Technical Change, Investment and Energy Intensity

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ABSTRACT  This paper analyses the role of different components of technical change on energy intensity by applying a Translog variable cost function setting with (short-run) fixed capital to the new EU KLEMS dataset for five selected EU countries (Denmark, Italy, Netherlands, UK and Spain). The framework applied represents an accounting of technical change components, comprising autonomous (disembodied) as well as technical change embodied in capital goods. It is extended in order to incorporate embodied technical change induced by energy prices by adding an equation for (physical) capital stock accumulation. The model can be used for explaining and tracing back the long-run impact of the interaction of prices, capital accumulation and technical change on energy intensity. The empirical results distinguish between industries with embodied technical change and industries with capital-energy complementarity.

KEY WORDS: Embodied technical change, industrial energy intensity, Translog cost function

1. Introduction

The explanation of trends in the use of energy in the economy is one main application of input–output analysis that recently attracted renewed attention. Energy intensity has continuously declined after the two oil price shocks but this development ground to a halt during the 1980s. These stylized facts can be seen in Figure 1 for the (aggregate) manufacturing sector in five European countries.1 Obviously, these long-term trends cannot be fully attributed to short-run price elasticities but must be explained by technological progress that has been ‘induced’ by the price development. One line of research focuses on decomposition of aggregate energy intensity into a technological and a structural change component (Ang and Zhang, 2000; Ang and Liu, 2006). The technological component measures the ‘hypothetical’ energy intensity resulting from the change in technology (input per unit of output) between the base and the end year with all other variables (demand level, demand structure, etc) at the base year level. The structural component measures the ‘hypothetical’ energy intensity resulting from the change in output structure.
The general result of these studies is that the contribution of the two components varies between different periods. In ‘low energy price periods’ after a drop in oil prices, the contribution of the structural component becomes increasingly important, because the technological component loses importance in most industries during these ‘low energy price periods’.

Another line of the literature therefore deals with explaining and further decomposing the technical change component at the industry level. Basically, there are two ways in which changes in an increase in energy prices can influence technical change: directly by inducing energy-saving innovations, for example by minimizing energy losses during production, or indirectly by inducing the development of new machines that are less energy intensive than the old machines. The latter is known as embodied technical change. The main idea of embodied technical change is that the technology is incorporated in the stock of equipment and technological change therefore only occurs with the installation of a new vintage of equipment. The importance of embodied technical change in a KLEM framework has first been shown empirically by Berndt et al. (1993).

The standard approach for this kind of analysis is the cost function and factor demand framework applied to datasets containing data on capital, labour, energy and other intermediate inputs (KLEM). The first generation of studies dealt with total factor productivity (TFP) and the bias in technical change (Jorgenson and Fraumeni, 1981; Jorgenson, 1984). A major result in these studies was that in some periods, as well as in some industries, energy-using bias in technical change dominated in the US. Sue Wing and Eckaus (2004) as well as Welsch and Ochsen (2005) apply the framework of factor demand equations to KLEM datasets in order to decompose different factors that impact energy use or energy intensity. In a translog function approach, Welsch and Ochsen (2005) allow for biased technological change and treat capital as a fully flexible factor. Therefore,
they do not explicitly take into account technical change embodied in capital goods, but have the link between capital and energy incorporated in the substitution elasticities. In that respect, Welsch and Ochsen (2005) corroborate other studies by finding complementarity between energy and capital.

Sue Wing and Eckaus (2004) are the first to analyse changes in energy intensity by differentiating between the two types of technical change (factor-biased technical change and embodied technical change) in a restricted variable cost function approach following (Berndt et al., 1981; Watkins and Berndt, 1992). Owing to their treatment of capital as a short-run fixed factor they are able to derive short as well as long-run elasticities of energy intensity to changes in prices. This short- and long-run distinction captures effects that operate by adjustment of capital stocks to their long-run equilibrium levels and represent one direct causal link between energy prices, technological progress and energy intensity. They find a number of industries, where the long-run price elasticity of energy intensity is significantly larger than the short-run elasticity, which is a clear indication for the role of embodied technical change.

Another important insight achieved with the inclusion of the capital stock adjustment in energy-use models is the impact of energy prices on embodied technical change. Only a few studies have established this link. Some studies establish a direct link between the technical progress behind energy intensity improvement and energy prices. These studies mostly use a direct specification of this relationship without embedding it into a complete framework of energy demand (for recent examples, see Metcalf, 2006; and Dowlatabadi and Oravetz, 2006). In these models, energy saving can occur without installing new vintages of equipment. Technical change is therefore not necessarily embodied in these models and they rather explain part of the disembodied and otherwise autonomous energy-saving technological progress.

To summarize, there is broad empirical evidence on the importance of embodied and biased technical change within the KLEM factor demand function framework. What is missing is the explicit link between embodied technical change and prices that could help to explain the stylized facts shown in Figure 1. The existing approaches dealing with embodied technical change focus on the long-run, but the dynamic adjustment of the capital stock to its long-run equilibrium level has not been analyzed yet. It is exactly this capital stock adjustment process that could explain how an energy price increase induces a 10-year period of energy-intensity decline, which is stopped or reversed for another 10-year period after a decrease in prices. One first hypothesis derived from these observations is that the adjustment process of the actual to the optimal capital stock is a long-lasting and sluggish activity. That should also help to explain the established empirical result that long-run reactions in energy intensity to energy prices exceed the short-run reactions by far (Hogan, 1989).

The analysis in this paper is also in line with approaches that link embodied with energy prices as in Newell et al. (1999) but (owing to lack of data) without dealing with the energy efficiency of the capital goods menu. Instead, the cost function approach is used to derive the impact of capital goods on energy efficiency and the corresponding cost reduction effect (for energy and other inputs) of an additional capital unit. The link to price-induced embodiment is introduced by adding an investment equation and quantifying the impact of price changes on capital stock adjustment. By bringing about a change in the optimal capital stock and in the ‘shadow price’ of capital, price shocks induce an adjustment to a new input saving capital stock. The relative quantitative contribution of
energy prices in this process compared with other input prices (labour, materials) is an empirical question and depends on the estimated parameters. The approach is applied to a new EUKLEMS dataset for five selected European countries (Denmark, Italy, Netherlands, Spain and UK). The EUKLEMS database contains detailed input structure data at the industry level for these countries, which are complemented by detailed data on labour and capital inputs. The empirical analysis in this paper takes advantage of this extensive and elaborate data work on adequate measuring of effective inputs in the EUKLEMS project.

The remainder of the paper is organized as follows: in the next section, the theoretical model is set up and in the third section data issues are laid down. The empirical results are presented in the fourth section and in the fifth section some preliminary conclusions are drawn.

2. Energy Demand and Technical Change

The starting point of the analysis is a variable cost function with capital input as a short-run fixed factor. There are several methods of extending this core framework to a model incorporating investment demand. The simplest method consists of including an equation that explains adjustment of the short-run fixed capital stock to its long-run level. This can be done by a partial and ad hoc adjustment mechanism, such as a flexible accelerator mechanism. As Galeotti (1996) has pointed out, this mechanism describes a systematic ex post adjustment, where errors in the past are corrected but where expectations about the future development of exogenous variables play no role. In that sense this approach describes backward looking behaviour and is only ‘pseudo-dynamic’. The next more elaborated step consists of explicitly taking into account internal adjustment costs of changing the capital stock (also of replacement of capital) as in Berndt et al. (1981) and in Watkins and Berndt (1992). In this case the derivation of the optimal capital stock yields a more complex optimality condition, from which an explicit adjustment term follows for the investment equation. This can be implemented in a full dynamic model, but has mainly been used also just in pseudo-dynamic ex post adjustment models. The final most elaborate model version consists of formulating a full dynamic model either with rational expectations (Galeotti, 1996) or with other expectations formation mechanisms (Morrison, 1986). In this study, the simplest type of ‘pseudo-dynamic’ model shall be used in order to get a first simple test for the role of including capital stock adjustment. The disadvantage of lacking theoretical consistency associated with this ‘pseudo-dynamic’ model is at least partly compensated for by allowing for a more flexible adjustment mechanism of the capital stock than in other studies, such as Watkins and Berndt (1992).

2.1. Cost Function and Factor Demand

Our set-up is as follows. The representative producers in each industry all face a cost function $G$ comprising short-run variable costs $VC[p_v, x_K, Y_t]$ as well as expenditure for (aggregate) investment $I$ with the corresponding price index of (aggregate) investment goods $p_I$:

$$G = VC[p_v, x_K, Y_t] + p_I I$$

(1)
where $p_v$ is a vector of variable input prices for input quantities $v$, $x_K$ is the level of the quasi-fixed input to production, $Y$ is the level of output and $t$ is time. Note that equation (1) would, in general, allow for different types of assets $x_K$. Dealing only with one aggregated capital stock and taking into account that gross investment in this stock comprises changes in the stock plus depreciation with depreciation rate $\delta$, we have:

$$G = VC[p_v, x_K, Y, t] + p_I(x_K + \delta x_K)$$

(2)

where $x_K$ stands for the change in $x_K$. The producers choose a time path of $x_K$ to minimize discounted costs over a time horizon $\tau$ for which values for the exogenous variables are given:

$$\min \int_{\tau}^{\infty} e^{-r(t-\tau)}[VC_i(p_v, x_K, Y, t) + p_I(x_K + \delta x_K)]dt$$

(3)

The two main optimality conditions following from this cost minimization problem are given by Shephard’s Lemma and the envelope condition for the capital stock:

$$\frac{\partial VC}{\partial p_v} = v$$

(4)

$$\frac{\partial VC}{\partial x_K} = (r + \delta)p_I$$

(5)

The envelope condition in this simple ‘pseudo-dynamic’ case just states that the shadow price of fixed assets must be equal to the user costs of capital. This expression becomes much more complex in the case with explicit adjustment costs for $x_K$ or in real dynamic models with rational expectations (see Galeotti, 1996). The shadow price of capital is given by the negative of the term that measures the impact of capital inputs on short-run variable costs.

The next step consists in parameterizing the variable cost function $VC$, which shall be assumed to be translog with one aggregate capital stock $x_K$:

$$\log VC = \alpha_0 + \alpha_Y \log Y + \alpha_E \log (p_E/p_M) + \log p_M + \alpha_L \log (p_L/p_M) + \beta_K \log x_K + \alpha_I t + \frac{1}{2} \alpha_I t^2 + \frac{1}{2} \gamma_{YY} (\log Y)^2 + \frac{1}{2} \gamma_{LL} [\log (p_L/p_M)]^2$$

$$+ \gamma_{EL} \log (p_E/p_M) \log (p_L/p_M) + \frac{1}{2} \gamma_{EE} [\log (p_E/p_M)]^2 + \frac{1}{2} \gamma_{KK} (\log x_K)^2$$

$$+ \rho_{YL} \log Y \log (p_L/p_M) + \rho_{YE} \log Y \log (p_E/p_M) + \rho_{KL} \log Y \log x_K + \rho_{KE} \log Y \log (p_E/p_M) + \rho_{KL} \log Y \log (p_L/p_M) + \rho_{KE} \log Y \log (p_E/p_M)$$

(6)

In this equation, $p_E$, $p_L$ and $p_M$ are the prices of the variable inputs energy ($E$), labour ($L$) and materials ($M$), and the $\alpha$, $\beta$, $\gamma$ and $\rho$ are vectors of parameters to be estimated. The homogeneity restriction for the price parameters $\Sigma_i \gamma_{ij} = 0$, $\Sigma_j \gamma_{ij} = 0$ has already been
imposed in equation (6), so that the terms for the price of materials \( p_M \) have been omitted.
The usual parameter restrictions of the translog function imply in this case: \( \Sigma_i \alpha_i = 1, \Sigma_i \gamma_{ij} = 0, \Sigma_i \rho_{ti} = 0, \Sigma_i \rho_{yi} = 0, \Sigma_i \rho_{Ki} = 0 \), with \( i, j = LE, M \) (the variable factors). Assuming constant returns to scale implies another set of restrictions (Berndt and Hesse, 1986):

\[
\alpha_Y + \beta_K = 1, \quad \gamma_{KK} + \rho_{YK} = 0, \quad \gamma_{YY} + \rho_{YK} = 0, \quad \rho_{Yi} + \rho_{Ki} = 0, \quad \rho_{Yi} + \rho_{Ki} = 0,
\]

with \( i = L, E, M \), which have also been imposed here. That leads to a different more condensed cost function than laid out in equation (6). Alternatively one could also directly work with the unit cost function like Berndt et al. (1993).

As is well known, Shepard’s Lemma yields the cost share equations in the translog case, for example:

\[
\frac{\partial \log VC}{\partial \log p_E} = \frac{\partial VC}{\partial p_E} \frac{p_E}{VC} = \frac{p_E}{VC}
\]

which for the case of constant returns to scale can be written as:

\[
\frac{p_{IL}}{VC} = \left[ \alpha_L + \gamma_{LL} \log (p_L/p_M) + \gamma_{LE} \log (p_E/p_M) + \rho_{KL} \log \left( \frac{X_K}{Y} \right) + \rho_{tL} \right] \quad (7a)
\]
\[
\frac{p_{EE}}{VC} = \left[ \alpha_E + \gamma_{LE} \log (p_L/p_M) + \gamma_{EE} \log (p_E/p_M) + \rho_{KE} \log \left( \frac{X_K}{Y} \right) + \rho_{tE} \right] \quad (7b)
\]

The omitted cost share equation can simply be derived as the residual:

\[
p_{MM} = VC = 1 - p_{IL}/VC - p_{EE}/VC.
\]

The missing parameters for \( M \) can be calculated using those restrictions imposed. In equations (7) we can clearly identify two of the three components of technical change we want to deal with in this study, namely the input-biases (measured by \( \rho_{ti} \)) and the impact of the quasi fixed capital stock (measured by \( \rho_{KL}, \rho_{KE}, \rho_{KM} \)) on factor demand. The first set of parameters describes disembodied or autonomous technical change and the second embodied technical change brought about by the installation of new capital equipment. If the \( \rho_{ti} \) with \( i = L, E, M \) are positive, autonomous technical change is factor using. Positive parameter values for the \( \rho_{Ki} \) imply factor-using embodied technical change and can also be interpreted as capital–energy complementarity.

The variable cost equation (6) contains all components of technical change and shows their impact on overall unit costs. That comprises components of autonomous and embodied technical change that exert an influence on total unit costs as well as on factor demand. Autonomous technical change can be found for the capital stock (\( \rho_{K} \)) and for the factors (i.e. the factor biases \( \rho_{Li}, \rho_{iE} \) and \( \rho_{Mi} \)). Another source of autonomous technical change that only influences unit costs is TFP, measured by \( \alpha_i \) and \( \alpha_{ii} \). Embodied technical change only exerts an influence on factor demand measured by the same parameters as appear in the factor demand equations, namely \( \rho_{KL}, \rho_{KE} \) and \( \rho_{KM} \).

2.2. Optimal Capital Stock and Investment Demand

The envelope condition (5) must in the translog case be formulated in terms of the shadow value expression, i.e. the share of the \( ex \ ante \) and the \( ex \ post \) (= shadow value) return to capital in variable costs. We can first of all proceed by deriving the shadow value
expression in analogy to Berndt and Hesse (1986):

\[
\frac{\partial \log VC}{\partial \log \chi_K} = \frac{\partial VC}{\partial \chi_K} = \left[ \beta_K - \rho_{YK} \log \left( \frac{\chi_K}{Y} \right) + \rho_{KL} \log \left( \frac{p_L}{p_M} \right) + \rho_{KE} \log \left( \frac{p_E}{p_M} \right) + \rho_{tK} t \right]
\]  

(8)

This expression must be negative and represents the negative value of the shadow price cost shares (i.e. \( z_K \chi_K / VC \)), so that the shadow price \( z_K \) corresponds to \(- \partial VC / \partial \chi_K\). Berndt and Hesse (1986) proceed by stating that the ex post rate of return for the capital stock must be equal to the shadow price of the capital stock. That means that \( z_K \chi_K / VC \) in equation (8) is substituted by the observed ‘cost share’ of gross operating surplus (II):

\[
\frac{\Pi}{VC} = -\left[ \beta_K - \rho_{YK} \log \left( \frac{\chi_K}{Y} \right) + \rho_{KL} \log \left( \frac{p_L}{p_M} \right) + \rho_{KE} \log \left( \frac{p_E}{p_M} \right) + \rho_{tK} t \right]
\]  

(9)

The last part of the model presented here describes the adjustment process of the capital stocks to its long-run equilibrium level. First we can combine the envelope condition (5) with equation (8) to arrive at an expression for the optimal capital stock (\( \chi_K^* \)):

\[
\log \chi_K^* = -\frac{1}{\rho_{YK}} \left( \beta_K - \rho_{YK} Y + \rho_{KL} \log \left( \frac{p_L}{p_M} \right) + \rho_{KE} \log \left( \frac{p_E}{p_M} \right) + \rho_{tK} t + \frac{u_K \chi_K}{VC} \right)
\]  

(10)

Here, \( u_K \chi_K / VC \) represents the user cost of capital-share, where \( u_K = (r + \delta)p_I \). The optimal stock is influenced by scale effects (\( \rho_{YK} \)), by embodied (\( \rho_{KL} \) and \( \rho_{KE} \)) and autonomous (\( \rho_{tK} \)) technical change. If the parameter \( \rho_{Ki} \) is negative the industry features factor \( i \) saving, technical change and the optimal capital stock rise with an increase in the corresponding factor price. If the parameter \( \rho_{Ki} \) is positive the industry features capital-factor \( i \) complementarity and the optimal capital stock decreases with an increase in the corresponding factor price. Anyway it must be noted that in both cases an incentive for adjusting the capital stock exists.

Because the translog cost function chosen here does not incorporate adjustment costs for the capital stock, as in the models of Berndt et al. (1981) or Watkins and Berndt (1992), a flexible accelerator model in the spirit of Jorgenson (1963) shall be applied:

\[
\Delta \log \chi_{K,J} = \lambda \left[ \log \chi_{K,J}^* - \log \chi_{K,J-1} \right]
\]  

(11)

In this equation, the adjustment of the capital stock corrects past errors and the parameter \( \lambda > 0 \) guarantees a smooth adjustment process. That implies that starting from a point out of equilibrium the relationship between the shadow price term ( = the ex post return of capital) and the user cost term ( = the ex ante return of capital) must guarantee convergence towards equilibrium without an instantaneous jump to the equilibrium value. That might be explained by costs of adjusting the capital stock, which have not been made explicit in this approach. Reformulating (11) gives an expression for the level of the
capital stock:

\[
\log x_{K,t} = \lambda \log x_{K,t}^* + (1 - \lambda) \log x_{K,t-1}
\]  (12)

This expression could be further transformed into a general distributed lag formulation with decreasing weights of past errors for the current stock adjustment. The explicit investment equation is then derived by inserting equation (10) into equation (12):

\[
\log x_{K,t} = \\
\lambda \left[ -\frac{1}{\rho_{YK}} \left( \beta_K - \rho_{YK} \log Y + \rho_{KL} \log (p_L/p_M) + \rho_{KE} \log (p_E/p_M) + \rho_{tK} t + \frac{u_{KxK}}{V_C} \right) \right] \\
+ (1 - \lambda) \log x_{K,t-1}
\]  (13)

The full model presented here is made up of the following equations: (i) the variable cost function (6) with constant returns to scale imposed, (ii) the factor demand functions (7), (iii) the rate of return equation (9), and (iv) the investment demand function (13). This model will be used in what follows to analyse short-run dynamics in energy intensity as well as the adjustment process towards long-run equilibrium.

### 2.3. Impacts on Intra-industry Energy Efficiency

As in Sue Wing and Eckaus (2004), one can proceed to derive the price elasticities of energy intensity, as well as the fixed capital elasticity (measuring embodied technical change). With the use of these elasticities it is possible to compare the short-run case with the long-run equilibrium without explicitly analysing the adjustment path. As the main extension of this study consists of describing this adjustment path by the inclusion of an investment function, a method of ‘mid term’ elasticities is additionally applied, measuring the impact of prices on energy intensity along the adjustment path. The starting point is the formulation of energy intensity \( E/Y \) from the factor demand function for energy:

\[
\frac{E}{Y} = \frac{VC/Y}{p_E} \left[ \alpha_E + \sum_v \gamma_{vE} \log p_v + \rho_{YE} \log Y + \rho_{KE} \log x_K + \rho_{tE} t \right]
\]  (14)

Defining \( s_E = \alpha_E + \sum_v \gamma_{vE} \log p_v + \rho_{YE} \log Y + \rho_{KE} \log x_K + \rho_{tE} t \), the short-run price elasticity of this energy intensity with respect to a change in the price of a variable factor \( v = L, E, M \) is:

\[
\frac{\partial \log (E/Y)}{\partial \log p_v} = \frac{\partial (E/Y)}{\partial \log p_v} \frac{Y}{E} = \frac{\partial ((VC/Y)/p_E s_E)}{\partial \log p_v} \frac{Y}{E}
\]  (15)

The impact of quasi fixed capital on energy intensity can in a first step simply be assessed
by the following elasticity:

\[
\frac{\partial \log (E/Y)}{\partial \log x_k} = \frac{\partial (E/Y) Y}{\partial \log x_k E} = \frac{\partial ((VC/Y)/pE) s_E Y}{\partial \log x_k E}
\]

As the elasticity is derived as a compensated elasticity, i.e. under the ceteris paribus condition \(\partial \log Y/\partial \log p_E = 0\), the price elasticity of \(E/Y\) is the same as the price elasticity of \(E\):

\[
\varepsilon_{EE} = \frac{\partial \log (E/Y)}{\partial \log p_E} = \frac{s_E^2 - s_E + \gamma_{EE}}{s_E}
\]

(17)

Taking into account that the term \(\partial VC/\partial x_k\) equals the negative of the shadow price of capital \((- z_K)\) the elasticity of energy intensity to quasi fixed capital becomes:

\[
\varepsilon_{KE} = \frac{\partial \log (E/Y)}{\partial \log x_k} = \frac{\rho_{KE}}{s_E} - \frac{z_K K}{VC}
\]

(18)

Equation (18) reveals that it is not necessary for embodied technical change to be energy saving and that parameter \(\rho_{KE}\) is negative. It is sufficient that the relationship of this parameter to the cost share for energy is smaller than the cost share of the shadow price of capital. Therefore, for energy intensive industries (high cost share of energy) we might – even with small positive values of the parameter \(\rho_{KE}\) – find energy saving embodied technical change. An industry with large positive values of \(\rho_{KE}\) is characterized by capital-energy complementarity and energy intensity rises with a larger installed stock of equipment.

In line with other studies that differentiate between the short and long-run impact of energy prices or energy intensity (like Sue Wing and Eckaus, 2004) the long-run price elasticity of energy intensity (after capital stock has adjusted to its optimal level) can be written as:

\[
\eta_{EE} = \frac{\partial \log (E/Y)}{\partial \log p_E} = \left[\frac{\partial x_k^E \partial (E/Y)}{\partial \log p_E \partial \log x_k^E} \right] \frac{Y}{E} = -\frac{\rho_{KE}}{\rho_{YK}} \left[\frac{\rho_{KE}}{s_E} - \frac{z_K K}{VC}\right]
\]

(19)

Note that this is only one part of the long-run elasticity, namely the part brought about by capital stock adjustment, whereas the full long-run elasticity is given by the sum of the short-run elasticity \(\varepsilon_{EE}\) and \(\eta_{EE}\) as in Sue Wing and Eckaus, 2004. If scale effects are positive \((\rho_{YK} > 0)\), the long-run elasticity in equation (19) exhibits the same sign as the elasticity of energy intensity to the quasi fixed capital stock in equation (18), if \(\rho_{KE} < 0\), i.e. if an energy price increase induces an increase in the capital stock in order to save costs. If on the other hand \(\rho_{YK} < 0\) an industry could fail to have energy saving embodied technical change \((\varepsilon_{KE} > 0)\) and still exhibit negative values for the long-run elasticity \(\eta_{EE}\). This is due to capital stock adjustment, which also takes place in the case of capital-energy complementarity, although in the opposite direction. With capital-energy complementarity, an industry views an incentive to reduce the capital stock after an energy price increase, thereby reducing the energy intensity of
production. The extension in this study consists of incorporating this capital stock adjustment via an explicit inclusion of an investment function. That leads to the option of deriving elasticities of energy intensity in period \( t \) \( (E_t/Y_t) \) to energy price changes in \( \tau \) periods before period \( t \):

\[
e_{EE(\tau)} = \frac{\partial \log(E_t/Y_t)}{\partial \log p_{E,t-\tau}} = \left[ \frac{\partial \log x_{K,t} \partial(E_t/Y_t)}{\partial \log p_{E,t-\tau} \partial \log x_{K,t}} \right] \frac{Y}{E}
\]  

(20)

From the distributed lag formulation of the investment function (13) one can derive for the impact of past energy price changes on current capital stock:

\[
\frac{\partial \log x_{K,t}}{\partial \log p_{E,t-\tau}} = -\lambda (1 - \lambda)^\tau \frac{\rho_{KE}}{\rho_{YK}}
\]  

(21)

Due to the equilibrium condition \( \lambda (1 - \lambda)^\tau > 0 \) we get the same result as for the long-run elasticity \( (\eta_{EE}) \), namely an induced increase in the capital stock, if the term \( \rho_{KE}/\rho_{YK} \) is negative. For positive values of \( \rho_{YK} \) the term becomes negative if an industry is characterized by energy saving embodied technical change. If capital and energy are complements and \( \rho_{YK} > 0 \), the capital stock adjusts downwards to positive energy price shocks. Equation (21) also captures the instantaneous impact of energy prices on capital \((\tau = 0)\) given by the term \(-\lambda (\rho_{KE}/\rho_{YK})\). The long-run impact is given by the sum of the instantaneous and the lagged impacts of equation (21) and therefore is \(- (\rho_{KE}/\rho_{YK})\), which can also be seen from equation (19). Inserting equations (21) into (20) and combining with equation (18) gives the final expression for the impact of past energy price changes on current energy intensity brought about by capital stock adjustment:

\[
e_{EE(\tau)} = -\lambda (1 - \lambda)^\tau \frac{\rho_{KE}}{\gamma_{KK}} \left[ \frac{\rho_{KE}}{s_E} \frac{z_{K}K}{VC} \right]
\]  

(22)

The full elasticity of past energy prices on current energy intensity is then derived by summing over all impacts as given in equation (22) along the path from period \( \tau \) to period \( t \) including the instantaneous impact in \( \tau = 0 \):

\[\hat{e}_{EE} = \sum_{\tau} e_{EE(\tau)}\]  

(23)

This elasticity \( (\hat{e}_{EE}) \) can be seen as the main instrument by which one can trace back the path of energy intensity to price changes in the past (for example 5 years) and show how the difference between short- and long-run reactions to price changes builds up along the capital adjustment path.

3. Data and Estimation

The econometric estimation is carried out for the system comprising the variable cost function (6) with constant returns to scale, the factor demand functions (7), the rate of return equation (9) and the investment demand function (13) using the EUKLEMS dataset for
five selected EU countries: Denmark, Italy, Netherlands, Spain and UK. This country group comprises large and small European economies as well as countries that have reacted with ‘active’ energy saving policies (Denmark) and those with ‘passive’ policies retarding the impact of energy price shocks on the economy (Spain). With the Netherlands and the UK, the data set also contains two economies with large structural changes after energy price shocks, partly in the form of a shift towards domestic energy extraction and production. From Figure 1, one perceives a similar development pattern for energy intensity in manufacturing sectors of these countries besides the different policy influences.

The EU KLEMS database is one major result of the EUKLEMS-project where data on input structures at the detailed industry level (NACE 2 digit) have been collected for all 25 EU countries (see Timmer et al., 2007, for an overview). The basic data in the EUKLEMS database are in general available for 60 NACE two-digit industries from 1970 to 2004 for Denmark, Italy, the UK and from 1980 to 2004 for the Netherlands and Spain. Owing to some lack of data in some variables the aggregation level that can be chosen for a certain analysis will always be determined by the largest common denominator. In the case of this analysis that leads to an aggregation level of 28 industries for the five economies, out of which 13 are manufacturing sectors, to which the analysis has been limited here. These industries, and the corresponding industries from the EU KLEMS database are given in Appendix Table A1.

The variables of the EUKLEMS database used in this study are as follows. Values: $p_{EE}$ = intermediate energy inputs at current purchasers’ prices (in millions of local currency); $p_{MM}$ = intermediate material and service inputs at current purchasers’ prices (in millions of local currency); $p_{LL}$ = labour compensation (in millions of local currency). Volumes: $Y$ = gross output, volume indices (1995 = 100); $M$ = intermediate material and service inputs, volume indices (1995 = 100); $E$ = intermediate energy inputs, volume indices (1995 = 100); $L$ = labour services, volume indices (1995 = 100); $x_K$ = real gross fixed capital stock, 1995 prices; $p_I$ = gross fixed capital stock formation price index (1995 = 100); $\delta$ = rate of depreciation by assets.

The energy inputs therefore are measured as a Tornqvist index of quantity and not – as in other studies – as quantities of energy (joules, BTUs). Besides differences due to conceptual differences and different statistical sources between these two measures of energy, the Tornqvist quantity index might show a lower increase in energy inputs than the energy unit quantity measure. This is due to historical fuel shifts from energy carriers with low net caloric values to those with high net caloric values.

For estimating the model outlined here the inputs for intermediate material inputs (IIM) and intermediate service inputs (IIS) from the EUKLEMS database have been aggregated into one materials (M) category, and price indices have been calculated for all inputs. Additional data that have been used are data for the aggregate capital stock as well as an estimate for the user costs of capital in each industry, based on data for price indices of investment and depreciation rates. The real rate of return, $r$, in the user cost term $u_K = (r + \delta)p_I$ was assumed to be a constant value for all countries and periods of 4%. Alternatively, one could have used some business relevant interest rate and deflate it with the consumers’ price index for each country. That would have resulted in a higher variance of the user cost term. For the investment function therefore the EUKLEMS project provided important pieces of a data set for capital inputs of different assets and their characteristics (depreciation). The estimation procedure (Seemingly Unrelated Regression) yields 16 parameter values for each industry in each of the five countries.
4. Econometric Results

One important result is the derivation of the short-run own-price-elasticity of energy intensity as described in equation (17). Without imposing restrictions on the cost function (concavity) the estimation results do not yield negative own-price elasticities based on significant parameter estimates for all industries in all countries. As shown in Table 1 this short-run own price elasticity exhibits the expected negative sign in most industries in Italy, but fails to do so in the other countries, especially in Spain and the UK. One possible interpretation of this result in the context of this paper is that quantity reactions to price shocks in some industries are fully linked to the installation of new equipment and therefore no short-run quantity reactions can be found.

The short-run elasticities in Table 1 are also characterized by a large heterogeneity across industries as well as across the five countries. If one defines the industries ‘pulp and paper’, ‘chemicals’, ‘other non-metallic minerals’ and ‘basic metals’ as energy intensive, it is not at all clear that the short-run price elasticity is generally higher in energy intensive industries than in other manufacturing. This is only the case for ‘basic metals’ in Italy and Spain. On the other hand, the non-energy intensive industries ‘machinery’ and ‘electrical and optical equipment’ show relatively high short-run price elasticities (almost) in all countries. The heterogeneity of these elasticities for different European countries is also a result of the aggregation level. The actual product mix at this relatively aggregate level of industries might vary considerably across countries.

Table 2 reports the elasticity of energy intensity with respect to the quasi fixed capital input. The main result is that the capital stock only in three to four out of 13 manufacturing industries exerts an energy saving impact. The exception is Spain, where six industries exhibit a negative sign of this elasticity. The industries with negative signs of $\varepsilon_{KE}$ are generally not the same in the five countries, only ‘coke, refined petroleum, nuclear’ and ‘other non-metallic mineral’ show a negative elasticity of energy intensity with respect to fixed capital input in three out of the five countries. In Table 3 the corresponding parameter values ($\rho_{KE}$) for the impact of fixed capital inputs are laid down. It can be seen that although the elasticity is given by $(\rho_{KE}/s_E) - (z_KK/VC)$ it is mainly the first term of

| Industry                                | Italy | Denmark | UK    | Netherlands | Spain |
|-----------------------------------------|-------|---------|-------|-------------|-------|
| Food, beverages and tobacco             | -0.363| ++      | -1.402| -0.025      | ++    |
| Textiles, leather and foodwear          | -0.657| -0.191  | ++    | ++          | ++    |
| Wood and of wood and cork               | -0.674| ++      | -2.046| ++          | -0.726|
| Pulp, paper, printing and publishing    | -0.313| -0.116  | ++    | -0.170      | ++    |
| Coke, refined petroleum, nuclear        | -0.031| -0.011  | ++    | -0.0556     | ++    |
| Chemical and pharmaceuticals           | -0.905| ++      | ++    | ++          | -0.457|
| Rubber and plastics                     | -0.648| ++      | ++    | -0.560      | ++    |
| Other non-metallic mineral              | ++    | -0.150  | ++    | -0.133      | ++    |
| Basic metals and fabricated metal       | -0.926| ++      | -0.613| ++          | -0.977|
| Machinery nec                           | -0.666| -0.237  | -1.624| -4.491      | -0.822|
| Electrical and optical equipment        | -0.380| ++      | -0.336| -0.596      | -3.907|
| Transport equipment                     | -0.392| ++      | ++    | ++          | ++    |
| Manufacturing nec and recycling         | ++    | -0.109  | ++    | ++          | ++    |

+++: estimated parameters yield a positive own price elasticity.
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branches is characterized by positive elasticities of energy intensity to quasi-fixed capital and therefore by capital-energy complementarity.

In Tables 4 and 5 the importance of energy price changes for this influence of the capital stock on energy intensity is shown, after five years in Table 4 and in the long-run in Table 5. The generally low or in some cases even positive values for $\bar{e}_{EE}$ in Table 4 are mainly due to the lack of importance of the energy price for the investment decision (the optimal capital stock). This is partly compensated by the low adjustment parameters $\lambda$ (not shown here) in the investment function. In some industries and countries one finds a considerable elasticity of past energy prices on energy intensity. In those industries with $e_{KE} < 0$ this is brought about by embodied technical change. In the other industries with $e_{KE} > 0$ a negative sign of $\bar{e}_{EE}$ indicates an inverse capital stock adjustment. Firms face an incentive to reduce the capital stock with higher energy prices in these industries, thereby reducing energy intensity due to the capital-energy complementarity.

In order to evaluate the importance of the lagged price elasticity $\bar{e}_{EE}$ one must combine the elasticity presented in Table 4 with the actual past energy price shocks, which were about $+30\%$ to $+50\%$ (1980) for the corresponding industries in the five countries. Given a $50\%$ energy price shock in 1980 therefore means that, for example, the ‘non-metallic mineral’ industry in the UK had a 16\% lower energy intensity in 1985 due to this price shock. In the case of this particular industry in the UK this was brought about via embodied technical change. Other industries in the UK (‘pulp and paper’, ‘manufacturing nec and recycling’) also still exhibit large impacts on energy intensity five years after a price shock, but mainly due to energy-capital complementarity brought about by negative capital stock adjustment. It must be noted that this downward adjustment of the capital stock might be accompanied by negative output effects (depending on the parameter value $\alpha_{YK}$) and therefore high macroeconomic adjustment costs. The upward adjustment of the capital stock in the case of energy saving embodied technical change on the other hand should ease adjustment costs via technological change. However, this analysis only holds for the ceteris paribus elasticity, during the actual sample. Labour and material prices have also changed and might have induced an upward capital stock adjustment.

**Table 4.** Price elasticity of energy intensity after 5 years ($\tau = 5$), due to capital stock adjustment, $\bar{e}_{EE}$

| Industry                                    | Italy   | Denmark | UK       | Netherlands | Spain  |
|---------------------------------------------|---------|---------|----------|-------------|--------|
| Food, beverages and tobacco                 | -0.034  | 0.002   | 0.014    | 0.000       | 0.054  |
| Textiles, leather and footwear              | -0.011  | -0.010  | 0.242    | -0.005      | 0.000  |
| Wood and of wood work                       | 0.004   | -0.093  | -0.060   | 0.008       | 0.007  |
| Pulp, paper, printing and publishing        | -0.008  | -0.040  | -0.164   | 0.057       | 0.002  |
| Coke, refined petroleum, nuclear            | 0.141   | 0.001   | -0.001   | 0.000       | 0.000  |
| Chemical and pharmaceuticals               | 0.017   | 0.100   | 0.005    | 0.064       | 0.026  |
| Rubber and plastics                         | 0.007   | 0.000   | 0.042    | 0.635       | 0.000  |
| Other non-metallic mineral                  | 0.001   | 0.001   | -0.325   | 0.000       | 0.001  |
| Basic metals and fabricated metal          | 0.000   | 0.000   | 0.003    | 0.023       | 0.002  |
| Machinery nec                               | -0.021  | -0.009  | 0.062    | 0.057       | 0.003  |
| Electrical and optical equipment            | -0.008  | 0.009   | 0.007    | -1.573      | 0.007  |
| Transport equipment                         | -0.034  | 0.000   | 0.047    | -0.020      | 0.000  |
| Manufacturing nec and recycling             | 0.012   | 0.004   | -0.407   | -0.189      | 0.099  |
Comparing the results in Table 4 with those of Table 1 one finds that the importance of the lagged price elasticity might explain the non-existence of short-run negative price elasticities in some industries. This seems to be the case for the energy intensive industries in the UK. As shown in Table 1, no short-run negative price elasticity can be found for ‘pulp and paper’, ‘coke, refined petroleum, nuclear’ and ‘other non-metallic minerals’ in the UK, whereas in Table 4 we see negative price elasticities in these cases after 5 years. The same result of a negative price elasticity after 5 years without a short-run negative price elasticity can be found for ‘textiles, leather and footwear’, ‘transport equipment’ and ‘manufacturing nec and recycling’ in the Netherlands and for ‘wood and products of wood and cork’ in Denmark. The main difference between the Netherlands and the UK is that industries without negative short-run price elasticities and with capital-energy complementarity show negative long-run price elasticities in the UK but not in the Netherlands. That has to do with scale effects (measured by $r_{YK}$) in the capital stock adjustment process, which are negative in these industries in the Netherlands.

Table 5 contains the long-run price elasticity of energy intensity due to full adjustment of the capital stock to its long-run equilibrium value. A clear result is that the price elasticity after 5 years (Table 4) is much smaller than this long-run elasticity. This result is determined by the generally low parameter values for $\lambda$. The values of $\lambda$ are far below 1, indicating sluggish adjustment towards the optimal capital stock. This result is corroborated by large and long-lasting deviations of the shadow price cost share $z_k x_k / VC$ from the user cost of capital-share $u_k x_k / VC$ in the past. On the other hand the results in Table 5 further confirm the importance of capital stock adjustment for explaining the energy intensity reactions to energy price shocks, especially in the UK.

The estimation results reported in Table 6 additionally confirm earlier studies for the US such as Jorgenson and Fraumeni (1981) and Sue Wing and Eckaus (2004) concerning the existence of energy saving as well as energy using bias in technical change, $\rho_{tE}$. Generally, the parameter values for the bias in technical change are near zero, although significant in a large number of industries. In the light of these results one could conclude that an approach taking into account embodied technical change and capital stock adjustment only leaves a small part of technical change explained by the autonomous component.
As Figure 1 shows, energy intensity has decreased continuously in the manufacturing sector of the five countries until the end of the 1980s after the energy price shock of 1979/80. After 1990, the path of energy intensity decrease has become flatter. This picture is most clear for Italy, the Netherlands and Spain, whereas the UK shows a high variance of energy intensity during the 1970s. The generally rather low values of $\lambda$ result in a long lasting impact of an energy price shock on energy intensity as adjustment takes time. This is counterbalanced by the relatively low importance of energy prices for the investment decision, measured by the absolute value of the parameter $\rho_{KE}$. Obviously, the optimal capital stock is also determined by other factor prices and autonomous technical change.

If we compare our results to those of Sue Wing and Eckaus (2004) and Sue Wing (2007) for the US we find some similarities. Both studies calculate a long-run elasticity of energy intensity comprising the usual short-run elasticity plus the elasticity after full adjustment of actual to optimal capital stock. Their results for the manufacturing sector also contain small differences between short and long-run elasticities and in some cases even a reversal of the sign or higher short-run elasticities. This result is found in the case of using aggregate capital stock as the fixed input. They also deal with different assets (information technology, electrical equipment, machinery, vehicles and structures) and find a significant and important contribution of certain assets to a long-run impact of energy prices.

### Table 6. Parameter values for autonomous technical change in energy intensity ($\rho_{KE}$)

|                        | Italy  | Denmark | UK    | Netherlands | Spain   |
|------------------------|--------|---------|-------|-------------|---------|
| Food, beverages and    | 0.00***| 0.00*** | 0.00  | 0.00        | (0.00)  |
| tobacco                | (2.71) | (3.09)  | (−0.34)| (−0.48)    | (−1.23) |
| Textiles, leather and  | 0.00***| 0.00    | 0.00**| 0.00        | (0.00)  |
| footwear               | (3.95) | −0.28   | (3.25)| (0.07)     | (−0.55) |
| Wood and of wood and   | (0.15) | 0.00    | 0.01***| 0.00*       | 0.00    |
| cork                   | 0.00   | (0.95)  | (7.82)| (1.92)     | (1.40)  |
| Pulp, paper, printing  | 0.00** | 0.00    | 0.00**| 0.00*       | 0.00**  |
| and publishing         | −(2.49)|−(0.77) | (2.17)| (1.84)     | (2.00)  |
| Coke, refined petroleum, | 0.00** | 0.00*   | 0.01***| 0.00***     | 0.01*** |
| nuclear                | −(0.90)| (1.74)  | (3.45)| (−6.59)    | (3.79)  |
| Chemical and           | 0.00** | 0.00*   | 0.00**| 0.01***     | 0.00**  |
| pharmaceuticals       | −(2.44)| (1.68)  | (2.45)| (8.82)     | (6.55)  |
| Rubber and plastics    | 0.00***| 0.00    | 0.00**| 0.00        | 0.00    |
| Other non-metallic     | (4.50) | (1.07)  | (2.02)| (1.13)     | (0.69)  |
| mineral               | 0.00***| 0.00    | 0.00***| 0.00*       | 0.00    |
| Basic metals and       | −(8.53)|−(0.33) | (3.34)| (1.91)     | (0.18)  |
| fabricated metal       | 0.00   | 0.00    | 0.00***| 0.00***     | 0.00    |
| Machinery nec          | 0.00*  | 0.00**  | 0.00  | 0.00***     | 0.00*** |
|                       | (1.67) | (2.17)  | (1.11)| (5.26)     | (−4.20) |
| Electrical and optical | 0.00   | 0.00    | 0.00***| 0.00        | 0.00    |
| equipment              | (1.41) | (0.62)  | (−4.42)| (−0.32)    | (−1.30) |
| Transport equipment    | 0.00   | 0.00    | 0.00**| 0.00*       | 0.00    |
|                       | (0.18) |−(0.64) | (−2.59)|−(1.94)     | (−0.49) |
| Manufacturing nec and  | 0.00   | 0.00    | 0.00   | 0.00***     | 0.00    |
| recycling             | (1.36) |−(1.36) | (−1.30)|−(2.96)     | (−0.44) |

$t$-values in parenthesis. Significance: 10%*, 5%**, 1%***.
via embodied technical change. This is especially the case (across different industries) for vehicles, information technology and electrical equipment and could be seen as a strong plea for disaggregating the capital stock into single assets.

5. Conclusions

In this paper, energy intensity for five selected EU countries (Denmark, Italy, the Netherlands, Spain and the UK) has been analysed by applying a Translog variable cost function setting to the new EUKLEMS dataset. The purpose was to trace back the impact of past energy price shocks on energy-saving technical change embodied in capital goods and to explain long lasting developments in energy intensity after energy price shocks. The central methodological innovation compared to existing studies was the incorporation of an explicit investment function into the model. This investment equation explicitly describes the adjustment path and therefore the duration of this process. We found that the adjustment process of actual to optimal capital stock in most industries is long-lasting and sluggish. This is in line with the stylized fact of long-term energy intensity adjustments after energy price shocks.

The main conclusion of the results presented here is that European manufacturing industries can be classified into two groups. One small group of industries exhibiting energy-saving technical change embodied in capital goods and a larger group characterized by energy-capital complementarity. In both groups, capital stock adjustment plays an important role, but this process cannot be entirely explained as induced by energy prices. This is mainly due to the low weight of energy prices in the derived expression for the optimal capital stock. However, given the large price shocks at the beginning of the 1980s a considerable impact can still be found also with low elasticity values for price induced adjustment.

An important insight of a framework with explicit modelling of the capital stock adjustment process is that this adjustment in the case of embodied technical change is the opposite of the adjustment in the case of capital-energy complementarity. In the latter case, the capital output ratio adjusts downwards, leading to a decrease in energy intensity due to the complementarity of both factors. What should be further investigated in future research is the difference in adjustment costs between these two processes. It might also be found that in a country where most industries are characterized by capital-energy complementarity, the structural change component explains a larger part of aggregate energy intensity development. Another important finding is that capital stock adjustment is essential for energy saving in some industries where no short-run negative price elasticity of energy intensity could be found. In these industries, the reactions of energy intensity to energy price shocks can only occur via adjustment in the capital stock and cannot be immediate.

As other studies for the US (Sue Wing and Eckaus, 2004; Sue Wing, 2007) also indicate, more significant parameter estimates for energy-saving embodied technical change might be found when the capital stock is split up into different asset categories. This extension in turn would also require to be complemented by a further development of the theoretical model. Investment functions for different assets would have as a precondition a methodology of allocating the aggregate ex post return to total capital (given as gross operating surplus minus labour-compensation for self-employed from national accounts) across the different assets. This task could probably best be integrated into a more complex
dynamic cost function framework explicitly including adjustment costs and expectation formation.

Another part of the analysis where further disaggregation could lead to new insights is the classification of industries. The industry classification applied here within the manufacturing sector does not allow dealing with energy intensive activities separately, which is owing to the lack of data for some of the needed variables for the framework applied here. This is the case for some of the energy intensive branches identified in this study, namely ‘pulp and paper’, ‘chemicals’, ‘other non-metallic minerals’ and ‘basic metals’. These industries all comprise energy intensive and non-energy intensive activities. A more detailed analysis therefore awaits the development of a more disaggregate dataset.

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Notes

1This database is one major result of the EUKLEMS-project where data on input structures at the detailed industry level (NACE 2 digit) have been collected for all 25 EU countries (the project is described at: www.euklems.net). These input data also include labour inputs by skills and capital inputs by assets in order to measure the quality of inputs.

2Details of the estimation results are available from the author upon request.

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**Appendix**

| NACE | Description | Description |
|------|-------------|-------------|
| 15t16 FOOD , BEVERAGES AND TOBACCO | Food, beverages and tobacco |
| 15   Food and beverages          | Textiles, leather and foodwear |
| 16   Tobacco                      | |
| 17t19 TEXTILES, TEXTILE, LEATHER AND FOOTWEAR | |
| 17t18 Textiles and textile       | Wood and of wood and cork |
| 17   Textiles                    | Pulp, paper, printing and publishing |
| 18   Wearing Apparel, Dressing And Dying Of Fur | |
| 19   Leather, leather and footwear | |
| 20   WOOD AND OF WOOD AND CORK   | |
| 21t22 PILP, PAPER, PAPER, PRINTING AND PUBLISHING | |
| 21   Pulp, paper and paper       | |
| 22   Printing, publishing and reproduction | |
| 221  Publishing                  | |
| 22x  Printing and reproduction   | |
| 23t25 CHEMICAL, RUBBER, PLASTICS AND FUEL | Coke, refined petroleum, nuclear |
| 23   Coke, refined petroleum and nuclear fuel | Chemicals and pharmaceuticals |
| 24   Chemicals excluding pharmaceuticals | Chemicals and pharmaceuticals |
| 24x  Chemicals excluding pharmaceuticals | Chemicals and pharmaceuticals |
| 25   Rubber and plastics         | Rubber and plastics |

*(Table continued)*
Table A1.  Continued

| Code | Description                                      | Description                      |
|------|--------------------------------------------------|-----------------------------------|
| 26   | OTHER NON-METALLIC MINERAL                       | Other non-metallic mineral        |
| 27   | Basic metals                                    | Basic metals and fabricated metal|
| 28   | Fabricated metal                                |                                   |
| 29   | MACHINERY, NEC                                  |                                   |
| 30   | ELECTRICAL AND OPTICAL EQUIPMENT                | Electrical and optical equipment  |
| 31   | Office, accounting and computing machinery      |                                   |
| 32   | Electrical engineering                          |                                   |
| 33   | Electrical machinery and apparatus, nec         |                                   |
| 34   | Insulated wire                                  |                                   |
| 35   | Other electrical machinery and apparatus nec     |                                   |
| 36   | Radio, television and communication equipment   |                                   |
| 37   | Electronic valves and tubes                     |                                   |
| 38   | Telecommunication equipment                     |                                   |
| 39   | Radio and television receivers                  |                                   |
| 40   | Medical, precision and optical instruments      |                                   |
| 41   | Scientific instruments                          |                                   |
| 42   | Other instruments                               |                                   |
| 43   | TRANSPORT EQUIPMENT                             | Transport equipment               |
| 44   | Motor vehicles, trailers and semi-trailers      |                                   |
| 45   | Other transport equipment                       |                                   |
| 46   | Building and repairing of ships and boats       |                                   |
| 47   | Aircraft and spacecraft                         |                                   |
| 48   | Railroad equipment and transport equipment nec   |                                   |
| 49   | MANUFACTURING NEC; RECYCLING                    | Manufacturing nec and recycling   |
| 50   | Manufacturing nec                               |                                   |
| 51   | Recycling                                       |                                   |
| 52   |                                                 |                                   |