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Abstract

In this paper we analyse to what extent movements in oil prices can help to explain business cycle fluctuations in Germany. We proceed in several steps: As a starting point we use a standard real business cycle model for the German economy and introduce energy as an additional factor in the production function. As in Kim/Loungani (1992) our finding is that oil price shocks increase the volatility of output but only to a limited extent. We therefore continue by using a real business cycle model for a small open economy and again include energy use in the production function (de Miguel et al. 2003). But compared to our previous model we could only find an additional increase in volatility of output under certain conditions. Subsequently, we use these models to analyse whether the impact of oil price movements has changed over time by splitting our data set into two subsamples: the first from 1970 to 1986 and the second from 1987 to 2002. The main results suggest that the reduced importance of energy for industrial production substantially decreases the vulnerability of the German economy with regard to oil price shocks.

JEL-Classification: E32

Keywords: Oil prices, business cycle, small open economy

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1. Introduction

Oil price shocks are often identified as a source of macroeconomic fluctuations by empirical studies. These studies rely heavily on the experience of the recessions in the seventies and early eighties, but the recession in the early nineties was also preceded by an oil price hike related to the first Gulf war (Barsky, Kilian 2004). On the other hand the oil price effects might be weakened by now as there is some evidence that the relation between oil prices and GDP has become looser during the eighties (Hooker 1996).

However, the ongoing discussion shows that the causes of these reduced real effects of energy price shocks are far from clear (for a recent overview of this discussion see Jones et al. 2004; Barsky, Kilian 2004). Some authors argue that the experiences of the seventies and eighties overstate the pure effects of oil price shocks. During these episodes monetary policy reacted on the rise in inflation rates and aggravated the dampening effects of increasing oil prices (Bernanke et al. 1997; Leduc, Sil 2004). Another source for a weakened link between oil prices and economic activity might be the fact of a declining importance of energy for industrial production and in addition industrial production becomes less important for the overall added value.

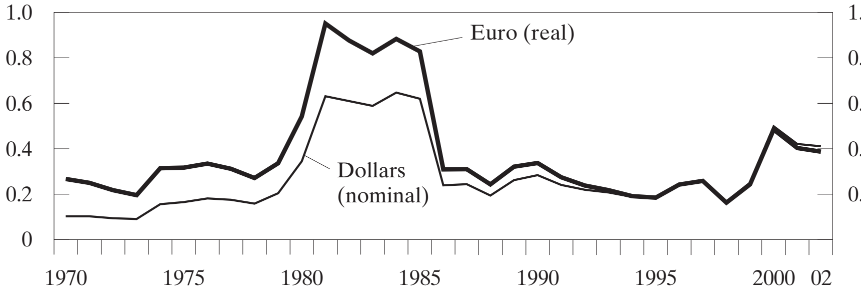
In this paper we try to measure to what extent this reduced importance of energy as an input helps to explain the reduced effect of oil price shocks. To answer this question we use a calibrated real business cycle model which has become a standard tool in quantitative economics. This approach can be seen as a computational experiment to assess the contribution of oil price shocks to business cycle fluctuations (Kydland, Prescott 1996). In our analysis we concentrate on the German economy because the existing real business cycle models for Germany (Harjes 1997; Lucke 1998a, 1998b; Maussner, Spatz 2003) up to now do not account for energy use in the production function. In a first step we try to answer the question to what extent oil price shocks contribute to German business cycles. To be able to compare our results with those of existing models for Germany, we use a closed and an open economy version. In addition, this procedure has the advantage of regarding also the increasing openness of the Germany economy. We take into account that during the seventies the degree of openness of the German economy is smaller than during the nineties.

We organise our analysis in the following manner: In the next section we report some stylised facts of oil prices, energy use and the degree of openness of the German economy. In section three, we introduce the closed- and small open economy versions we use in the proceeding sections. Afterwards we calibrate the models to the German data and carry out stochastic simulations to investigate to what extent energy price movements can explain business cycle fluctuations. In addition we calibrate our models in accordance with two dif-

Figure 1

Crude oil price

1970 to 2002; per 100,000 BTU



Authors' calculations. Source: IEA and Federal Statistical Office Germany.

ferent subsamples of our data set and replicate our simulations for these subsamples in order to find evidence whether the importance of oil prices for economic activity has changed over time. Additionally we discuss if the model economies are able to replicate some stylised facts of German business cycles. In section six we draw some conclusions.

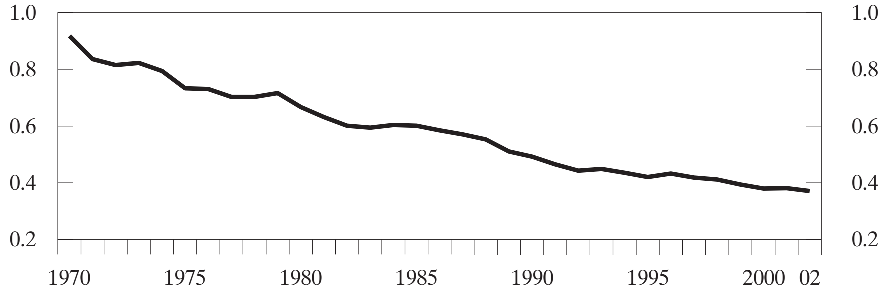
2. Stylised facts on energy prices and economic activity

In this section we present some facts on the three most important ingredients of our analysis: energy prices, the amount of energy use in production and the openness of the German economy. First of all energy price movements which are mainly driven by oil prices are considered as a source of business cycle fluctuations if these movements are exogenous to economic activity (Rotemberg, Woodford 1996: 551). This is not very likely to be always the case but there are several episodes in which this is a plausible assumption. The two best known periods are the oil price shocks of 1973 and 1979/80 which were triggered by political events in the Middle East (Barsky, Kilian 2004: 116). As figure 1 indicates, these events dominated oil price movements at least until the mid-eighties. Especially the shock of 1979/80 in view of the German economy is enforced by an increase in the exchange rate. Later on at least the first Gulf war in 1991 and the second Gulf war in 2003 are often seen as additional exogenous sources for oil price increases, even if the oil price shock of 1991 was not very long lasting as well as counterbalanced by exchange rate movements and the second is probably still under way. This means that the oil price shocks of the seventies and nineties were quite different with respect to the amount of the oil price increase and the duration. In this paper crude oil prices are measured in burn time units (BTU) since this enables us to use the total input of fossil fuels in the German economy.

Figure 2

Energy use in the German economy

1970 to 2002; % of GDP



Authors' calculations. Source: IEA and Federal Statistical Office Germany.

If the effects of oil price shocks on economic activity have declined at least one of the transmission mechanisms must have changed. In a recent paper Leduc/Sil (2004) investigated the role of monetary policy for the transmission of oil price shocks. They argue that monetary policy during the seventies and early eighties reacted on these shocks by raising interest rates and therefore amplifying the dampening effects. During the recent increases of oil prices monetary policy reacted less restrictive. One of the results is that the dampening effects on economic activity are much smaller. However, it is also possible that the direct effects of oil prices on the real economic activity have changed. One could expect such direct effects because changing oil prices affect the costs of production and therefore alter the level of production itself (Finn 2000; Kim, Loungani 1992; de Miguel et al. 2003; Rotemberg, Woodford 1996). Our investigation relies on this argument, since the ratio of energy use to GDP has decreased substantially since the seventies (figure 2).

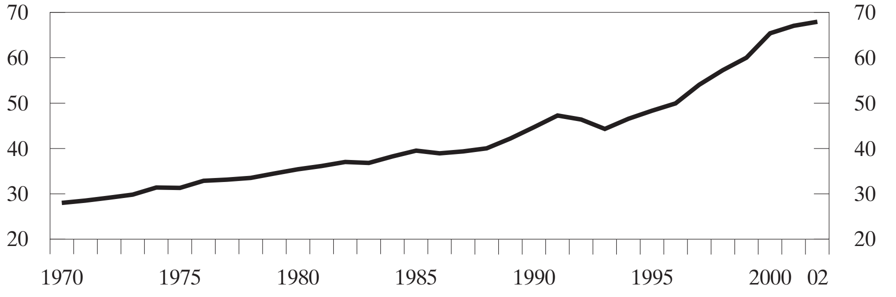
Another development of the German economy often referred to is the increasing openness. As an indicator we add exports and imports and divide by GDP. This indicator strongly supports the impression that the German economy is becoming more open since the seventies (figure 3).

To account for the changing structure of the German economy we split the sample period from 1970 to 2002 into two subsamples. We choose 1986 because a structural break in this relation might be related to the OPEC collapse during this year (Cuñado et al. 2003: 151; Barsky, Kilian 2004: 118). We use annual data because of data availability for this period.

Figure 3

Openness of the German economy

1970 to 2002; Import plus Export in % of GDP



Authors' calculations. Source: Federal Statistical Office Germany.

3. The model

We investigate the effects of oil prices on economic activity by using a general equilibrium model. To account for the increasing openness of the German economy the effects are analysed in a closed and a small open economy version. Hence we implement foreign trade and international capital markets in our model to answer the question whether these components alter the vulnerability of the German economy with regard to energy price shocks. In the small open economy individuals have access to a perfectly competitive capital market where they can buy and sell any amount of foreign bonds with an exogenously determined real interest rate. Most other components of the two versions of the model are identical so we introduce them jointly.

Preferences

In the model economy there is an infinite number of identical households and the representative households maximize the expected value of future utility. To get a consistent framework for the closed and open economy version of our model we use a special form of time separable preferences proposed by Greenwood et al. (1988). As it is shown by Correia et al. (1995) this form ensures that consumption, net foreign assets and net exports are the only variables of the small open economy model that have a unit root. If we used the standard preference specification belonging to the class described in the fundamental paper by King et al. (1988) and which is often embodied in closed economy models, the unit root properties of net foreign assets would pass on the other variables of the national income identity. We assume that representative households maximise the sum of discounted future utility that has the following form:

$$(1) \qquad U_0 = \sum_{t=0}^{\infty} \beta^t \frac{1}{1-\sigma}[(c_t - \theta n_t^{\nu})^{1-\sigma} - 1].$$

The utility of a certain period depends on the amount of current consumption (c_t) and the amount of current leisure ($1-n_t$). The parameter σ is the parameter of relative risk aversion and the parameter ν is one plus the inverse of the intertemporal elasticity of substitution of labour supply (s), i.e. $(s+1)/s$. The remaining positive parameter θ weights the utility of consumption relative to the utility of leisure. By choosing this preference structure we introduce two simplifying assumptions restricting the explanation of labor market fluctuations. Firstly, the utility function has the property that the elasticity of intertemporal substitution associated with leisure is zero. This implies that labor and output as well as productivity and output are perfectly correlated which is typically not supported by the data. Secondly, we specify a utility function with divisible labor. In this case fluctuations in the total amount of hours occur at the inside margin, which means by variations in the number of hours achieved by each individual. This is a crucial assumption because there is some evidence that in developed countries with frequently regulated labor markets individuals only have the opportunity to work a fixed amount of hours. However, the primary objective of this paper is to quantify the influence of oil price shocks for German business cycles in general without too much respect for the cyclical properties of the labor market. Hence for simplicity and because of the other advantage mentioned we use the special divisible labor preferences described above.

Production technology

To model the transmission channel of oil price shocks we use a standard production function and add energy use. In this economy the single commodity good can either be consumed or invested. This good is produced by an infinite number of representative firms. Similar to the production function used by Kim/Loungani (1992) we employ a nested CES production function. Firms transform the three factor inputs labor, capital and energy according to the following specification:

$$(2) \qquad y_t = n_t^{\alpha} [(1-\psi)k_t^{-\upsilon} + \psi e_t^{-\upsilon}]^{\frac{-(1-\alpha)}{\upsilon}}.$$

The decisions about the amount of labour hired (n_t) and the amount of energy used (e_t) in a certain period t is made by competitive firms in the same period after they have observed the realisation of the stochastic oil price shock which the model economy is exposed to. The decision about the amount of capital that is rent from the representative households depends on their consumption and investment decision made in the period before ($t-1$). The parameter υ depends on the elasticity of substitution between capital and energy. We decided to allow for an elasticity of substitution between capital and energy greater than one which is in line with the CES production function.

Capital accumulation

The capital accumulation law of the model economy is:

$$k_{t+1} = (1-\delta)k_t + i_t - \Phi(k_t, k_{t+1}). \tag{3}$$

Capital of the subsequent period (k_{t+1}) is current capital (k_t) less depreciation (δk_t) plus investment (i_t) less capital adjustment costs ($\Phi(\cdot)$). The capital adjustment cost function is assumed to be quadratic, following Bruno/Portier (1995):

$$\Phi(k_t, k_{t+1}) = \frac{\phi}{2}\left(\frac{k_{t+1}-k_t}{k_t}\right)^2. \tag{4}$$

In the open economy case the introduction of capital adjustment costs guarantees that there is a difference between the speed of adjustment of physical and financial capital. Without these adjustment costs, individuals would be able to use the international bond market to smooth consumption almost completely. Hence consumption would be a constant term with an one step adjustment after one period to a new permanent level. In this version capital adjustment costs are also necessary to obtain more or less persistent differences between the international real interest rate and the domestic marginal product of capital after depreciation. Without capital adjustment costs individuals would make sure that the domestic marginal product of capital after depreciation always equals the international real interest rate. In this case the adjustment process of the domestic real interest rate would be similar to the one described for consumption.

Net exports

Representative firms have to purchase an amount of energy at an international energy market, where the price of oil (p_t) is determined exogenously. In addition, in the small open economy case the representative households have the opportunity to buy and sell bonds (b_t) on a perfectly competitive capital market; the constant international real interest rate (r^*) is given exogenously. The equation of net exports is therefore:

$$nx_t = p_t e_t + b_{t+1} - (1+r^*)b_t. \tag{5}$$

Restrictions

In every period the economy has to satisfy some additional restrictions. At first, in the close economy case consumption plus investment plus energy use valued at market prices must be less or equal to the aggregated supply of goods. In the small open economy case the sum of consumption, investment and net exports has to be less or equal to aggregate supply. The resource constraint in a general form is:

$$c_t + i_t + p_t e_t + b_{t+1} - (1 + r^*) b_t \leq y_t. \tag{6}$$

Additionally, the time the representative agent spends for working and leisure must be less or equal the total time endowment that is normalized to one. Finally, the model economy has to satisfy some non-negativity constraints, leading to the following equations:

$$l_t = 1 - n_t,$$

$$l_t \geq 0, n_t \geq 0, c_t \geq 0, k_t \geq 0, b_t \geq 0.$$

Exogenous shocks

The model economy can only be hit by one exogenous stationary stochastic shock: The oil price process is specified similar to the standard shocks in most real business cycle studies:

$$\ln p_t = \gamma_0 + \gamma_1 \ln p_{t-1} + \varepsilon_t^p \tag{7}$$

where $0 < \gamma_1 < 1$ and $\varepsilon_t^p \sim N(0, \sigma_p)$. The restricting assumption concerning the parameter γ_1 implies a stationary oil price process. However, as mentioned above the small open economy versions of the model exhibit unit root properties with respect to some variables. In other words, in case of the small open economy non-permanent oil price shocks have permanent effects in spite of the special shape of the preferences.

First order conditions

Using the representative agent character of our models we are able to centralize the problem of representative households and competitive firms to a social planer's problem. The resulting dynamic optimization problem can be solved using a standard Lagrange approach. We simulate the model in the close and in the open economy case omitting the variable b_t and the exogenous international real interest rate r^* in the first variation. The general Lagrange function becomes:

(8) $$L_t = \sum_{t=0}^{\infty} \beta^t \frac{1}{1-\sigma}[(c_t - \theta n_t^{\nu})^{1-\sigma} - 1]$$

$$+\Lambda_t \left\{ n_t^{\alpha} [(1-\psi)k_t^{-\upsilon} + \psi e_t^{-\upsilon}]^{\frac{-(1-\alpha)}{\upsilon}} - c_t - [k_{t+1} - (1-\delta)k_t] \right.$$

$$\left. -\frac{\phi}{2}\left(\frac{k_{t+1}-k_t}{k_t}\right)^2 - p_t e_t - b_{t+1} + (1+r^*)b_t \right\}.$$

Discounting of the Lagrange multipliers and differentiation in the decision variables $(c_t, n_t, k_{t+1}, e_t, b_{t+1}, \lambda_t = \Lambda_t / \beta^t)$ leads to five and in the open economy case six necessary first order conditions. After eliminating the Lagrange multiplier the equilibrium is determined by the following system of difference equations that fully characterises the cyclical properties of the model economies:

(9) $$\nu\theta n_t^{\nu-1} = \alpha n_t^{\alpha-1}[(1-\psi)k_t^{-\upsilon} + \psi e_t^{-\upsilon}]^{\frac{-(1-\alpha)}{\upsilon}},$$

$$\beta^t E_t \left\{ (c_{t+1} - \theta n_{t+1}^{\nu})^{-\sigma} \left[(1-\alpha) n_{t+1}^{\alpha} [(1-\psi)k_{t+1}^{-\upsilon} + \psi e_{t+1}^{-\upsilon}]^{\frac{-(1-\alpha)}{\upsilon}-1} \right.\right.$$

(10) $$\left.\left. (1-\psi)k_{t+1}^{-\upsilon-1} + (1-\delta) + \phi\left(\frac{k_{t+2}-k_{t+1}}{k_{t+1}}\right)\frac{k_{t+2}}{k_{t+1}^2} \right] \right\} = (c_t - \theta n_t^{\nu})^{-\sigma}\left(1 + \phi\,\frac{k_{t+1}-k_t}{k_t^2}\right),$$

(11) $$p_t = (1-\alpha) n_t^{\alpha} [(1-\psi)k_t^{-\upsilon} + \psi e_t^{-\upsilon}]^{\frac{-(1-\alpha)}{\upsilon}-1} \psi e_t^{-\upsilon-1},$$

(12) $$\beta^t E_t\left[(c_{t+1} - \theta n_{t+1}^{\nu})^{-\sigma}(1+r^*)\right] = (c_t - \theta n_t^{\nu})^{-\sigma},$$

(13) $$n_t^{\alpha}[(1-\psi)k_t^{-\upsilon} + \psi e_t^{-\upsilon}]^{\frac{-(1-\alpha)}{\upsilon}} =$$

$$c_t + k_{t+1} - (1-\delta)k_t + \frac{\phi}{2}\left(\frac{k_{t+1}-k_t}{k_t}\right)^2 + p_t e_t + b_{t+1} - (1+r^*)b_t.$$

Using the neoclassical assumptions of the model economy other macroeconomic variables can be determined in dependence of the decision variables (c_t, n_t, e_t), the state variables (k_t, b_t) and the exogenous variable (p_t). Output and investment are already determined in equations (2) and (3). The input factors are paid at their marginal products so the domestic real interest rate after depreciation is

$$(14) \qquad r_t = (1-\alpha)n_t^{\alpha}[(1-\psi)k_t^{-\upsilon} + \psi e_t^{-\upsilon}]^{\frac{-(1-\alpha)}{\upsilon}-1}(1-\psi)k_t^{-\upsilon-1} - \delta$$

and the real wage can be obtained as:

$$(15) \qquad \mathrm{w}_t = \alpha n_t^{\alpha-1}[(1-\psi)k_t^{-\upsilon} + \psi e_t^{-\upsilon}]^{\frac{-(1-\alpha)}{\upsilon}}.$$

4. Steady state solution and calibration

In this section we derive the steady state solutions of our models and calibrate them to the German data.[1] To solve these models and to conduct stochastic simulations we use DYNARE – a pre-processor and a collection of Matlab routines (Juillard 2003). These routines linearise the system around its deterministic steady state and perform a second order Taylor approximation in a way proposed by Schmitt-Grohé/Uribe (2004). As apparent from the first order conditions in their deterministic forms the model exhibits explicit steady state solutions for all variables in the closed economy case and for labor, capital, energy and output in the small open economy case. The steady state values for consumption, net foreign assets and net exports depend on the initial amount of net foreign assets and the past development of the exogenous variables.

At first we use static versions of equations (9)–(11) to get explicit steady state values for capital, oil and labor:

$$(16) \qquad k = \left(\frac{\nu\theta}{\alpha}\right)^{\frac{1}{1-\nu}} X_2^{\frac{\nu-\alpha}{\alpha(1-\nu)}} \left((1-\psi)+\psi X_1^{\frac{-\upsilon}{-\upsilon-1}}\right)^{\frac{1-\alpha}{\upsilon(1-\nu)}},$$

$$(17) \qquad e = X_1^{\frac{1}{-\upsilon-1}} k,$$

$$(18) \qquad n = X_2^{\frac{1}{\alpha}} k.$$

The steady state solution for consumption is:

$$(19) \qquad c = n^{\alpha}[(1-\psi)k^{-\upsilon} + \psi e^{-\upsilon}]^{-\frac{1-\alpha}{\upsilon}} - \delta k - pe + r^* b$$

[1] All variables are in Logs except net exports because of negative values. For net exports we use the following approximation (Correia et al. 1995): $\log(X) \approx X / \overline{X} - 1$. We used the HP-Filter to detrend the data. Lambda was set to 400. A more detailed description of the data and sources can be found in the Appendix.

where

$$X_1 = \frac{p\beta(1-\psi)}{[1-\beta(1-\delta)]\psi}$$

and

$$X_2 = \frac{p}{X_1\psi(1-\alpha)\left[(1-\psi)+X_1^{\frac{-\upsilon}{-\upsilon-1}}\right]^{-\frac{1-\alpha}{\upsilon}-1}}.$$

Equation (19) shows that the steady state value of consumption in the closed economy case only depends on the unique steady state values of labor, capital and energy. In the small open economy case consumption in the steady state additionally depends on the initial value of net foreign assets and the previous sequence of the exogenous oil price shock. This permanent effect on consumption is possible because of the unit root properties of net foreign assets. A non-permanent negative oil price shock for example leads to a higher permanent value of net foreign assets, higher returns on interest and therefore to a higher consumption level in the steady state. In the small open economy versions the value of b is calibrated in a way that the proportion of net exports to output matches the average of the German data.

Equation (12) in the steady state simplifies to:

(20) $$\beta = \frac{1}{(1+r^*)}.$$

so the discount factor of the utility function (β) is set equal to the inverse of one plus the international real interest rate that is taken from de Miguel et al. (2003). We use the international real interest rate to calibrate the discount factor, in the close economy case too.

From the accumulation law of capital the depreciation rate can be derived as:

(21) $$\delta = \frac{i}{k},$$

so we set δ equal to the average ratio of investment and capital. Depending on the model used the parameter ϕ in the adjustment cost function will be adjusted in a way that the model mimics the volatility of investment relative to the volatility of output (σ_i / σ_y) in the data.

Other parameters of the model are calibrated in a way that some of the model's steady state ratios match the corresponding average ratios in the data. Rearranging equation (17) gives:

$$\psi = \frac{1}{\left(\frac{e}{k}\right)^{-\upsilon-1}\left(\frac{\frac{1-\beta}{\beta}+\delta}{p}\right)+1} \tag{22}$$

Given the parameters on the right hand side of the equation and the value of p which is the unconditional mean of equation (7) we calibrate the parameter ψ in a way that the model matches the ratio of energy use and capital given by our data set. The remaining parameter of the production function υ is taken from Kim/Loungani (1992).

Rearranging equation (18) yields:

$$\theta = n^{1-\nu}\frac{\alpha}{\nu}X_2^{-\frac{1-\alpha}{\alpha}}\left[(1-\psi)+\psi X_1^{\frac{-\upsilon}{-\upsilon-1}}\right]^{-\frac{1-\alpha}{\upsilon}}. \tag{23}$$

We set n equal to the average fraction of the time budget Germans spend for working and borrow the value for ν from the paper of de Miguel et al. (2003). The parameter α representing the labor share in total income is set equal to the proportion of labor income in Germany on average. Substituting these values into the above formula yields a definite value for the weighting parameter θ that makes sure that the model's steady state labor input matches the corresponding averages in the data. The remaining parameter of risk aversion (σ) is also taken from de Miguel et al. (2003).

As mentioned above we distinguish between the period 1970–1986 and the period 1987–2002. As was highlighted in section two, some of the parameters and so called great ratios have changed substantially, above all the ratio of capital and the amount of energy use in the German production e/k. Moreover, the substantial increase of the ratio of investment and capital i/k implies a higher depreciation rate in the later subperiod of our data set. All together this leads to lower values of ψ and a higher value of δ in the second period.

The parameters that characterise the properties of the exogenous stochastic process are determined by an estimated AR(1) process of the real oil price converted in Euro by current exchange rates in the period 1970–2002. We think that the choice of the price index is not crucial since it is highly correlated with prices of refined products (Asche et al. 2003). As we estimate the coefficients of the exogenous oil price process for the whole sample period we use the same energy price shock for both subperiods. This enables us to answer

Table 1

Calibration of model versions
1970–2002

Parameter	1970–1986 Closed Economy Model	1970–1986 Open Economy Model	1987–2002 Closed Economy Model	1987–2002 Open Economy Model
Production				
α	0.72	0.72	0.72	0.72
υ	0.7	0.7	0.7	0.7
ψ	0.0083	0.0083	0.0048	0.0048
Preferences				
β	0.96	0.96	0.96	0.96
σ	1.001	1.001	1.001	1.001
ν	1.7	1.7	1.7	1.7
θ	1.2776	1.2776	1.2814	1.2814
Capital Accumulation				
δ	0.1225	0.1225	0.1301	0.1301
ϕ	38	23	50	30
Exogenous Shocks				
γ_0	–0.1766	–0.1766	–0.1766	–0.1766
γ_1	0.8079	0.8079	0.8079	0.8079
σ_p	0.1362	0.1362	0.1362	0.1362
International real interest rate				
r^*	–	0.0417	–	0.0417

Authors' calculations. Source: IEA und Federal Statistical Office.

the question to what extent the decreasing importance of energy as an input factor lowers the vulnerability of the German economy to this kind of shock. Table 1 summarizes the parameter calibration for the different models and the different periods.

5. Simulation Results

In this section we present simulation results in the closed- and the small open economy case for each subperiod. As mentioned above the small open economy models differ from the closed economy models only in the opportunity of households to buy and sell foreign assets at an exogenously given interest rate. In particular, the preferences in the closed economy models are identical to the preferences in the small open economy models. Hence the simulation results are not directly comparable with other closed economy studies. To get an impression of the differences between the two subsamples and to what extent these models are able to reproduce the properties of the German data, some standard indicators for our real business cycle models are calculated.

Table 2 confirms the impression of a reduced importance of energy for the German economy. The ratios of energy use to GDP as well as to capital re-

Table 2

Ratios of macroeconomic variables of German data and models in the steady state
1970–2002

	1970–1986			1987–2002		
	German Data	Closed Economy Model	Open Economy Model	German Data	Closed Economy Model	Open Economy Model
Energy imports/output	0.0315	0.0223	0.0223	0.0124	0.0162	0.0162
Net exports/output	0.0025	–	0.0025	0.0147	–	0.0147
Private consumption/output	0.5631	0.7854	0.8053	0.5573	0.7840	0.7854
Capital/output	2.0438	1.5699	1.5699	1.7445	1.5359	1.5359
Energy use/output	0.0709	0.0559	0.0559	0.0445	0.0406	0.0406
Energy use/capital	0.0357	0.0357	0.0357	0.0263	0.0263	0.0263
Investment/capital	0.1225	0.1225	0.1225	0.1301	0.1301	0.1301

Authors' calculations.

duced nearly to 50% of the former value. In contrast, the ratio of energy imports, which is energy use multiplied by the oil price, to GDP decreased by over 50%, indicating that not only the amount of energy use but also the average price of a certain amount of BTU's is lower in the second subsample.

As described above our models are calibrated in a way that the energy/capital ratio, the investment/capital ratio as well as the net exports/output ratio match exactly the corresponding average ratios in the German data. Besides, the oil use/output and the capital/output ratios of the model economies are only slightly lower than their data pendants. As mentioned above the average price of energy is slightly lower in the second subsample. Since the models are exposed to the same exogenous shock process in both periods the relation of energy imports to output has to be less than the average data value in the first and greater than the average data value in the second period. After all, the models substantially overrate the average consumption/output ratio and substantially underrate the average capital/output ratio.

Table 3 shows standard deviations of the four simulated models and of the corresponding variables in the German data. Of particular interest for our analysis are the characteristics of oil related variables. All of these variables have a higher volatility than output but their volatility is lower in the period 1987–2002 than in the seventies and early eighties. This highlights that not only the importance of energy use in the German industry is far lower in the nineties than in the seventies and early eighties but that the parameters of the exogenous oil price shocks probably declined too. As mentioned before we expose our models to the same shock in both periods.

Our simulation results show that the lower steady state energy/capital ratio in the later subperiod substantially reduces the vulnerability of the model economies with regard to oil price shocks. Using the calibration based on the aver-

Table 3

Standard deviations in German data and models
1970–2002; %

	1970–1986			1987–2002		
	German Data	Closed Economy Model	Open Economy Model	German Data	Closed Economy Model	Open Economy Model
Output	2.17	0.25	0.26	2.29	0.18	0.18
Private Consumption	2.78	0.27	0.18	1.59	0.20	0.13
Hours	1.66	0.15	0.15	1.80	0.10	0.11
Energy use	6.52	3.81	3.82	3.23	3.71	3.72
Capital	1.59	0.17	0.17	1.47	0.12	0.11
Investment	5.42	0.62	0.66	5.10	0.40	0.40
Energy price	40.26	5.89	5.89	27.26	5.89	5.89
Energy imports	34.78	2.09	2.07	27.13	2.18	2.17
Net exports	76.04	–	101.34	109.38	–	0.87
Energy use/capital	6.02	3.74	3.72	2.38	3.66	3.66
Productivity	2.19	0.10	0.11	2.90	0.07	0.08
Net exports/output	77.53	–	99.47	110.01	–	0.84

Authors' calculations.

age ratios of the prior subperiod we find that our estimated oil price process could explain 12% of the fluctuations in output whereas the same shock is only able to explain 8% of the output fluctuations in the second subsample. In contrast to models described in the literature the simulation results do not directly point at an increase of the volatility in our models after introducing international elements. The volatility of most of the variables increases only barely whereas the volatility of consumption declines substantially.

Further investigations reveal that the introduction of a perfect international capital market does not always increase the volatility of output and consumption but that our small open economy model looses the property of a greater volatility if capital adjustment costs of a certain amount are included. As they circumvent the domestic real interest rate to approach the international real interest rate very fast, the business cycles smoothing effects of pro- cyclical domestic real interest rates work in our small open economy models too. Hence, we would be able to boost the volatility of our models in a significant amount simply by reducing the capital adjustment costs. However, this would be accompanied by a reduction of the consumption volatility relative to the volatility output and by an increase of investment volatility in relation to the volatility of output and therefore violate our calibration restrictions. A detailed sensitivity analysis concerning these parameters of a similar model is given by Harjes (1997). The volatility of all variables directly related to net exports is extremly higher than the corresponding data values in the first subperiod whereas the opposite occurs in the second one. In general this measure is not reliable since it seems to be extremely sensitive to the steady state level of net exports that is determined by the calibration procedure.

Table 4

Relative standard deviations to output of German data and models
1970-2002

	1970–1986			1987–2002		
	German Data	Closed Economy Model	Open Economy Model	German Data	Closed Economy Model	Open Economy Model
Private Consumption	1.28	1.08	0.69	0.69	1.11	0.72
Hours	0.76	0.60	0.58	0.79	0.55	0.61
Energy use	3.00	15.24	14.69	1.41	20.61	20.67
Capital	0.73	0.68	0.65	0.64	0.66	0.61
Investment	2.50	2.48	2.53	2.23	2.22	2.22
Energy price	18.55	26.56	22.65	11.90	32.72	32.72
Energy imports	16.03	8.36	7.96	11.85	12.11	12.06
Net exports	35.04	–	389.77	47.76	–	4.83
Energy use/capital	2.77	14.96	14.31	1.04	20.33	20.33
Productivity	1.01	0.40	0.42	1.27	0.39	0.44
Net exports/output	35.73	–	382.58	48.04	–	4.67

Authors' calculations.

Table 4 presents relative standard deviations of the four simulated models and of the corresponding variables in the German data. The data values reproduce most of the stylised facts for Germany that are reported in the literature (Brandner, Neusser 1992; Harjes 1997). One distinctive feature of this data set is the higher volatility of consumption compared to output in the period 1970 to 1986. Another feature of the data is that hours are much less volatile than output, while the volatility of productivity is much higher.

Like other real business cycle models our models perform well in replicating the volatility of investment in proportion to the volatility of output. However, as described above this exact match is rather a result of the parameter choice of the adjustment costs function than a distinct property of the models. The models also perform well in reproducing the relative volatility of capital in both subperiods. As mentioned above, concerning the variability of consumption there is a significant difference between the closed and the open economy case. Whereas in the closed economy the volatility of consumption always exceeds the volatility of output it is always less volatile in the open economy. The reason is that individuals can smooth consumption by buying or selling the desired amount of foreign assets on the international capital market. The corresponding volatilities in the data show that the relative standard deviation of consumption is much higher in the seventies and eighties than in the nineties. This could be evidence for the increasing openness of the German economy. Like other real business cycle models our models significantly underestimate the volatility of hours worked relative to the volatility of output. Since in our model real wages are fully flexible the effects of exogenous shocks on labor demand are moderated by procyclical variations in real wages. Hence the ratio of the volatility of hours worked and the volatility of output that is significantly lower than in the German data.

Both models reproduce that relative standard deviation of energy use, energy use/capital and oil price are much too high for both subperiods. In contrast the volatility of energy imports in proportion to the volatility of output is much to low in the first subperiod but is very close to the data value in the second subsample. The relative standard deviations of all of these variables increase from the first to the second subsample what is a consequence of a nearly unchanged variability of these variables but a lower variability of output. All together these findings reveal that in our model economies the declining amount of energy use compensates the positive influence of rising oil prices on the value of energy imports to a bigger extent than in the German economy.

Table 5 shows the simultaneous correlation of the variables and some ratios with output. Again most of the data measures show the typical properties. As one should expect the correlation between output and net exports is negative. In the second period this correlation is much higher in absolute values which indicate the increasing openness of the German economy. Most interesting for our study is that the correlation between energy prices and output rises from the earlier to the later period while the correlation between oil use and output decreased substantially. The same is true for the energy to capital ratio.

Altogether the models do not perform well in replicating the corresponding correlations in the German data. With regard to these figures one has to consider that the special shapes of the utility and production functions create a labor input that is perfectly correlated to output whereas the correlation between hours and output in the data is only slightly positive in the prior subperiod and near zero in the second subperiod. In contrast to the German data our simulations do not show a negative correlation between output and net exports, hence, our model does not exhibit this important feature of small open economies that can be observed in reality. But further simulations reveal that these results are also sensitive to the adjustment costs function. By lowering the adjustment costs we would be able to reproduce less procyclical net exports but would again violate our calibration restrictions. In all cases consumption and output are at least nearly perfectly correlated whereas consumption and output in the data are strongly positively but not perfectly correlated. Our models are well in replicating the correlations of investment as well as capital and output in the second and satisfying for the first period. Then, the closed economy version performs better in mimicking the correlations of capital and output and the small open economy version in replicating the correlations of investment and output.

Whereas the correlation of oil used and output in our models is still contenting for the first subperiod they are far too high for the time of the nineties. The

Table 5

Correlations with output of German data and models
1970–2002

	1970–1986			1987–2002		
	German Data	Closed Economy Model	Open Economy Model	German Data	Closed Economy Model	Open Economy Model
Private Consumption	0.89	1.00	1.00	0.88	1.00	1.00
Hours	0.37	1.00	1.00	0.01	1.00	1.00
Energy use	0.82	0.96	0.96	0.35	0.96	0.96
Capital	0.52	0.68	0.79	0.62	0.66	0.75
Investment	0.76	0.97	0.92	0.92	0.98	0.94
Energy price	–0.52	–0.95	–0.95	–0.05	–0.95	–0.96
Energy imports	–0.45	–0.93	–0.93	–0.04	–0.94	–0.95
Net exports	–0.68	–	0.06	–0.27	–	0.30
Energy use/capital	0.75	0.94	0.95	0.09	0.95	0.96
Net exports/output	–0.69	–	0.05	–0.29	–	0.10

Authors' calculation.

strong negative correlation between oil price and output that our models present can not be found in the data. This indicates that the oil price shock is overlaid by another supply shock that produces procyclical variations in oil prices.

Table 6 presents the simulated first order autocorrelations of our simulated variables. First of all most variables in the simulated models have no problems in replicating the corresponding first order autocorrelation in the data. The closed economy model produces a first order autocorrelation of output that is almost identical to the corresponding data value in the first period whereas both economies achieve the same for the second subperiod. Fortunately, the first order autocorrelation of the other variables also differs only to a very limited extent from the corresponding data values. One exception are the simulated first order autocorrelations of capital. Our models overrate the values of the German data slightly in the second and strongly in the first subperiod. Unfortunately the same is true for the first order autocorrelation of net exports of our small open economy model in both subperiods.

Other exceptions are the variables directly related to oil prices. In the second subperiod both models overrate the first order autocorrelations with regard to these variables whereas in the first subsample the opposite is true. This could be interpreted again as an indication of changing coefficients of the exogenous oil price process.

Our main results are illustrated in figures 4 and 5. We plot the impulse response functions after an initial oil price rise by one percent using the closed and the small open economy models. The solid lines show the effect of a one percent oil price shock using the parameter calibration for the seventies and

Table 6

First order autocorrelations of German data and models
1970–2002

	1970–1986			1987–2002		
	German Data	Closed Economy Model	Open Economy Model	German Data	Closed Economy Model	Open Economy Model
Output	0.62	0.63	0.65	0.63	0.62	0.64
Private Consumption	0.74	0.63	0.64	0.61	0.61	0.63
Hours	0.61	0.63	0.65	0.69	0.62	0.64
Energy use	0.57	0.55	0.56	0.46	0.55	0.55
Capital	0.53	0.90	0.88	0.81	0.90	0.89
Investment	0.64	0.56	0.52	0.49	0.57	0.54
Energy price	0.64	0.55	0.55	0.44	0.55	0.55
Energy imports	0.62	0.54	0.54	0.47	0.54	0.54
Net exports	0.54	–	0.72	0.34	–	0.84
Energy use/capital	0.57	0.55	0.55	0.20	0.56	0.55
Productivity	0.61	0.63	0.65	0.71	0.62	0.64
Net exports/0utput	0.55	–	0.72	0.34	–	0.75

Authors' calculation.

eighties and the dashed lines for the nineties. Comparing the two lines it becomes clear that output, consumption, capital, investment and labor in the nineties decline much less than in the seventies and eighties in response to an oil price shock. In the nineties the economy finds back to its steady state more rapidly than in the seventies. Comparing the closed and the open economy, we find that consumption falls less in the small open economy case. The reasoning is analogue to that in the context of the relative standard deviations of the closed- and the small open economy models. Furthermore both figures reveal again that the positive effect of higher oil prices on the value of energy used overrates the negative effect on the amount of energy used in production. Altogether this leads to higher energy imports in the case of a positive oil price shock.[2] Besides, figure 5 demonstrates once more the unit root properties of consumption in the case of the small open economy that we discussed in Section 3 and that the cyclical properties of net exports depend on the number of periods after a shock that are analysed. Subject to our calibration net exports are procyclical for nearly fithteen and countercyclical for subsequent periods.

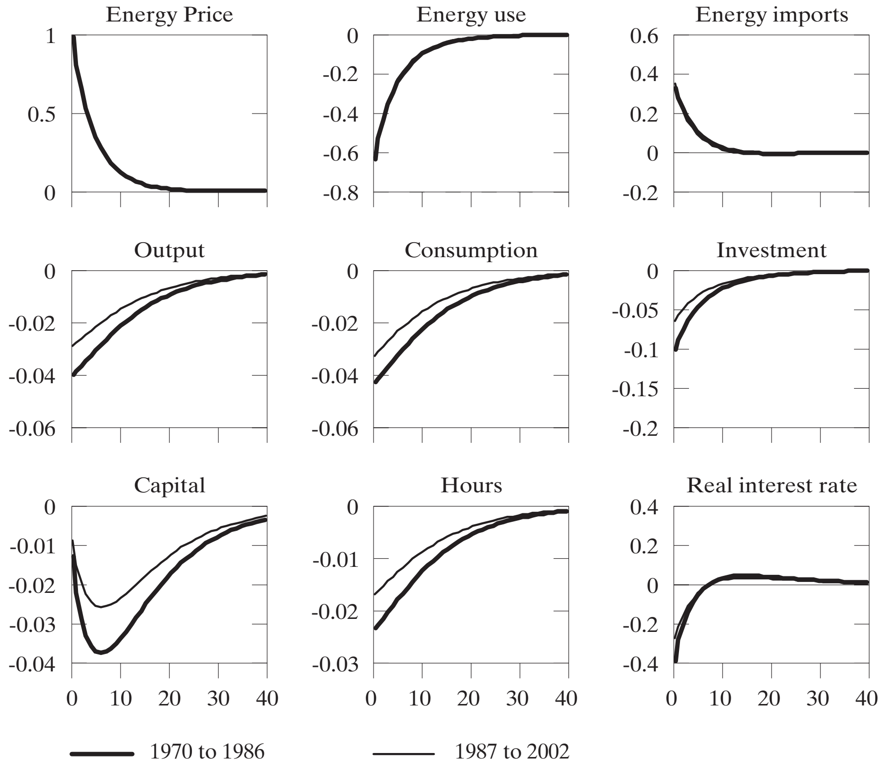
6. Conclusions

In this paper we analyse to what extent movements in oil prices can help to explain business cycle fluctuations in Germany. To account for the increasing

[2] Alternatively this could be demonstrated on the basis of table 5. Oil price and energy imports are negatively correlated with output, whereas the opposite is true for the amount of oil used in production.

Figure 4

Impulse response to an oil price shock in the closed economy case



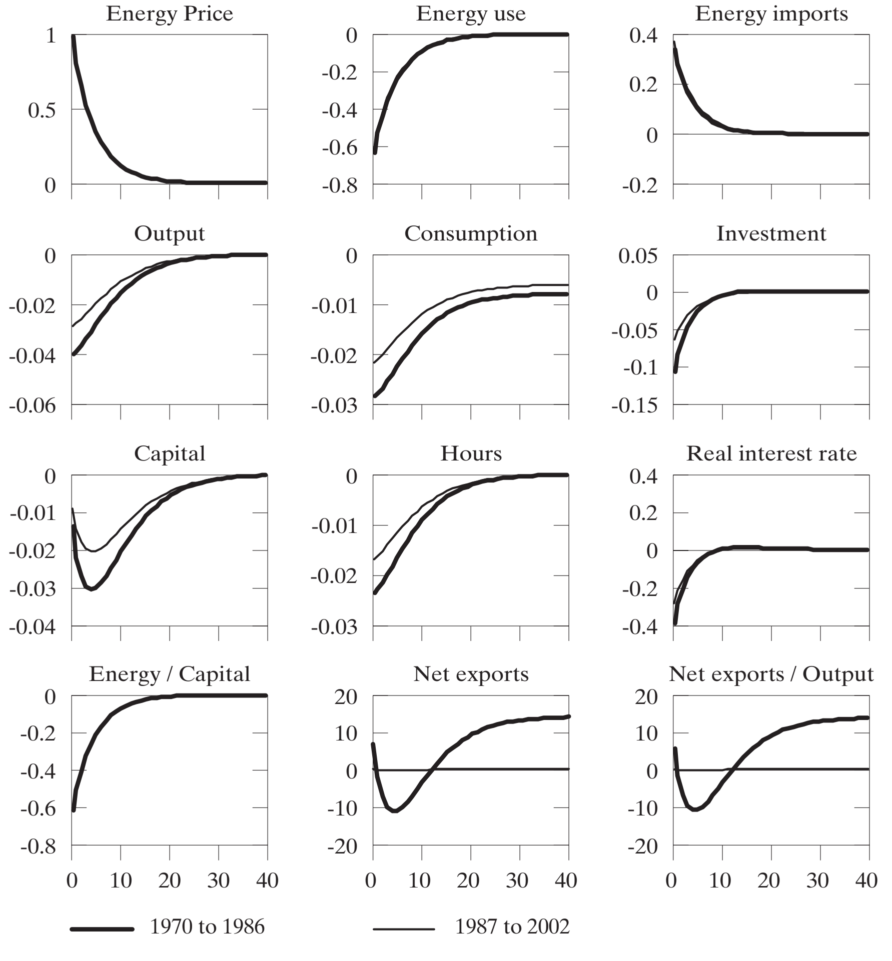
Authors' calculations.

openness of the German economy we apply a closed and an open economy model. In a second step we use these models to analyse whether the effects of oil price movements have changed over time. Therefore we split our data into two subperiods namely 1970 to 1986 and 1987 to 2002 and calibrate our models to both subsets.

First of all, our investigation shows that all of our simulated models are able to replicate most of the ratios of macroeconomic variables on average. The results indicate also that it is more appropriate to use the small open economy model for the second subperiod because of the higher openness of the German economy. For the first subperiod the indication is not as clear. In contrast to differing statements in the literature, the introduction of open economy elements enhances the volatility of our models only to a very limited extent because our choice of capital adjustment costs nearly compensates the addi-

Figure 5

Impulse response to an oil price shock in the open economy case



Authors' calculations.

tional volatility that is created by the introduction of small open economy elements. However, a lower volatility of consumption in relation to the volatility of output in the small open economy models seems to be robust to variations of the parameter in the adjustment costs function.

With regard to oil price shocks our finding is that they contribute to business cycle movements in Germany but only to a limited and declining extent. Considering the decreasing importance of energy as a factor for industrial production our simulations indicate reduced effects of energy price shocks. In the period from 1970 to 1986 oil price shocks can explain nearly 15% of the German business cycle fluctuations. However, if we calibrate our models to the period from 1987 to 2002 energy price shocks can only account for not even 8% of business cycle fluctuations. Taking into account that the level, the volatility and the persistence of real oil prices also decreased over time they seem to be negligible as a source for German business cycles since the mid eighties. However, to quantify the overall effects of oil price shock other transmission mechanisms have to be taken into account.

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Appendix – Data description

Capital: Capital stock Germany. OECD Economic Indicators.

Consumption: Private household consumption expenditure at 1995 prices. National Accounts. Federal Statistical Office Germany.

Crude oil price: Nominal crude oil price of a hundred thousand burn time units (BTU) in US $. International Energy Agency (IEA) Annual Energy Review (2003).

Exports: Exports at 1995 prices. National Accounts. Federal Statistical Office Germany.

GDP: Gross Domestic Product at 1995 prices. National Accounts. Federal Statistical Office Germany.

GDP deflator: GDP, implicit Price Deflator. National Accounts. Federal Statistical Office Germany.

Hours: Working hours per day times working day per year times employed persons. Federal Statistical Office Germany.

Imports: Imports at 1995 prices. National Accounts. Federal Statistical Office Germany.

Energy imports: Amount of BTUs used in the German economy (in hundred thousands) multiplied by the price of a hundred thousands BTU in Euro at 1995 prices.

Investment: Gross fixed capital formation at 1995 prices. National Accounts. Federal Statistical Office Germany.

Energy use: Total final consumption of coal, gas and petroleum products. Amount of BTUs used in the German economy (in hundred thousands). Inernational Energy Agency (IEA) Energy Balance.