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Supply-side effects of strong energy price hikes in German industry and transportation

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Abstract

The paper studies the short-term effects of energy price hikes on the supply of industrial goods and transport services including the repercussions on remuneration of input factors. While industry had suffered more strongly from the oil price shock of the late 1970s compared with the one of the early 1970s and the 2004-08 upsurge, evidence is reverse for transportation. Regarding the impact on the income distribution, both sectors share the pattern that in the recent episode rising energy costs were more than compensated by falling unit labor costs while in the 1970s cost structures had been strained by expansive wage policy in addition to the oil price shocks.

Keywords: energy prices, supply of goods and services, income distribution.

JEL classification: E23, E25, Q43.

Non-technical summary

Oil prices rose strongly in the period between 2004 and 2008. In this paper, we analyze how firms have reacted to this shock in the short run, as regards the supply of goods and services and/or output prices. The focus is on industry and transportation, as these sectors possess the highest shares in corporate energy consumption. In addition, the effects are compared with those of the two oil price shocks during the 1970s. (Since a partial-equilibrium analysis is adopted here, we do not need to distinguish whether oil price movements are driven by demand-side or supply-side factors.)

In a first step, the short-run effect of an energy price hike on the supply of industrial goods and transport services is calculated on the basis of a theoretical model. In this setup, we assume that the output good is produced by three factors of production, namely capital, labor and energy. Firms react to energy price changes by adjusting the use of energy, labour input and, as a consequence, the volume of output. (In the short run, however, the capital stock is fixed and, for simplification, output prices are constant and money wages are settled.) The implications of the theoretical model are used to structure the empirical analysis. In particular, it is shown that the elasticity of substitution between capital and energy is central to the strength of the output response. Hence, the empirical analysis pays special attention to the estimation of this parameter.

Contrary to the assumption imposed in theory, strong and lasting energy price surges cause firms to adjust output prices even in the short run. It is therefore more realistic to compute the output response on the basis of the increase in the effective energy price relative to the change in the output price. In order to obtain a comprehensive view of firms' reactions in such circumstances, the output price change is studied as well. In particular, it is decomposed into the contributions of the changes in the unit costs of factor inputs.

The empirical analysis shows that industrial production was more severely affected by the oil price shock of the late 1970s than by those of the early 1970s and of the period between 2004 and 2008. By contrast, transport services were dampened more in the recent episode compared with the two phases in the 1970s. This difference is due to the fact that, on the one hand, industrial energy consumption decreased relative to the demand for other input factors and, on the other hand, effective energy prices increased less sharply in industry compared with transportation. The central results of the paper are not only shown as point estimates, they are also informed by confidence bands. This is recommendable owing to the limited number of observations, resulting in a great deal of estimation uncertainty.

On the price side, the central result, which is generally the same for both sectors, is that the cost burden induced by rising energy prices had been an add-on on the generally much more impressive push stemming from unit labor costs in the 1970s, while the flat trend in money wages was able to compensate for higher energy prices and to raise the rental rate of capital in the 2004-08 period. As a consequence, firms had strongly lifted output prices in the 1970s, but have not done so recently.

Nicht technische Zusammenfassung

Zwischen 2004 und 2008 sind die Ölpreise stark gestiegen. In diesem Papier wird untersucht, wie die Unternehmen kurzfristig mit ihrem Güterangebot und/oder ihren Preisen darauf reagiert haben. Dabei konzentrieren wir uns auf die Industrie und das Transportgewerbe, die die höchsten Anteile am gewerblichen Energieverbrauch aufweisen. Zudem vergleichen wir die Effekte mit denen der Ölpreisschocks in den siebziger Jahren. (Da wir uns auf eine partialanalytische Fragestellung konzentrieren, müssen wir dabei nicht danach unterscheiden, ob der Ölpreisanstieg auf Angebots- oder Nachfrageänderungen zurückzuführen ist.)

In einem ersten Schritt werden die kurzfristigen Effekte eines kräftigen Anstiegs der Energiepreise auf das Angebot von Industrieerzeugnissen und Transportleistungen auf der Basis eines theoretischen Modells bestimmt. In diesem Modell wird angenommen, dass die Unternehmen ihren jeweiligen Output mit den Faktoren Kapital, Arbeit und Energie produzieren. Auf Energieverteuerungen können die Firmen reagieren, indem sie den Energieverbrauch, den Arbeitseinsatz und das Ausbringungsvolumen variieren. (Dagegen werden der Kapitalstock und – vereinfachend – der Outputpreis sowie die Nominallöhne in der kurzen Frist als konstant unterstellt). Dieses theoretische Modell soll der nachfolgenden empirischen Untersuchung eine Führung geben. Insbesondere zeigt es auf, dass die Substitutionalität zwischen Kapital und Energie von zentraler Bedeutung für die Outputreaktion ist. In der empirischen Untersuchung wird deshalb der Schätzung dieser Elastizität besondere Aufmerksamkeit geschenkt.

Im Gegensatz zur in der Theorie aus Vereinfachungsgründen unterstellten Annahme werden die Unternehmen durch starke und anhaltende Energiepreissteigerungen auch in der kurzen Frist zu einer Anpassung der Güterpreise gezwungen. Demnach ist es realistischer, die Outputreaktionen auf Basis des in Relation zur Veränderung des Endproduktpreises gemessenen Anstiegs der effektiven Energiepreise zu bestimmen. Um ein Bild vom gesamten Reaktionsmuster der Unternehmen unter diesen Umständen zu erhalten, wird auch die Güterpreisveränderung untersucht. Konkret wird eine Zerlegung in die Beiträge vorgenommen, welche die Faktorstückkosten zur Veränderung des Endproduktpreises rechnerisch leisten.

In unserer empirischen Analyse kommen wir zum Schluss, dass der aktuelle Ölpreisschock die Industrieproduktion weniger stark gedämpft hat, als es bei dem Ölpreisanstieg gegen Ende der siebziger Jahre der Fall gewesen war. Die Outputreaktion war aber umfangreicher als während der Schockphase zu Beginn der siebziger Jahre. Im Gegensatz dazu sind die Transportdienstleistungen zuletzt stärker gedämpft worden als in jeder der beiden Vergleichsperioden. Dieser Unterschied ist darauf zurückzuführen, dass der Energieeinsatz in der Industrie relativ an Gewicht verloren hat und die effektiven Energiepreise in der Industrie weniger stark gestiegen sind als im Transportgewerbe. Die zentralen empirischen Ergebnisse werden zudem nicht nur als Punktschätzungen dargestellt, sondern auch um Konfidenzbänder ergänzt. Dies empfiehlt sich angesichts der begrenzten Anzahl von Beobachtungen und der damit verbundenen beträchtlichen Schätzunsicherheit.

Auf der Preisseite zeigt sich, dass in den siebziger Jahren die Energiepreissteigerungen eine Belastung waren, die zusätzlich zu den hohen Steigerungen der Lohnstückkosten auf die Unternehmen auftrat. Der flache Trend der Nominallöhne in der Periode zwischen 2004 und 2008 ermöglichte es hingegen, nicht nur den Kostendruck von Seiten der höheren Energiepreise intern abzufedern, sondern auch die Kapitalrendite zu steigern. In der Konsequenz mussten die Unternehmen die Güterpreise während der siebziger Jahre stark erhöhen, während sie in der Periode zwischen 2004 und 2008 kaum gestiegen sind.

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1 Introduction

In July 2008, the price of crude oil peaked at almost 150 U.S. dollar after a tempestuous upsurge from a level of around 30 U.S. dollar in 2003. During this hike, the oil price not only achieved new historical records in nominal terms but, at least including the rise in the first half of 2008, it also surpassed the highs of the two oil price shocks in the 1970s when measured in real terms. In the meantime, the oil price has dropped tremendously. Of course, the sharp ups and downs indicate that a speculative element has recently been playing a substantive role in price formation on the oil market. However, the large appetite for energy as a result of the rapid catching-up process in emerging countries, the growing perception that fossil energy resources are limited and steadily rising exploitation costs are structural factors with a long-term impact on the fundamental price of crude oil in the future.

In industrialized countries, the production of goods and services is usually based on a broad energy mix. Apart from refined oil, it includes a relatively high percentage of gas, coal and electricity, recently also renewable sources. The oil price can nonetheless be seen as a good proxy for cost pressure from energy use as a whole because the prices of the other energy carriers are more or less closely linked to the oil price. The literature on oil and the macroeconomy is therefore well advised to formulate parsimonious reduced form models, which are typically applied in this context, in terms of the oil price or oil price shocks (see Hamilton, 1983, 2003, 2009; Hooker, 1996; Kilian, 2008a,b, for instance). This paper, however, looks only at the impact of energy prices on the supply side of the economy, making it promising to, first, impose more economic structure on the model; second, focus on sectors strongly dependent on energy use such as industry and transportation and, third, use (sectoral) data on total energy use and effective energy prices.

From an analytical point of view, studying only on supply-side effects makes it easier to compare the recent oil price hike with the oil price shocks experienced during the 1970s. In terms of production costs, it makes no difference that the fundamental source of the steep upsurge was strong demand for oil as a consequence of the global economic boom between 2003 and 2008, while it had been an OPEC policy induced supply-side shortage in the 1970s. Predominantly reacting to relative price signals, the supply of goods and services is equally affected in both scenarios. Economic activity, however, differs strongly owing to the contradictory implications the two scenarios have on aggregate demand in an export-oriented economy.

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As standard in the literature (see Pindyck and Rotemberg, 1983; Atkeson and Kehoe, 1999, for instance), the analysis distinguishes between the short-run and long-run responses of firms to energy price shocks. While the capital-energy substitutability is central to explaining firms' long-run responses, the short-run scenario is dominated by scale effects on production, as firms are faced with a number of rigidities. In particular, it is assumed that capital is fixed, production coefficients are predetermined and output prices as well as money wages are given. Firms' immediate reaction to strongly rising energy prices is a reduction of energy consumption which, in turn, leads to a decline in production and a layoff of workers. Substitution effects are limited in the short run because only regular capital turnover allows the installation of more energy-efficient capital. When energy prices increase drastically, the obsolescence of machinery and equipment has to be considered as a further negative effect on productive capital.

The theoretical basis is a production structure with labor, capital and energy as input factors as well as exogenous technical progress, which is assumed to be labor-augmenting. The three-factors production technology is characterized by constant returns to scale and a nesting assumption in the sense that the outer production function combines labor with a capital-energy bundle. The latter is the outcome of an inner production function of the constant-elasticity-of-substitution (CES) type. Its specification consists, on the one hand, in estimating the elasticity of substitution between capital and energy with a time-series model of energy demand using cointegration methodology. On the other hand, the CES is normalized following the idea of Klump and de La Grandeville (2000) and Klump and Preissler (2000). Both elements of the specification exercise involve separate sources of model uncertainty, which is captured by presenting the central results as point estimates surrounded by confidence bands. The latter are constructed using stochastic simulations based on the empirical distributions assigned to the parameters of the CES production function.

The empirical analysis is carried out for industry and transportation separately and in parallel. The focus on these two sectors is justified by their comparatively high shares in corporate energy consumption of 63 percent in industry and 18 percent in transportation on average over the period between 1995 and 2007. A disaggregate view seems appropriate because the effective cost burden of rising energy prices might significantly differ from sector to sector as a result of different compositions of the energy mix. The capital-energy substitutability is likely to differ from one sector to another. In contrast to a number of papers estimating the elasticity of substitution between capital and energy on a highly disaggregate level (see Thompson and Taylor, 1995, and the literature quoted therein), industry as a whole and transportation are considered here because, on the one hand, the two sectors are sufficiently broad to satisfy the ultimately macroeconomic interest of the analysis and, on the other hand, they may be good examples for the scope and diversity of sectoral supply-side responses to the oil price hikes of the 1970s and the recent past.

Firms will generally react to pressures on production costs by reducing output or lifting output prices or a combination of the two—depending on the extent and duration of the cost shock and the structure of input and output markets. For ease of exposition, the theoretical model focuses purely on the output effect, assuming that the price of the output good as well as the money wage is constant. In reality, however, price adjustments at the stage of intermediate and final goods are likely when energy prices increase substantially over a long time span. As this has been the case in the periods under consideration, the empirical part of the paper makes a distinction between the output and price effects of rising energy prices. In the short-term perspective taken, it is fair to assume incomplete price pass-through, suggesting that the output response be calculated on the basis of the extent to which the energy price increases relative to the output price.

Building on the algebraic expression derived in the theoretical analysis, the short-term energy price elasticities of industrial goods and transport services are estimated. In industry, the point elasticity is about -0.3, while it fluctuates around -0.1 in transportation. The variations in output sensitivity are the result of changing energy price levels. The estimation results are applied to compare the supply effects induced by the energy price hikes in the 1970s and in the recent past. While the oil price shock of the late 1970s affected the supply of industrial goods more severely than those of the early 1970s and of the 2004-08 period, the opposite is found for transportation. The reason is that, thanks to its broader energy mix, industrial production has reduced its exposure to petroleum products whose price trend was extraordinarily steep between 2004 and 2008. Whereas supply effects show marked inter-sectoral differences, the output price changes, including their decomposition into the contributions of unit factor costs, are very similar in industry and transportation during the three periods under consideration. The central result is that the cost burden induced by rising energy prices had been an add-on on the generally much more impressive push stemming from unit labor costs in the 1970s, while the flat trend in money wages was able to compensate for higher energy prices and to raise the rental rate of capital in the 2004-08 period. As a consequence, firms had strongly lifted output prices in the 1970s, while they have done so to a very limited extent recently.

The remainder of the paper is organized as follows. Section 2 establishes the theoretical framework, from which central analytical concepts such as the short-run energy price elasticity of supply are derived. Section 3 illustrates the econometric approaches to the empirical measurement of these concepts using data on the industrial sector and the transport services sector. In Section 4, the periods of strong energy price hikes in the 1970s and between 2003 and 2008 are compared in terms of the short-term responses to the supply of output and the effects on output prices as well as factor remuneration. Section 5 concludes.

2 Theory

The theoretical model is an extension of the standard exogenous growth model. While maintaining most of its theoretical features and empirical relevance (see Barro and Sala-i-Martin, 1995, Chapter 1, for instance), the aim is to implant energy as a third factor of production (apart from capital and labor). This is done by replacing capital by the construct of a capital-energy bundle which is a flexible combination of these two input factors. The framework resembles the putty-putty model of production proposed by Atkeson and Kehoe (1999). In contrast to their approach (building on Pindyck and Rotemberg, 1983), however, labor-augmenting technical progress is introduced as a source of exogenous growth. In connection with the constant-returns-to-scale production function, the effects of an energy price shock can thus be studied along the balanced growth path.

2.1 Production structure and competitive equilibrium

Output Y_t in period t is produced by three factors of production which are capital K_t, labor L_t and energy E_t. As common in the existing literature, the production technology is characterized by a nesting restriction, making the substitution possibilities between capital and energy explicit. In particular, we assume the outer production function

$$Y_t = F[X_t(K_t, E_t), A_t L_t] = A_t L_t f(x_t) \quad \text{with} \quad x_t = X_t(K_t, E_t)/(A_t L_t), \tag{1}$$

possessing familiar properties such as constant returns to scale and labor-augmenting technical progress modelled by the exogenous factor A_t. The capital-energy bundle may be seen as an intermediate good, which is produced by the linear-homogenous CES production function

$$X_t(K_t, E_t) = D[(1-b)K_t^{-\rho} + bE_t^{-\rho}]^{-1/\rho}, \tag{2}$$

where D is a scaling factor, b the distribution parameter, $0 < b < 1$, and $\rho = \sigma^{-1} - 1$ with $\sigma > 0$ the (partial) elasticity of substitution between capital and energy.

Firms are supposed to maximize profits by setting capital, labor and energy, taking the output price P_t^Y, the energy price P_t^E, the rental rate of capital R_t and the (money) wage W_t as given. The optimization program

$$\max_{K_t, E_t, L_t} P_t^Y Y_t - R_t K_t - P_t^E E_t - W_t L_t$$

yields the first order conditions (FOC)

$$\frac{R_t}{P_t^Y} = f'(x_t)\frac{\partial X_t(\cdot)}{\partial K_t}, \tag{3}$$

$$\frac{P_t^E}{P_t^Y} = f'(x_t)\frac{\partial X_t(\cdot)}{\partial E_t}, \tag{4}$$

$$\frac{W_t}{P_t^Y} = A_t[f(x_t) - x_t f'(x_t)]. \tag{5}$$

If a competitive market for the capital-energy bundle is established, firms might opt for external procurement instead of in-house production if the market price is $P_t^X = P_t^Y f'(x_t)$. This arbitrage condition implies that the FOCs with respect to capital and energy can be rewritten as

$$\frac{R_t}{P_t^X} = \frac{\partial X_t(\cdot)}{\partial K_t}, \tag{3'}$$

$$\frac{P_t^E}{P_t^X} = \frac{\partial X_t(\cdot)}{\partial E_t}. \tag{4'}$$

The outer and inner constant-returns-to-scale production functions and full competition on output and factor markets imply that profits are zero in equilibrium. Thus, total earnings are fully distributed amongst factors of production, suggesting that the output price is the sum of unit factor costs, i.e.

$$P_t^Y = \frac{W_t}{Y_t/L_t} + \frac{P_t^E}{Y_t/E_t} + \frac{R_t}{Y_t/K_t}. \tag{6}$$

Provided that there are no binding factor supply restrictions, market clearing quantities follow from the implicit factor demand functions (3), (4) and (5) given the demand for the output good.

2.2 Long-run implications

Regardless of whether the savings rate is exogenously given or derived from households' intertemporal utility maximization problem, the production function (1) implies the existence of a balanced growth path, meaning that output, the capital-energy bundle and the effective labor input,[1] i.e. $A_t L_t$, grow at the same rate. In other words, the economy possesses a steady state to which it always converges after a temporary shock.

In formal terms, the steady-state equilibrium is characterized by the condition that the capital-energy bundle per unit of effective labor is time-invariant, i.e. $x_t = \bar{x}$ for all t. This implies that labor input is a long-run complement of capital and energy as a whole, while the composition of the capital-energy bundle might change permanently as a result of persistent shifts in energy price relative to user cost of capital. The reason is that, owing to (2), capital and energy are substitutes even in the long run.

Despite potential price variations in components, the (virtual) real price of the energy-capital bundle is constant in the steady state because $\bar{P}_t^X / \bar{P}_t^Y = f'(\bar{x})$. Moreover, it follows from (5) that, along the balanced growth path, real wages are proportionate to labor productivity, both rising at the rate of labor-augmenting technical progress. Of course, this result implies that the labor income share is constant, i.e. $\bar{\alpha}^L = 1 - \bar{x} f'(\bar{x})/f(\bar{x})$. By contrast, the income shares of energy and capital might alter in the steady state.

2.3 Short-run supply effects of energy price shocks

While moving along the balanced growth path, we assume that the economy is suddenly hit by an adverse energy price shock in period t, i.e. $P_t^E = \bar{P}_t^E + \mathrm{d}P_t^E$ with $\mathrm{d}P_t^E > 0$. In the short run, money wage and output price are fixed, while the remuneration of capital services may vary. Firms react with quantity adjustments, accounting for the fact that energy use and labor can be changed flexibly, while productive capacities are fixed at the previously installed steady-state level $\bar{K}_t$.

[1] See Barro and Sala-i-Martin (1995) for the proof. Note that the arguments of the proof are not affected by considering the capital-energy bundle, as defined here, instead of capital only.

As real wage $\bar{W}_t/\bar{P}_t^Y$ remains unchanged by assumption, it follows from (5) that firms keep the ratio between the capital-energy bundle and labor at its steady-state value $\bar{x}$. As a consequence, $P_t^X = \bar{P}_t^X$, suggesting that the composition of the capital-energy bundle is varied without changing its price.

Given that the capital stock is fixed, the adjustment of energy consumption means that not only the composition but also the "volume" of the capital-energy bundle is altered. In reacting to the energy price shock, firms choose the use of energy by maximizing their short-term profits

$$\max_{E_t} \bar{P}_t^X D\left[(1-b)\bar{K}_t^{-\rho} + bE_t^{-\rho}\right]^{-\frac{1}{\rho}} - R_t\bar{K}_t - P_t^E E_t.$$

From the FOC, demand for energy is derived as

$$E_t = (1-b_t)^{-\frac{1}{\rho}}\left[\left(\frac{P_t^E/\bar{P}_t^X}{Db}\right)^{-\frac{\rho}{1+\rho}} - b\right]^{\frac{1}{\rho}} \bar{K}_t. \tag{7}$$

Substituting this expression in the production function (1) yields the "volume" of the capital-energy bundle

$$X_t = D(1-b)^{-\frac{1}{\rho}}\left[1 + \frac{b_t}{\left(\frac{P_t^E/\bar{P}_t^X}{Db}\right)^{-\frac{\rho}{1+\rho}} - b}\right]^{-\frac{1}{\rho}} \bar{K}_t, \tag{8}$$

where (short-term) energy price elasticity is given by the expression

$$\varepsilon_t^{X,P^E} = -\frac{b}{1+\rho}\left[\left(\frac{P_t^E/\bar{P}_t^X}{Db}\right)^{-\frac{\rho}{1+\rho}} - b\right]^{-1}. \tag{9}$$

The elasticity is time-dependent, as it varies with the relative energy price $(P_t^E/\bar{P}_t^X)$.

Since the capital-energy bundle per unit of effective labor is time-invariant in the steady-state, firms reduce the demand for labor at the same rate as the capital-energy bundle. Using (1), this implies that the percentage effect on the output good equals that on the capital-energy bundle and labor. Hence, with $\varepsilon_t^{Y,P^E} = \varepsilon_t^{X,P^E}$, the short-term effect of an increase in the energy price (from its initial level $\bar{P}_t^E$) on the supply of the output good can be written as

$$\frac{\mathrm{d}Y_t}{Y_t} = -\frac{b}{1+\rho}\left[\left(\frac{\bar{P}_t^E/\bar{P}_t^X}{Db}\right)^{-\frac{\rho}{1+\rho}} - b\right]^{-1} \frac{\mathrm{d}P_t^E}{\bar{P}_t^E}. \tag{10}$$

The elasticity of substitution between energy and capital is a crucial parameter in this respect. In the range of plausible parameter values, the less it is possible to replace energy through capital, the lower is, other things being equal, the impact of an energy price increase on the output level. For a general CES production function, its magnitude depends on the energy price level itself, while, in the Cobb-Douglas case ($\rho = 0$), the elasticity simplifies to $-b/(1-b)$.[2] From this result as well as from the general expression in (10), it is obvious that the short-term supply of output is normally more sensitive the higher the energy cost share in production or the distribution parameter, respectively.

3 Empirical analysis

At the core of the empirical analysis is the estimation of the parameters of the CES production function (2). In particular, the elasticity of substitution between capital and energy is derived from an energy demand equation which is estimated using a cointegration approach.[3] To run the regressions, data on energy consumption, the effective energy price and the volume and the price of the capital-energy bundle are required. As the capital-energy bundle is a theoretical construct, its volume and price need to be derived from available statistics, accounting for the theoretical framework in which it is embedded. A further complexity arises from the fact that the usual output concepts published in national accounts (such as GDP or gross output) are inappropriate measures of the outcome of a production function with capital, labor and energy as input factors.

The econometric part is therefore preceded by detailed presentations on the data used. For instance, it is shown that effective energy prices may not only depart significantly from oil prices but also differ from one sector to another as a result of the sectoral energy mix. Furthermore, the time series of fixed capital and energy use are displayed to shed light on the long-run capital-energy substitutability in the sectors under consideration. The preparatory work concerning the calculation of volumes and prices for the output good and the capital-energy bundle is detailed as well.

All computations and estimations are performed in parallel for industry and transportation using annual data in the period from 1970 to 2008 where data before 1990 refers to western Germany. The time series used in the subsequent analysis are corrected for statistical breaks. Appendix A provides more information of the sources and the treatment of data.

3.1 Energy prices and shifts in the use of capital and energy

Increases in the price of energy consumption affect industrial firms and carriers to different degrees, depending on the sectoral energy mix and the price trends for individual energy products. Effective energy prices in a sectoral breakdown are computed by using nominal energy expenditure taken from input-output tables in conjunction with the accounts of energy use (in petajoule).[4]

[2] Note that the distribution parameter (equalling the energy cost share in intermediate goods production) is time-invariant by construction.

[3] The natural tension arising from the fact that the elasticity of substitution as a long-run parameter has to be estimated by short-run data is resolved using Chirinko's (2008) preferred approach.

[4] By construction, the series are not price indices in pure form, as they reflect not only price changes but also shifts in the energy mix.

Figure 1: Effective energy prices

The solid line depicts the effective energy price, while the dashed line depicts the oil price (in euro). The index series are transformed into logs.

As shown in Figure 1, the energy price trend since 1970 has been steeper overall but somewhat less volatile in industry compared with transportation. This is due to the fact that industrial production is based on a broad mix of energy sources (see Table 1). In particular, it is characterized by comparatively high shares of electricity and coal where price trends are fairly smooth. The share of petroleum products is currently at about 28 percent. In former times, the dependence of industrial production on oil was considerably higher. In the late 1970s, the consumption of petroleum products amounted to 45 percent to industrial energy use. However, during the last thirty years petroleum has been increasingly substituted by gases, electricity and renewable sources. The energy use of firms in transportation has been extremely exposed to petroleum products even if the share dropped from 90 percent to 83 percent in the last few years owing to an intensified use of renewable sources, in particular biodiesel. Hence, it comes as no surprise that the correlation between effective energy prices and oil prices, both entities measured in terms of contemporaneous percentage changes, is higher in transportation (0.77) than in industry (0.64). In sum, the oil price shocks of the 1970s and in the 2004-08 period are generally mimicked by rising energy prices in both sectors under review.

Table 1: Shares in total energy use (in percent)

	industry*				transportation*,†			
	1978	1985	1995	2007	1978	1985	1995	2007
petroleum	45.3	35.5	32.0	28.1	90.3	89.2	89.9	82.5
gases	17.9	20.8	26.6	27.2	1.0	1.2	1.9	1.9
coal	19.2	24.1	18.2	15.7	0.9	0.4	0.2	0.0
renewable sources	0.0	0.1	0.3	3.7	0.0	0.0	0.1	8.5
electricity / others	17.6	19.5	23.0	25.3	7.7	9.2	7.9	7.1

* including non-energetic use of energy carriers.
† including telecommunication services.

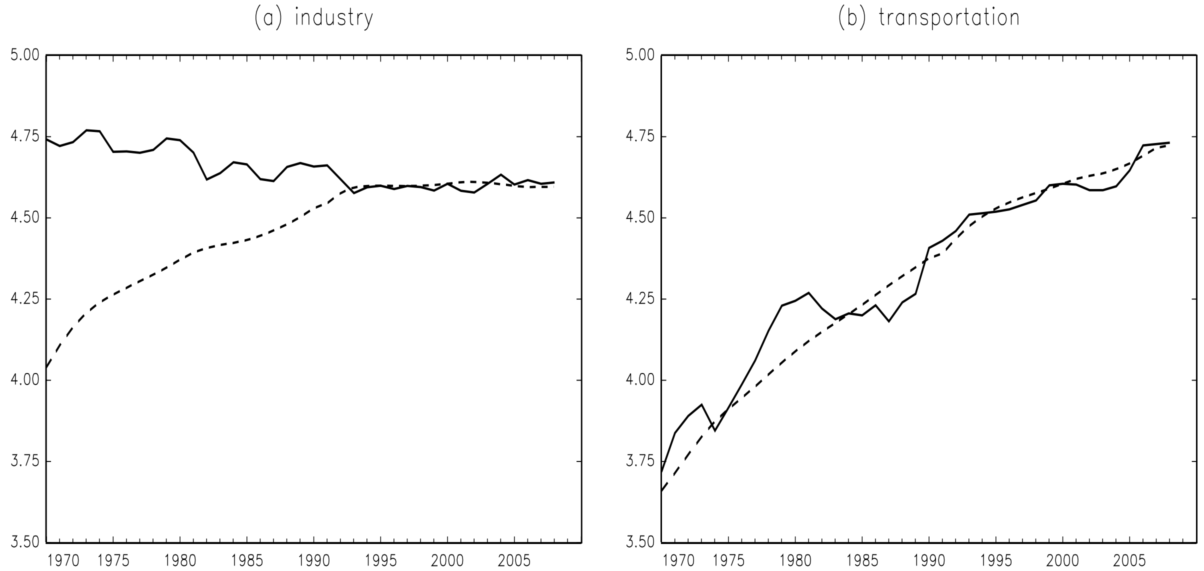
The two sectors differ significantly from each other as regards the extent of capital-energy substitution since the 1970s. Apart from cyclical fluctuations, the west German industrial sector (absolutely) reduced energy consumption until unification despite relatively high rates of capital formation, while energy use increased in line with the rise in the capital stock held by transport services providers (see Figure 2). After unification, the energy-to-capital ratio remained more or less unchanged along a path characterized by a stable capital stock. In transportation, however, the trends in capital stock and energy use continued to rise at similar rates after unification.

3.2 Volume and price of output and the capital-energy bundle

The three-factors production function considered in the theoretical analysis requires an output measure which is not reflected by the standard concepts defined in the national accounts. While value added is constructed as "a device for allocating the origins of national income to the services of the primary inputs capital and labor" (Berndt and Wood, 1995, p.265), gross output is conceptually too broad because it measures the outcome of a production function in capital, labor and *all* intermediate inputs. From the standpoint of national income accountants, the statistical counterpart of Y_t is therefore gross output less the value of intermediate goods except energy. In nominal terms, this entity can be constructed by summing up value added and the value of energy consumption. In real terms, the index of value added in the previous year's prices is combined with energy consumption in petajoule in a way which mimics the current measurement practice of real quantities in the national accounts. The respective deflator P_t^Y is then measured by the ratio of the nominal and real quantity.

For the estimation of sectoral energy demand equations, data on the volume and price of the capital-energy bundle are required. These entities are unobservable but can be measured by a top-down approach using information on output and labor input and assuming

Figure 2: Capital input and energy consumption



The solid line depicts energy consumption, while the dashed line depicts capital input. The index series are transformed into logs.

that the economy evolves along the balanced growth path during the time period under consideration.[5]

In the steady state, the capital-energy bundle and effective labor grow at the same rate, suggesting that $\bar{X}_t = \lambda\, A_t \bar{L}_t$ where λ is the proportionality factor. As A_t is the sole source of technical progress in the model, its growth path can be measured in a growth accounting framework. In formal terms, $A_t = A_0 \prod_{i=1}^{t}(1+\theta_i)$ where A_0 is the initial technological level and the rate of technical progress in period t is given by

$$\theta_t = [\Delta \ln Y_t - \bar{\alpha}^L \Delta \ln L_t - \bar{\alpha}_t^E \Delta \ln E_t - (1 - \bar{\alpha}^L - \bar{\alpha}_t^E)\Delta \ln K_t]/\bar{\alpha}^L. \tag{11}$$

Imposing the steady-state implication of a constant labor income share, $\bar{\alpha}^L$ is measured by the sample average. By contrast, the energy cost share is time-varying even on the balanced growth path. Following the Törnqvist index formula usually applied in growth accounting exercises, it is $\bar{\alpha}_t^E = \frac{1}{2}(\alpha_t^E + \alpha_{t-1}^E)$. As a result, the evolution of the capital-energy bundle over time can be described up to a normalization.

Having X_t, the price of the capital-energy bundle is obtained by using the joint income of capital and energy which, of course, is total factor remuneration less labor income; in formal terms, $P_t^X = (P_t^Y Y_t - W_t L_t)/X_t$.

[5]For instance, Lucke (2005) provides evidence that economic growth in Germany since 1970 might generally be of a balanced nature, while the evolution during the 1950s and 1960s might be well approximated by a strong process of convergence towards the steady-state equilibrium, starting from the low post-war activity level.

3.3 Estimating the CES production function

The section is devoted to specifying the CES production function (2) for industry and the transportation sector. The elasticity of substitution between capital and energy is estimated as a coefficient in a cointegrating regression. On the basis of this estimate, the distribution and scaling parameters are computed using data on output, inputs and the energy cost share in intermediate production. The common basis is the theoretical expression of the demand for energy in the context of a CES production function. Not least because of the relatively small number of observations, the point estimates are surrounded by a great deal of sampling variability and model uncertainty. Building on approximate probability distributions of the parameters of interest, stochastic simulations are run in order to figure out the effect of these types of inaccuracy on the empirical appraisal.

The energy demand equation can be derived by solving its implicit form (4′) with (2) for energy use. Taking logs, the formal result is

$$\ln(E_t/X_t) = \ln Db - \sigma \ln(P_t^E/P_t^X). \tag{12}$$

As the equation is regarded as an equilibrium relationship and the time series of the variables involved are nonstationary, cointegration methodology is applied. However, caution has to be exercised with respect to the econometric results because available time series are far too short to draw firm conclusions. The elasticity of substitution is obtained by estimating the empirical counterpart of (12) as the cointegrating regression

$$\ln(E_t/X_t) = \mu'\Phi_t - \sigma \ln(P_t^E/P_t^X) + u_t \tag{13}$$

where u_t is a stationary residual process. The parameter vector μ is attached to the set of deterministic regressors stacked in Φ_t. Theory suggests that Φ_t contains an intercept term only. If, in practice, cointegration cannot be established in this setup, a linear trend is augmented because it might capture diverse forms of misspecification in the theoretical structure imposed. Contrary to the assumptions, for instance, technical progress might not only be of labor-augmenting nature and/or exclusively measured by the TFP component (11). Moreover, the assumptions of constant returns to scale and perfectly competitive output and factor markets could be violated, in particular as far as the comparatively small transport sector is concerned.

The initial step of the econometric analysis is to test for cointegration between $\ln(E_t/X_t)$ and $\ln(P_t^E/P_t^X)$. With only 39 annual observations at hand, systems cointegration tests are not recommendable because they likely suffer from serious problems in test power. Instead, we follow Hansen (1992) who suggests using the L_c test version for parameter instability in cointegrating regressions as a test of cointegration against the alternative of no cointegration. Test results are confirmed by applying the standard two-step methodology proposed by Engle and Granger (1987). The latter method is expected to provide supplementary information because it takes the hypothesis of no cointegration under the null. As the necessity to include a linear trend is unknown a priori, tests are performed with and without this deterministic component.

Table 2: Cointegration tests

	Hansen's L_c test		Engle-Granger test	
null hypothesis	cointegration		no cointegration	
linear trend	with	without	with	without
industry	0.095	0.164	3.13	1.78
transportation	$0.632^{(*)}$	0.077	4.39^{*}	0.03
c.v. 10%	0.520	0.497	3.69	3.16
c.v. 5%	0.654	0.623	4.05	3.51
c.v. 1%	0.999	0.959	4.77	4.21

Critical values of the Hansen's L_c test are taken from Hansen (1992, Table 3). Critical values of the Engle and Granger (1987) method are taken from MacKinnon (1991). $^{**},^{*},^{(*)}$ mean rejection of the null hypothesis at the 1%, 5% and 10% level respectively.

Overall, Table 2 provides weak evidence that energy use and energy prices are cointegrated. In industry, the null of cointegration is not rejected using Hansen's procedure, while the null of no cointegration cannot be rejected with the Engle-Granger method. As this pattern is found for the specifications with and without a linear trend, its inclusion is not enforced by econometric reasons. In transportation, the Engle-Granger test rejects the absence of cointegration at the 5% level in the specification including a linear trend.

Taking into consideration the general shortcomings of cointegration tests in short samples, it is fair to conclude that (13) can be regarded as a valid cointegrating regression if a linear trend is considered in the case of transportation, while the primary specification without a linear trend is supported by the data of the industrial sector. The ordinary least squares (OLS) estimates are as follows (standard errors in parentheses).

$$\text{industry:} \quad \ln(E_t/X_t) = \underset{(0.5)}{8.7} - \underset{(0.11)}{0.87} \ln(P_t^E/P_t^X) + u_t, \quad \mathrm{R}^2 = 0.62, \tag{14}$$

$$\text{transportation:} \quad \ln(E_t/X_t) = \underset{(0.3)}{6.3} - \underset{(0.001)}{0.016}\, t - \underset{(0.06)}{0.26} \ln(P_t^E/P_t^X) + u_t, \quad \mathrm{R}^2 = 0.83. \tag{15}$$

The elasticity of substitution between capital and energy is below unity in both sectors. In comparative terms, the capital-energy substitutability is substantially higher in industry than in transportation.

The energy demand equation can be solved for the CES distribution parameter, yielding the expression

$$b(\rho; K_t, E_t, \beta_t^E) = \frac{\beta_t^E K_t^{-\rho}}{(1-\beta_t^E)E_t^{-\rho} + \beta_t^E K_t^{-\rho}}, \tag{16}$$

where $\beta_t^E = (P_t^E E_t)/(P_t^X X_t)$ is the energy cost share in intermediate production. Substituting this formula into (2) and solving the resulting equation for the scaling factor gives

$$D(\rho; X_t, K_t, E_t, \beta_t^E) = \frac{X_t}{K_t E_t} \left[(1-\beta_t^E) E_t^{-\rho} + \beta_t^E K_t^{-\rho} \right]^{-1/\rho}. \tag{17}$$

From a theoretical point of view, fixing $(X_t, K_t, E_t, \beta_t^E)$ is a means of normalizing the CES production function in the sense of Klump and de La Grandeville (2000) as well as Klump and Preissler (2000). In this paper, the normalization is effected by using the sample means of the random variables $b(\rho; \cdot)$ and $D(\rho; \cdot)$ conditional on ρ, i.e.

$$\hat{b}(\rho) = (1/T) \sum_{t=1}^{T} b(\rho; \cdot) \quad \text{and} \quad \hat{D}(\rho) = (1/T) \sum_{t=1}^{T} D(\rho; \cdot).$$

In statistical terms, normalization is a source of model uncertainty as is the estimation of the elasticity of substitution. A measure of the full uncertainty surrounding the CES production function may thus be given by merging the unconditional sampling variabilities of ρ as well as b and D.

In the subsequent section, supply effects will be quantified on the basis of (10). The point estimates are the result of substituting $[\hat{\rho}, \hat{b}(\hat{\rho}), \hat{D}(\hat{\rho})]$ where $\hat{\rho} = 1/\hat{\sigma} - 1$ is the estimate taken from the cointegrating regression (13). In order to assess the uncertainty surrounding the point estimates, it might be useful to simulate confidence bands. For simplicity, assume that the marginal distributions of the model parameters are approximated by the mutually independent Gaussian distributions $\rho \sim \mathrm{N}(\hat{\rho}, s_\rho^2)$, $b \sim \mathrm{N}(\hat{b}, s_b^2)$ and $D \sim \mathrm{N}(\hat{D}, s_D^2)$. An estimate of s_ρ^2 is taken from the cointegrating regression. Since only realizations of the conditional variables $b(\rho; \cdot)$ and $D(\rho; \cdot)$ are observed, the marginal variances s_b^2 and s_D^2 are computed using the formulae

$$s_b^2 = \underset{\rho}{\mathrm{E}}[\, \mathrm{Var}\, b(\rho; \cdot)\,] + \underset{\rho}{\mathrm{Var}}[\, \mathrm{E}\, b(\rho; \cdot)\,] \quad \text{and} \quad s_D^2 = \underset{\rho}{\mathrm{E}}[\, \mathrm{Var}\, D(\rho; \cdot)\,] + \underset{\rho}{\mathrm{Var}}[\, \mathrm{E}\, D(\rho; \cdot)\,].$$

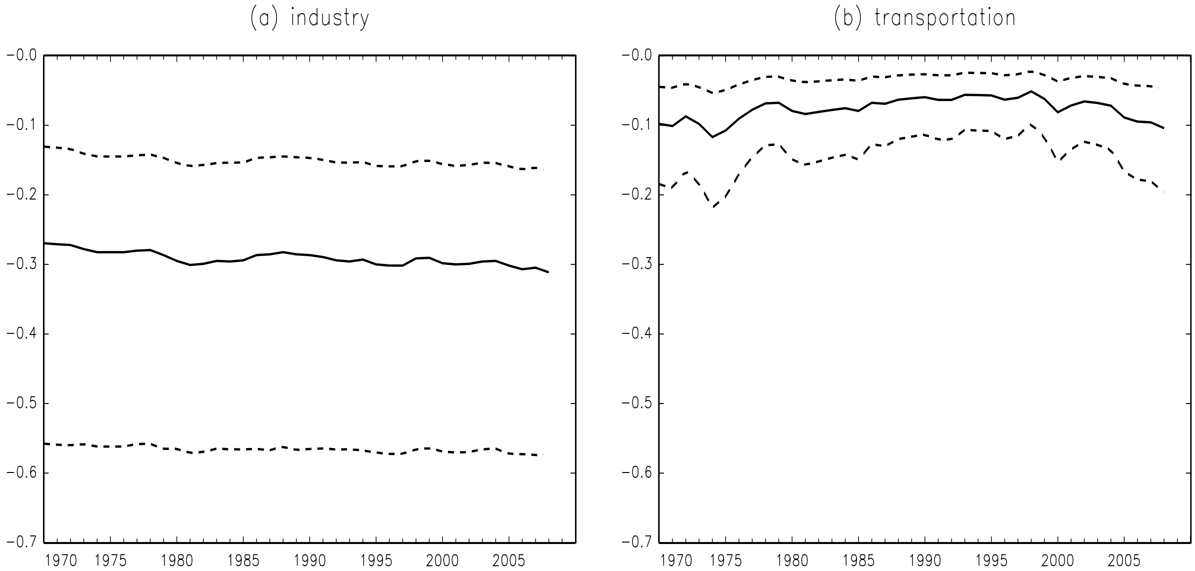
Hence, the model uncertainty regarding the CES production function is simulated by randomly drawing values from the distributions assigned to the parameters ρ, b and D.

4 Periods of strong energy price increases compared

Since 1970, there have been three periods when oil prices rose steeply over a time span sufficiently long to expect significant effects on the supply of output and the income distribution in industrialized countries. The first upsurge lasted from 1973 to 1975 and is typically known as the first oil price shock. The second oil price shock started in 1979 and ended in 1982. A third drastic oil price surge happened between 2004 and mid-2008. Looking just at the cost structure of oil-consuming production sectors, from an analytical point of view, it makes no difference that the last increase was fundamentally driven by sharply expanding oil demand, while the shocks in the 1970s had been caused by oil supply shortages.

Given their extent and duration, the increases in energy prices strained the cost structures of firms to such an extent that an incomplete pass-through to output prices is likely

Figure 3: Short-term energy price elasticity



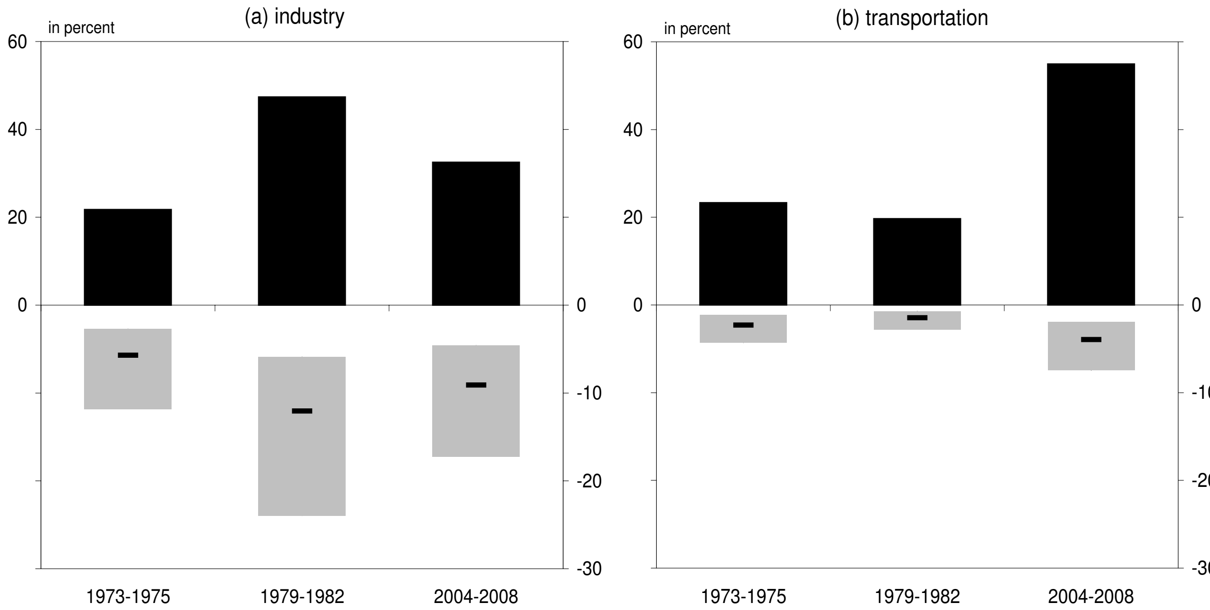
The point estimates of the short-term energy price elasticity are depicted by the solid line, while the dashed lines limit the 90% confidence band simulated on the basis of 1,000 random draws from the distributions assigned to the three parameters of the CES production function.

in the time horizons considered. This means that, contrary to what is assumed in the theoretical model for ease of simplification, output price movements in reaction to energy price hikes are explicitly accounted for in the empirical analysis. In the first part of this section, the short-run effects to the supply of output are computed on the basis of (10), replacing the absolute energy price change by the relative one, where the reference is the price of the capital-energy bundle. The second part quantifies the change in output prices during the periods of energy price hikes and provides a decomposition of these movements into the changes in the unit costs of factors of production. Albeit descriptive in nature, the evidence on output and input price developments complements the view on the economic conditions industrial firms and carriers faced in the periods of strong energy price hikes.

4.1 Short-run supply effects

The aim of this section is to compare the three periods of strong energy price hikes with regard to short-term effects on the supply of industrial goods and transport services. The calculation of these effects relies on (10), using the parameter values of the CES production function estimated in the previous section for industry and transportation. Figure 3 reveals that, according to the point estimates (in absolute values), the supply elasticity is roughly stable at about 0.3 in industry, while it fluctuates around 0.1 in transportation. Confidence

Figure 4: Relative energy price shocks and supply effects



The percentage changes in the relative effective energy prices cumulated over the indicated periods of time are displayed by the black bars, with the relevant scale located on the left side. The point estimates of supply responses (in percent) are shown by short horizontal lines where the relevant scale is on the right-hand side. The grey bars cover the 90% probability of all possible realizations of the supply effects according to the confidence bands shown in Figure 3.

bands are visibly smaller in the latter sector, mainly owing to the relatively small standard error attached to the coefficient representing the elasticity of substitution in the energy demand equation.

Capturing the generally time-varying output sensitivities, the short-term supply responses to the energy price shocks of the three periods under consideration may be approximated by the expression

$$\sum_{i=t}^{t+\tau} \frac{1}{2}(\varepsilon_i^{Y,P^E} + \varepsilon_{i-1}^{Y,P^E})\Delta \ln(P_i^E/P_i^X),$$

where the price shock starts in period t and lasts τ years.

Figure 4 displays the relative energy price shocks on the positive scale and the resulting estimated short-run effects on the supply of output in industry and transportation on the negative scale. The point estimation is informed by a 90% confidence band, capturing the uncertainty surrounding the specification and estimation of the sectoral production functions.

Perhaps most striking is the fact that, in a cross-sector comparison, the three periods under consideration are not equally ranked—in terms of not only the initial price shocks but also the output responses. Thus, while the second oil price shock in the late 1970s hit the industrial sector hardest, in transportation it is the 2004-08 period which led to, by far, the strongest rise in effective energy prices. Though this hike is distinctly more than double the size of the energy price movements during the oil price shocks of the early 1970s, the dampening effect on transport services is only 70 percent higher. Since the first oil price hike carriers have been able to reduce their energy price sensitivity only to a small extent.

Concerning the output effects, it is a general pattern that industry was more severely affected than transportation in each energy price hike period. During the first oil price shock, this was due solely to the higher elasticity because effective energy prices rose by almost the same percentage in the two sectors. During the second oil price shock, industry suffered from a price impulse more than twice as strong as the one affecting transportation. Together with the structurally higher sensitivity, the upsurge resulted in a negative effect on industrial production which was exceedingly more pronounced than the carriers' output reduction. In the 2004-08 period, however, the strains on the two sectors were more similar in strength owing to the fact that the transport sector had to cope with an almost two-times stronger increase in effective energy prices.

4.2 Short-run effects on output prices and factor remuneration

Rising energy prices usually impact the price of the output good and/or the income distribution. From a theoretical point of view, the assumed constant-returns-to-scale production functions imply zero profits in the competitive equilibrium, suggesting that increasing costs of energy use must either feed into output prices or be compensated by a declining remuneration of the other factors of production. Of course, a combination of both adjustments is also possible.

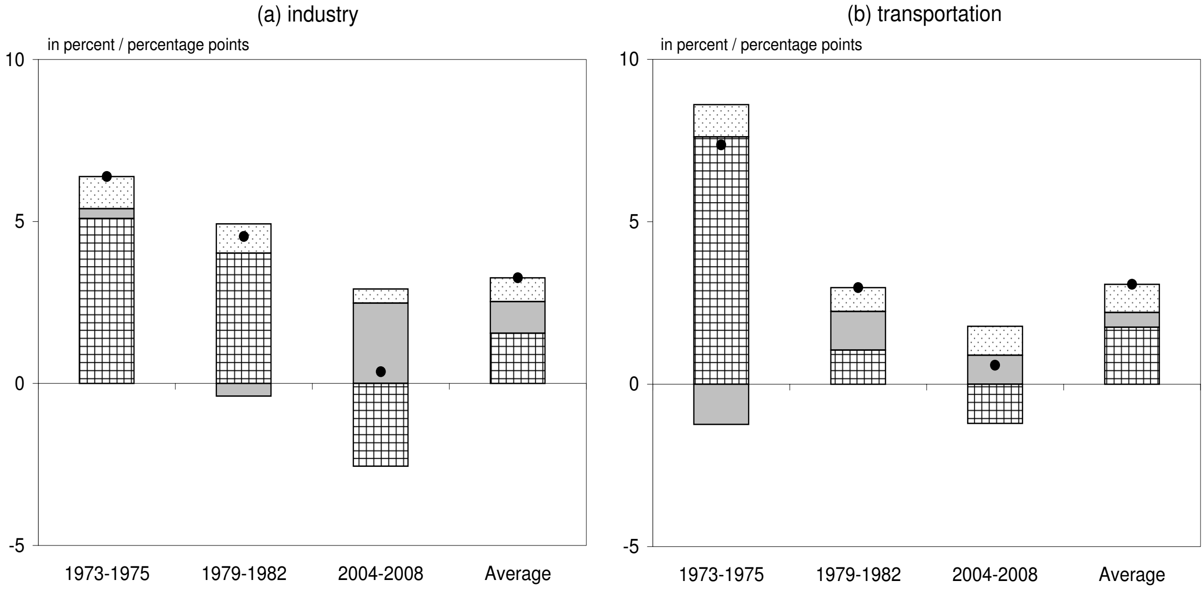
When real wages are predetermined and the rents on installed productive capital are fixed costs, the theoretical model predicts that an increase in energy prices lifts short-run average costs above their long-run level. With unchanged output prices, firms incur losses.[6] In the accounting framework employed, where the return on capital is measured as a residual, it is impossible to split this residual into the short-run loss and the rental rate which was agreed upon by firms and the owners of the capital stock. Hence, the actual returns on capital, which can be computed from the data, have to be interpreted as a mixture of both elements.[7]

[6] This implication results from the profit-maximizing factor demand according to the FOCs (3′) and (4′) where energy consumption adjusts while capital is fixed in the short run. The reduction of energy use makes the marginal product of capital decline below the rental rate. Starting from the long-run equilibrium where all input factors are compensated by their marginal products and the output price is equal to (long-run) average costs, firms incur losses, i.e.

$$\frac{R_t}{P_t^X} = \left.\frac{\partial X_t(\cdot)}{\partial K_t}\right|_{(\bar{K}_t, \bar{E}_t)} > \left.\frac{\partial X_t(\cdot)}{\partial K_t}\right|_{(\bar{K}_t, E_t)} \quad \text{for} \quad E_t < \bar{E}_t.$$

[7] This distribution of gains and losses is in line with a property structure where entrepreneurs completely own the capital stock installed in their firms.

Figure 5: Decomposition of output price changes



The annual output price change in percent is shown by the bold dot. Its decomposition into contributions from unit factor costs is displayed as a bar where the checked area refers to labor, the grey area to capital and the light dotted area to energy.

In order to avoid the short-term losses from becoming entrenched, firms endeavor to raise output prices and/or to lower the expansion path of money wages if possible. In a framework with labor-augmenting technical progress, the strain on the return on capital will be relieved by the latter mechanism if real wages grow at a lower rate than labor productivity.

Output and factor price movements can be analyzed on the basis of (6). Formulating the equilibrium relationship between the output price and unit factor costs in growth rates yields the result that the percentage change in the output price is the weighted sum of the percentage changes of unit factor costs, where the weighting scheme is given by the factor income shares of the previous period; in formal terms,

$$\Delta \ln P_t^Y = \alpha_{t-1}^L \Delta \ln \frac{W_t}{Y_t/L_t} + \alpha_{t-1}^E \Delta \ln \frac{P_t^E}{Y_t/E_t} + (1 - \alpha_{t-1}^L - \alpha_{t-1}^E) \Delta \ln \frac{R_t}{Y_t/K_t}. \quad (18)$$

The decomposition of output price changes into the contributions of unit factor costs is a descriptive measure which sheds light on the actual consequences rising energy costs have had on output prices and factor remuneration, when applied to the periods of the energy price hikes.

Figure 5 displays this decomposition for the three periods in comparison. The average decomposition over the whole sample is presented as a reference. The main difference between the 1970s and the 2004-08 period is the evolution of wage compensation during the energy price hike. Both in industry and transportation, the additional cost burden of energy use was more than offset by a marked reduction in unit labor costs between 2004 and 2008, while the phase of expansive wage policy had continued after the occurrence of the oil price shocks in the 1970s. Without relief from wages, the productivity-adjusted return on fixed capital sank at that time. However, since this form of internal compensation is generally limited, it comes as no surprise that firms raised output prices, setting in motion a wage-price spiral. The situation in the transport services sector during the second oil price shock deviates from this pattern, as carriers were obviously able to contain wage growth, making it possible to both stabilize the return on capital and limit output price pressures.

The upsurge of energy prices in the 2004-08 period coincided a persistent phase of pronounced wage moderation, which has started back in the mid-1995. Wage compensation grew at a distinctly slower rate than labor productivity. Sharply falling unit labor costs helped firms not only to slightly lower output prices despite rising energy costs. Especially in the industrial sector, the returns on capital also recovered markedly during that time. It is worth mentioning that the flattening of the output price trend and the correction of the income distribution were market-conform adjustment mechanisms, restoring, on the one hand, the international price competitiveness of German products, which had deteriorated strongly after unification. On the other hand, it enhanced the attractiveness of investments in German industrial locations and carriers, which had come under increasing pressure from competitors from emerging countries during the process of globalization and from neighboring transformation economies after the fall of the iron curtain (see Deutsche Bundesbank, 2007, for instance). Hence, it is overstating the case that the recent energy price hike triggered the moderate wage reaction. It is rather that the price shock partly coincided with a period of structural change, in which the wage was the major adjustment variable.

Besides relief from the wage side, the pressure on unit costs in industry remained low overall in the 2004-08 period because the contribution from unit energy costs was not only smaller than during the two oil price shocks of the 1970s but also below the average over the whole sample. The cost-pushing impact was mitigated by gains in energy productivity which was four times higher than during the first oil price shock. However, already in the late 1970s it was twice as high as in the early 1970s. In comparison, carriers were only able to realize a relatively small increase in energy productivity. The biggest improvement has been made at the end of the 1970, but it was rather modest compared with those experienced in industry. By contrast to energy productivity, variations in the energy income share are shown to be of negligible importance in explaining the comparatively small contribution of rising energy costs to output price changes.

5 Conclusions

The paper has quantified the impact of energy price hikes on the short-term supply of industrial goods and transport services as well as their effect on the income distribution in the two sectors under consideration. Industrial production was more severely affected by the oil price shock of the late 1970s than by the energy price surge between 2004 and 2008, whose magnitude was nonetheless markedly higher than the one of the early 1970s. By contrast, transport services shrank more in the recent episode than in the two phases in the 1970s. The contrasting inter-sectoral picture in output responses reflects the relative strengths of the effective energy price movements the sectors have experienced during the periods under comparison. Moreover, industrial firms have steadily reduced the energy consumption per unit of installed capital since the second oil price shock, which had hit this sector disproportionately hard.

According to estimates based on energy demand equations, the (marginal) elasticity of substitution between capital and energy is somewhat less than 0.9 in industry, whereas it is almost 0.3 in transportation. Hence, it seems generally more appropriate to model the capital-energy-substitutability using a CES production function than by assuming a Cobb-Douglas specification for analytical convenience. As a consequence of the higher elasticity of substitution, the output responses to (unitary) energy price impulses are stronger in industry than in transportation.

The effects on the supply of output have been measured on the basis of an algebraic expression for the energy price elasticity of output provided that the capital stock is predetermined while energy use and labor input are variable factors of production. On the one hand, it might be critically discussed whether or not the immediate one-to-one reaction of labor input to a change in the capital-energy bundle conforms to reality. However, the modelling of a sluggish response of labor input would not only complicate the theoretical analysis, it would also confound the pure effects of an energy price hike with effects originating in other economic circumstances such as adjustment lags or labor hoarding. On the other hand, the assumption of a fixed capital stock might be challenged for reasons which are directly related to energy price shocks. On the production side, a persistent rise in the relative price of energy use, or at least the expectation of such a development, alters the optimal capital-energy combination, making it rather costly to operate energy-intensive machines. On the demand side, consumers are likely to abstain from buying durables with an unfavorable energy profile. Both effects cause capital goods to become obsolete in economic terms. This phenomenon, however, is better studied within vintage-capital models than in the theoretical setup chosen here.

It was beyond the scope of this paper to study the long-run implications of an energy price hike on the production structure. Apart from the question of whether the shock is regarded as temporary or persistent, the consequences hinge on the sharing of the extra cost burden. The paper has revealed that the recent surge coincided with a period of pronounced wage moderation while in the 1970s an expansive wage policy added to higher energy prices lifted total costs sharply. Hence, firms came out of the recent episode with cost structures which were less strained than after the oil price shocks. Furthermore, the return on fixed capital recovered despite rising energy prices, creating incentives to invest in productive capital. Accelerated capital accumulation might be seen as a central prerequisite for energy substitution in industrialized countries, as available energy-saving technology is usually embodied in new capital goods.

A Data

The data on gross output, hours worked, productive capital and the labor income share are taken from national accounts. In general, productive capital is assigned to the sector where it is used. This is contrary to the practice in national accounts, where operating leases are understood as a specific business whose assets are reported separately. The distribution of assets to the sectors in which they are actually employed is based on turnover shares taken from input-output tables. The labor income share is based on the compensation of employees including the wage component in the revenues of the self-employed. All time series are annual, from 1970 to 2008. In order to remove the structural break due to German unification, data prior to 1991 are constructed by chaining up the pan-German data using the percentage changes of the West German time series. Apart from the territorial basis, the time series are coherent as regards statistical concept and measurement. In general, the time series of energy use and effective energy prices are also based on sources provided by the *Statistisches Bundesamt*. However, they are constructed by merging information from environmental accounting and input-output tables. The raw data are interpolated and extrapolated by appropriate indicator series to fill gaps in the time series. In addition, they are adjusted for structural breaks to remove discrepancies owing to heterogeneity in statistical measurement.

Sectoral data on energy use are provided by the *Statistische Bundesamt* and, alternatively, by the *Arbeitsgemeinschaft Energiebilanzen*. With regard to sector classification, in particular the imputation of small business firms to the household sector, the former source fits the other data better but the statistic only starts in 1978. However, the latter provides figures for the full time span under consideration, which suggests that they can be used as indicator series in an extrapolation exercise. The effective energy price in a sector is calculated by dividing the sectoral turnover for domestic energy producers and importers by the sectoral energy use. The energy transactions between sectors are taken from input-output tables, ensuring that transactions of industrial branches transforming primary energy carriers (gas, coal, crude oil, natural energy sources) into secondary energy carriers (mineral oil, electricity, district heating) are excluded to avoid double-counting.

Since input-output tables are not available for a number of years, predominantly in the early 1970s, effective energy prices cannot be computed for the whole time period under consideration. Missing values are filled by interpolation using the price indices of the sector's most important energy carriers as indicator series; in industry, these are natural gas, electricity, coal and petroleum, while they constitute petroleum and electricity in the transportation services sector. Within this exercise, the time series of effective energy prices are also adjusted for structural breaks as a result of various methodological revisions in the original data sources.

As the input-output tables are not able to discriminate between energetic and non-energetic utilization of energy carriers, the corresponding real energy consumption must incorporate both types of utilization. Since it might be more difficult to substitute energy carriers that are used in non-energetic ways through capital in the production process, the substitution elasticity may be somewhat higher if only energetic use of energy carriers is considered. Nonetheless, an energy price increase raises production costs, irrespective of the type of energy utilization. Thus, to explore the output effects of an energy price hike, both types of utilization have to be considered. However, in industry and transportation, energy carriers are almost entirely used for energetic purposes. The only exception is the production of chemical commodities, where roughly two-thirds of the input of energy is non-energetic.

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