDP-deflated. Foreign trade price statistics, Federal Statistical Office Germany.
Nominal interest rate	Three month interbank rate. German Bundesbank.
Global GDP	Real Gross Domestic Product of Belgium, Canada, Denmark, France, Italy, Japan, Korea, Mexico, Netherlands, Spain, Sweden, United Kingdom, USA. OECD.

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