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Technical Change, Investment and Energy Intensity

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Abstract

This paper analyzes the role of different components of technical change on energy intensity by applying a Translog variable cost function setting to the new EU KLEMS dataset for 3 selected EU countries (Italy, Finland and Spain). The framework applied represents an accounting of technical change components, comprising autonomous as well as embodied and induced technical change. The inducement of embodied technical change is introduced by an equation for the physical capital stock that is a fixed factor in the short-run. The dataset on capital services and user costs of capital in EUKLEMS enables explaining capital accumulation depending on factor prices. The model can be used for explaining and tracing back the long-run impact of prices and technical change on energy intensity.

Contents

1. INTRODUCTION

Decomposition of the development of energy intensity is one main application of input-output analysis. This line of research focuses on decomposition of aggregate energy intensity into a technological and a structural change component (Ang and Zhang, 2000, 2006). The general result of these studies is that the contribution of the two components also varies between different periods. In "low energy price periods" the contribution of the structural component becomes increasingly important. The focus in this discussion was on appropriate decomposition methodology especially on the theoretical background of different indices.

Another line of the literature deals with explaining and further decomposing the technical change component within a cost function and factor demand framework applied to disaggregate KLEM datasets. 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. 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. Welsch and Ochsen (2005) in a Translog function approach allow for biased technological change and treat capital as a fully adjusting factor. Sue Wing and Eckaus (2004) in a restricted variable cost function approach (Berndt *et al.*, 1981; Watkins and Berndt, 1992) differentiate between different types of technical

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change (biased and embodied technical change) and due to their treatment of capital as a short-run fixed factor 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.

To summarize, there is broad empirical evidence on the importance of the structural component on energy intensity in input-output analysis and on the role of embodied and biased technical change within the KLEM factor demand function framework. As all approaches focus on the aspect of how embodied and induced technical change is influenced by energy prices in the *long-run*, the dynamic adjustment of the capital stock to its long-run equilibrium level has not been analyzed yet. This extension would allow quantifying the role of energy prices for technical progress in a framework accounting also for induced technical change. 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 concept of inducement of technical change used in this paper therefore is one of "price-induced" (Sue Wing, 2006) and embodied in the (physical) capital stock. Alternative formulations deal with induced technical change as embodied in the stock of knowledge (cumulated R&D expenditure) or explain it by applying time series models such as Carraro and Sartore (1986) and Boone *et al*. (1996). Several attempts can be found in the literature to 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)).

The main feature in this paper therefore is the extension of studies dealing with the long-run, such as Sue Wing and Eckaus (2004), by adding a consistent investment equation and applying that to a new preliminary KLEMS dataset for selected European countries with long time series (Finland, Italy and Spain). An important empirical feature of the application in this paper is that for explaining investment one can take advantage of the extensive and elaborate data work on adequate measuring of capital inputs in the EUKLEMS project.

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 types 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 like 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 behavior 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) such as in the work of Berndt *et al*. (1981) as well as 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 or again into a pseudo-dynamic *ex post* adjustment model. 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 first type of "pseudo-dynamic" model shall be used, where the capital stock is adjusted *ex post* to its optimal level with fixed parameters of adjustment.

2.1 Cost function and factor demand

The representative producers in each industry all face a cost function, G, comprising short-run variable costs, $VC\left[p_v, x_K, Y, t\right]$, as well as expenditure for (aggregate) investment, I, with price index of (aggregate) investment goods, p_I :

$$G = VC\left[p_v, x_K, Y, t\right] + p_I I \,, \tag{1}$$

where $\mathbf{p_v}$ is a vector of variable input prices, x_K is the level of the quasi-fixed input to production, Y is the level of output and t is time. Note then 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, δ, we have:

$$G = VC\left[p_v, x_K, Y, t\right] + p_I(\dot{x}_K + \delta x_K) \,. \tag{2}$$

The producers choose a time path of x_K to minimize discounted costs over a time horizon τ for which values for the exogenous variables are given:

$$\min \int_{\tau}^{\infty} e^{-r(t-\tau)} \left[VC_t(p_v, x_K, Y, t) + p_I(\dot{x}_K + \delta x_K)\right] dt \,, \tag{3}$$

where $\dot{x}_K$ represents the change in x_K.

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:

$$\frac{\partial VC}{\partial p_v} = v \tag{4}$$

$$-\frac{\partial VC}{\partial x_K} = (r + \delta) p_I \,. \tag{5}$$

The envelope condition in this simple, "pseudo-dynamic" case just states that the shadow price of fixed assets must equal the user costs of capital. This expression becomes much more complex in the case with explicit adjustment costs for $\dot{x}_K$ 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:

$$
\begin{aligned}
\log VC = {} & \alpha_0 + \alpha_Y \log Y + \alpha_E \log(p_E / p_M) + \log p_M + \alpha_L \log(p_L / p_M) \\
& + \beta_K \log x_K + \alpha_t t + \frac{1}{2}\alpha_{tt} t^2 + \frac{1}{2}\gamma_{YY}(\log Y)^2 + \frac{1}{2}\gamma_{LL}(\log(p_L / p_M))^2 + \\
& + \gamma_{LE}\log(p_L / p_M)\log(p_E / p_M) + \frac{1}{2}\gamma_{EE}(\log(p_E / p_M))^2 + \frac{1}{2}\gamma_{KK}(\log x_K)^2 + \\
& + \rho_{YL}\log Y \log(p_L / p_M) + \rho_{YE}\log Y \log(p_E / p_M) + \\
& + \rho_{YK}\log Y \log x_K + \rho_{KL}\log x_K \log(p_L / p_M) + \rho_{KE}\log x_K \log(p_E / p_M) + \\
& + \rho_{tY} t \log Y + \rho_{tK} t \log x_K + \rho_{tL} t \log(p_L / p_M) + \rho_{tE} t \log(p_E / p_M)
\end{aligned}
\tag{6}
$$

In this equation p_E, p_L and p_M are the prices of the variable inputs energy (*E*), labor (*L*), and materials (*M*), and the α, β, γ and ρ are vectors of parameters to be estimated. The homogeneity restriction for the price parameters $\sum_i \gamma_{ij} = 0$, $\sum_j \gamma_{ij} = 0$ has already been imposed in (6), so that the terms for the price of materials, p_M, have been omitted. As is well known, Shepard's Lemma yields the cost share equations in the Translog case, for example: $\frac{\partial \log VC}{\partial \log p_E} = \frac{\partial VC}{\partial p_E}\frac{p_E}{VC} = \frac{p_E E}{VC}$:

$$
\begin{aligned}
\frac{p_L L}{VC} &= \left[\alpha_L + \gamma_{LL}\log(p_L / p_M) + \gamma_{LE}\log(p_E / p_M) + \rho_{YL}\log Y + \rho_{KL}\log x_K + \rho_{tL} t\right] \\
\frac{p_E E}{VC} &= \left[\alpha_E + \gamma_{LE}\log(p_L / p_M) + \gamma_{EE}\log(p_E / p_M) + \rho_{YE}\log Y + \rho_{KE}\log x_K + \rho_{tE} t\right]
\end{aligned}
\tag{7}
$$

The omitted cost share equation can simply be derived as the residual: $\frac{p_M M}{VC} = 1 - \frac{p_L L}{VC} - \frac{p_E E}{VC}$. The usual parameter restrictions of the Translog function imply in this case:

$$\sum_i \alpha_i = 1,\ \sum_i \gamma_{ij} = 0,\ \sum_j \gamma_{ij} = 0,\ \sum_i \rho_{ti} = 0,\ \sum_i \rho_{Yi} = 0,\ \sum_i \rho_{Ki} = 0$$

with *i,j* = *L*, *E*, *M* (the variable factors). Assuming constant returns to scale implies another set of restrictions (Berndt and Hesse, 1986): $\alpha_Y + \beta_K = 1$, $\gamma_{KK} + \rho_{YK} = 0$, $\gamma_{YY} + \rho_{YK} = 0$, $\rho_{tY} + \rho_{tK} = 0$, $\rho_{Yi} + \rho_{Ki} = 0$, with *I* = *L*, *E*, *M*, which have not been imposed here. The missing parameters for *M* can be calculated using those restrictions imposed. In (7) we can clearly identify two of the three components of technical change we want to deal with in this study, namely the biases (measured by ρ_{tL}, ρ_{tE} and ρ_{tM}) and the impact of embodied technical change (measured by ρ_{KL}, ρ_{KE}, ρ_{KM}) on factor demand.

The variable cost equation (7) 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 output (ρ_{tY}), for the capital stock (ρ_{tK}) and for the factors (*i.e.* the factor biases ρ_{tL}, ρ_{tE} and ρ_{tM}). Another source of autonomous technical change that only influences unit costs is TFP, measured by α_t and α_{tt}. Embodied technical change only exerts an influence on factor demand measured by the same parameters as appear in the factor demand equations, namely ρ_{KL}, ρ_{KE} and ρ_{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* (the 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):

$$\frac{\partial \log VC}{\partial \log x_K} = \frac{\partial VC}{\partial x_K}\frac{x_K}{VC} = -\left[\beta_K + \gamma_{KK}\log x_K + \rho_{YK}\log Y + \rho_{KL}\log(p_L / p_M) + \rho_{KE}\log(p_E / p_M) + \rho_{tK}t\right]. \quad (8)$$

This expression must be negative and represents the negative value of the shadow price cost shares, $\frac{z_K x_K}{VC}$, so that the shadow price, z_K, correspond to $-\frac{\partial VC}{\partial x_K}$.

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 $\frac{z_K x_K}{VC}$ in equation (8) is substituted by the observed "cost share" of gross operating surplus (*Π*):

$$\frac{\Pi}{VC} = -\left[\beta_K + \gamma_{KK}\log x_K + \rho_{YK}\log Y + \rho_{KL}\log(p_L / p_M) + \rho_{KE}\log(p_E / p_M) + \rho_{tK}t\right]. \quad (9)$$

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 (x_K^*):

$$\log x_K^* = -\frac{\beta_K + \rho_{YK}\log Y + \rho_{KL}\log(p_L / p_M) + \rho_{KE}\log(p_E / p_M) + \rho_{tK}t + \frac{u_K x_K}{VC}}{\gamma_{KK}}. \quad (10)$$

In equation (10), $\frac{u_K x_K}{VC}$ represents the share of the user cost of capital in the variable cost, where $u_K = (r+\delta)p_I$. As the Translog cost function chosen here does not incorporate adjustment costs for the capital stock, as in the models of Berndt, Morrison and Watkins (1981) or Watkins and Berndt (1992), a flexible accelerator model in the spirit of Jorgenson (1963) shall be applied:

$$\Delta \log x_{K,t} = \lambda\left[\log x_{K,t}^* - \log x_{K,t-1}\right]. \quad (11)$$

In equation (11) 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 equation (11) gives an expression for the level of the capital stock:

$$\log x_{K,t} = \lambda \log x^{*}_{K,t} + (1-\lambda)\log x_{K,t-1}\,. \tag{12}$$

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 (10) into (12):

$$\log x_{K,t} = \lambda \left[-\frac{\beta_K + \rho_{YK}\log Y + \rho_{KL}\log(p_L/p_M) + \rho_{KE}\log(p_E/p_M) + \rho_{tK}t + \dfrac{u_K x_K}{VC}}{\gamma_{KK}} \right] + \tag{13}$$
$$+(1-\lambda)\log x_{K,t-1}$$

The full model presented here consists of the following equations: (i) the variable cost function (6), (ii) the factor demand functions (7), (iii) the rate of return equation (9), and (iv) the investment demand function (13). This model shall be used in what follows to analyze short-run dynamics in energy intensity as well as the adjustment process towards long-run equilibrium in Italy, Finland and Spain.

2.3 Impacts on intra-industry energy efficiency

As in Sue Wing and Eckaus (2004), one can proceed by deriving the elasticities of energy intensity on prices, as well as on embodied and disembodied technical change. With the use of these elasticities it is possible to compare the short-run case with the long-run equilibrium without explicitly analyzing 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. An alternative methodology would be to apply different decomposition methods, as in the one proposed by Sue Wing and Eckaus (2004) or the similar method of Welsch and Ochsen (2005). The starting point is the formulation of energy intensity E/Y from the factor demand function for energy:

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

The short-run elasticity of this energy intensity with respect to a change in the price of a variable factor $v = L, E, M$ is:

$$\frac{\partial \log(E/Y)}{\partial \log p_v} = \frac{\partial (E/Y)}{\partial \log p_v}\frac{Y}{E} = \frac{\partial\left(\dfrac{VC/Y}{p_E}s_E\right)}{\partial \log p_v}\frac{Y}{E}. \tag{15}$$

The impact of embodied technical change on energy intensity can in a first step simply be assessed by the following elasticity:

$$\frac{\partial \log(E/Y)}{\partial \log x_k} = \frac{\partial (E/Y)}{\partial \log x_k}\frac{Y}{E} = \frac{\partial\left(\dfrac{VC/Y}{p_E}s_E\right)}{\partial \log x_k}\frac{Y}{E}. \tag{16}$$

In equations (15) and (16) the cost share equation for energy, $\left[\alpha_E + \sum_v \gamma_{vE}\log p_v + \rho_{YE}\log Y + \rho_{KE}\log x_K + \rho_{tE}t\right]$, has been substituted by the term s_E.

As the elasticity is derived as a compensated elasticity, *i.e.* under the *ceteris paribus* condition $\frac{\partial \log Y}{\partial \log p_E} = 0$, the elasticity of E/Y to changes in p_E is the same as the elasticity of E:

$$\varepsilon_{EE} = \frac{\partial \log(E/Y)}{\partial \log p_E} = \frac{s_E^2 - s_E + \gamma_{EE}}{s_E}. \tag{17}$$

Taking into account that the term $\frac{\partial VC}{\partial x_K}$ equals the negative of the shadow price of capital ($-z_K$), the elasticity of energy intensity to embodied technical change becomes:

$$\varepsilon_{KE} = \frac{\partial \log(E/Y)}{\partial \log x_k} = \frac{\rho_{KE}}{s_E} - \frac{z_K K}{VC}. \tag{18}$$

Equation (18) reveals that it is not a necessary condition for embodied technical change to be energy-saving, and that the parameter for capital in the factor share equation (ρ_{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 ρ_{KE}, find energy-saving embodied technical change.

This analysis is in line with other studies that differentiate between the short- and long-run impact of energy prices on energy demand or energy intensity (*e.g.*, Sue Wing and Eckaus, 2004). The extension in this study in terms of the explicit inclusion of an investment function leads to the option of deriving elasticities of energy intensity in period t (E_t/Y_t) to energy price changes in τ periods before period t. This can be done by taking into account the adjustment in the capital stock to changes in energy prices as given in investment function (13) and combining this impact with the elasticity of embodied technical change as given in equation (18):

$$\varepsilon_{EE(\tau)} = \frac{\partial \log(E_t / Y_t)}{\partial \log p_{E,t-\tau}} = \left[\frac{\partial \log x_{K,t}}{\partial \log p_{E,t-\tau}} \frac{\partial (E_t / Y_t)}{\partial \log x_{K,t}} \right] \frac{Y}{E}. \tag{19}$$

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:

$$\frac{\partial \log x_{K,t}}{\partial \log p_{E,t-\tau}} = -\lambda \left(1-\lambda\right)^{\tau} \frac{\rho_{KE}}{\gamma_{KK}}. \tag{20}$$

Due to the equilibrium condition the parameter λ is restricted to be positive and the impact of energy price increases in the past on the capital stock are positive, if the term ρ_{KE}/γ_{KK} is negative. Equation (20) could also capture the instantaneous impact of energy prices on capital ($\tau = 0$), which is given by $-\lambda \frac{\rho_{KE}}{\gamma_{KK}}$. The long-run impact is given by the sum of this instantaneous and the lagged impacts of equation (20) and therefore is $-\frac{\rho_{KE}}{\gamma_{KK}}$, which can also be seen from (10). Reinserting equation (20) into (19) and combining with (18) gives the final expression for the impact of past energy price changes on current energy intensity brought about by embodied technical change:

$$\varepsilon_{EE(\tau)} = -\lambda \left(1-\lambda\right)^{\tau} \frac{\rho_{KE}}{\gamma_{KK}} \left[\frac{\rho_{KE}}{s_E} - \frac{z_K K}{VC} \right]. \tag{21}$$

The full elasticity of past energy prices on current energy intensity is then derived by summing up over all impacts as given in equation (21) along the path from period τ to period t (without including the instantaneous impact in $\tau = 0$):

$$\bar{\varepsilon}_{EE} = \sum_{\tau} \varepsilon_{EE(\tau)}. \tag{22}$$

This elasticity ($\bar{\varepsilon}_{EE}$) 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 explain the difference between short- and long-run reactions to price changes.

One could further also derive the elasticity of energy intensity to autonomous technical change by applying the formula $\frac{\partial (E/Y)}{\partial t} \frac{Y}{E} = \frac{\partial \left(\frac{VC/Y}{p_E} s_E \right)}{\partial t} \frac{Y}{E}$. This elasticity not only depends on the bias of technical change towards energy but also on the TFP-impact on variable costs.

3. DATA AND ESTIMATION RESULTS

The econometric estimation is carried out for the system comprising the variable cost function (6), the factor demand functions (7), the rate of return equation (9), and the investment demand function (13) using the preliminary dataset of the EUKLEMS project[1] for those EU countries with longest time series available: Italy (1970-2004), Finland (1970-2003) and Spain (1980-2004). The basic data in the EUKLEMS database are in general available for 60 NACE 2 digit industries. Due 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 in each of the three economies (Italy, Finland and Spain) out of which 13 are manufacturing sectors, to which this analysis has been limited. The core variables in EUKLEMS are:

Values

GO	Gross output at current basic prices (in millions of local currency)
II	Intermediate inputs at current purchasers' prices (in millions of local currency)
IIE	Intermediate energy inputs at current purchasers' prices (in millions of local currency)
IIM	Intermediate material inputs at current purchasers' prices (in millions of local currency)
IIS	Intermediate service inputs at current purchasers' prices (in millions of local currency)
VA	Gross value added at current basic prices (in millions of local currency)
LAB	Labor compensation (in millions of local currency)
CAP	Capital compensation (in millions of local currency)

Volumes

GO_QI	Gross output, volume indices, 1995 = 100
II_QI	Intermediate inputs, volume indices, 1995 = 100
IIE_QI	Intermediate energy inputs, volume indices, 1995 = 100
IIM_QI	Intermediate materials inputs, volume indices, 1995 = 100
IIS_QI	Intermediate serviceinputs, volume indices, 1995 = 100
VA_QI	Gross value added, volume indices, 1995 = 100
LAB_QI	Labor services, volume indices, 1995 = 100
CAP_QI	Capital services, volume indices, 1995 = 100
LP_I	Gross value added per hour worked, volume indices, 1995 = 100

For estimating the model outlined here the inputs for intermediate material inputs (IIM) and intermediate service inputs (IIS) have been aggregated into one materials (M) category and price indices have been calculated for all inputs. Additional data available 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 5 different assets (investment and depreciation) and for interest rates in the business sector. The EU KLEMS project has been inspired by the work of Jorgenson on growth accounting for the US (*e.g*, Jorgenson, Ho and Stiroh, 2003) and therefore puts special emphasis

[1] This dataset has been made available by the EUKLEMS project team at the University of Groningen and I am especially indebted to Marcel Timmer for supplying me with these data.

on measuring the effective inputs (input services), especially for labor and capital. That leads to a rich data set for capital inputs of different assets and their corresponding rates of return (*ex ante* and *ex post*), which is a precondition for estimating the investment equation (13). The estimation procedure (SURE) yields 22 parameter values for each industry in each of the three countries Italy, Finland and Spain.

One important result is the derivation of the short-run own price-elasticity of energy intensity as described in equation (17). Most of the elasticities show the right sign and are based on significant parameter estimates.[2] The analysis has been limited here to the manufacturing sector, where energy plays a more important role in production than for (most) services. These short-run elasticities show a large heterogeneity across industries as well as across the three countries. If one defines the industries "pulp and paper," "coke, refined petroleum," "chemicals," "other non-metallic minerals" and "basic metals" as energy intensive, it is not at all clear that the short-run elasticity is generally higher in these industries than in other manufacturing (**Table 1**). This is only the case for "pulp and paper" in Spain and "basic metals" in Italy.

Table 1. Own price elasticities of energy intensity (short-run), ε_{EE}. (Comma indicates decimal separator.)

	Italy	Finland	Spain
Food, beverages and tobacco	-0,507	-0,346	-0,109
Textiles, leather and footwear	-0,710	-0,328	-0,921
Wood and of wood and cork	-0,636	-0,639	-0,458
Pulp, paper, printing and publishing	-0,304	-0,882	-1,236
Coke, refined petroleum, nuclear	-0,074	-0,166	-0,315
Chemicals and pharmaceuticals	-0,819	-0,253	-0,505
Rubber and plastics	-0,456	-0,288	-0,187
Other non-metallic mineral	-0,245	-0,429	-0,683
Basic metals and fabricated metal	-1,170	-0,583	-0,919
Machinery nec	-0,898	-0,557	-0,490
Electrical and optical equipment	-0,835	-0,503	-3,975
Transport equipment	-0,596	-0,312	-1,431
Manufacturing nec and recycling	-0,507	-0,619	-1,111

The estimation results for the parameters measuring embodied as well as autonomous technical change are only significant and only show energy-saving technical change for a limited number of industries. The anticipated negative sign for the embodied technical change parameter (ρ_{KE}) is found in 5 out of 13 manufacturing industries in Italy, but only in 3 industries in Spain. For Finland most of the industries show this negative sign for embodied technical change, though not based on significant estimation results. An unresolved and probably important issue in this model's estimates is a possible multicollinearity problem between the capital stock and the deterministic trend. Welsch and Ochsen (2005), who have tested for multicollinearity between a deterministic trend and other variables in the Translog model, have shown that this can be an important issue.

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

The first conclusion therefore is that energy-saving embodied technical change plays some role for energy intensity in certain industries, but is not a general phenomenon in production. The estimation results reported in **Table 2** additionally confirm other former 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, ρ_{tE}.

Table 3 reports the elasticity of energy intensity with respect to embodied technical change in those industries, where the parameter (ρ_{KE}) has a negative sign, *i.e.* embodied technical change is energy-saving. These elasticities are not concentrated among the energy intensive industries and also do not in general show higher values in energy intensive industries. Especially Finland and Spain reveal high elasticities of energy intensity with respect to embodied technical change in non-energy intensive industries.

As has been emphasized in the theoretical part of this paper the main extension compared to existing studies is the incorporation of an investment function into the system. The estimation results for the parameters concerning capital (which play an important role in the investment function) generally show the importance of additions to the capital stock for total variable costs (γ_{KK}) as well as for the variable inputs (ρ_{KL}, ρ_{KE}).

Only some industries in the three countries exhibit negative signs for ρ_{KL}, so that embodied technical change is generally also not labor-saving. The absolute magnitude of the two parameters ρ_{KL}, and ρ_{KE} plays an important role for the impact of price changes in variable factors for investment decisions. The general picture is that the role of the price of labor is more

Table 2. Parameter values for embodied (ρ_{KE}) and autonomous technical change (ρ_{tE}) in energy intensity. (t-values in parenthesis)

	Italy ρ_{KE}	Italy ρ_{tE}	Finland ρ_{KE}	Finland ρ_{tE}	Spain ρ_{KE}	Spain ρ_{tE}
Food, beverages and tobacco	0,0443	0,0004	-0,0381	0,0004	0,0224	-0,0003
	(2,88)	(0,48)	(-3,11)	(1,82)	(1,69)	(-0,54)
Textiles, leather and footwear	0,0176	0,0001	-0,0346	0,0000	-0,0105	-0,0007
	(2,46)	(0,44)	(-3,57)	(-0,15)	(-0,44)	(-1,46)
Wood and of wood and cork	-0,0001	-0,0008	-0,0005	-0,0003	-0,1412	0,0062
	(-0,01)	(-2,20)	(-0,03)	(-0,71)	(-6,18)	(5,54)
Pulp, paper, printing and publishing	-0,0047	0,0009	0,0055	-0,0051	0,1013	-0,0041
	(-0,41)	(1,23)	(0,30)	(-1,63)	(2,49)	(-2,92)
Coke, refined petroleum, nuclear	-0,0094	0,0018	-0,0287	-0,0026	0,0549	-0,0097
	(-0,34)	(1,08)	(-1,44)	(-1,34)	(1,81)	(-5,21)
Chemicals and pharmaceuticals	0,1173	-0,0006	0,1275	-0,0013	0,0073	-0,0022
	(8,21)	(-0,64)	(7,51)	(-0,65)	(0,39)	(-1,20)
Rubber and plastics	0,0119	0,0002	-0,0109	0,0003	0,0361	-0,0006
	(1,06)	(0,34)	(-1,02)	(0,82)	(2,42)	(-0,50)
Other non-metallic mineral	-0,0173	0,0011	-0,0034	-0,0009	0,1336	-0,0067
	(-0,70)	(-0,67)	(-0,20)	(-2,73)	(3,79)	(-3,83)
Basic metals and fabricated metal	0,0282	-0,0031	0,0702	-0,0030	0,0865	-0,0036
	(2,71)	(-3,39)	(5,92)	(-3,87)	(3,52)	(-6,12)
Machinery nec	0,0268	0,0009	0,0108	-0,0002	0,0798	-0,0035
	(3,40)	(2,57)	(0,71)	(-0,53)	(3,48)	(-4,97)
Electrical and optical equipment	0,0062	0,0006	-0,0076	-0,0038	-0,0472	0,0024
	(0,79)	(1,55)	(-0,63)	(-3,20)	(-3,03)	(2,04)
Transport equipment	0,0126	-0,0002	0,0155	-0,0004	0,0036	-0,0005
	(1,56)	(-0,57)	(0,92)	(-1,82)	(0,61)	(-0,86)
Manufacturing nec and recycling	-0,0039	-0,0013	0,0157	0,0004	0,0163	-0,0007
	(-0,45)	(-4,11)	(0,99)	(0,89)	(1,25)	(-2,68)

Table 3. Elasticities of energy intensity to embodied technical change, ε_{KE}.

	Italy	Finland	Spain
Food, beverages and tobacco		-2,071	
Textiles, leather and footwear		-1,677	-0,550
Wood and of wood and cork	-0,162	-0,081	-5,009
Pulp, paper, printing and publishing	-0,248	-0,092	
Coke, refined petroleum, nuclear	-0,104	-0,135	-0,048
Chemicals and pharmaceuticals			-0,100
Rubber and plastics		-0,540	
Other non-metallic mineral	-0,335	-0,229	
Basic metals and fabricated metal			
Machinery nec			
Electrical and optical equipment		-1,438	-2,707
Transport equipment			
Manufacturing nec and recycling	-0,283		

Table 4. Parameter values for capital: Italy. (t-values in parenthesis)

	λ	ρ_{KE}	ρ_{KL}	γ_{KK}
Food, beverages and tobacco	0,1672	0,0443	-0,0459	0,7004
	(4,40)	(2,88)	(-1,94)	(1,95)
Textiles, leather and footwear	0,2702	0,0176	0,0306	0,3122
	(12,46)	(2,46)	(1,60)	(8,42)
Wood and of wood and cork	0,3098	-0,0001	-0,0339	1,0633
	(8,26)	(-0,01)	(-1,32)	-5,32
Pulp, paper, printing and publishing	0,1810	-0,0047	0,0937	0,2411
	(4,02)	(-0,41)	(3,59)	(3,75)
Coke, refined petroleum, nuclear	0,0944	-0,0094	-0,1030	0,2417
	(2,66)	(-0,34)	(-5,46)	(2,61)
Chemicals and pharmaceuticals	0,1543	0,1173	0,1253	0,2824
	(4,83)	(8,21)	(9,83)	(8,73)
Rubber and plastics	0,1753	0,0119	-0,0019	0,2839
	(6,17)	(1,06)	(-0,06)	(7,12)
Other non-metallic mineral	0,0110	-0,0173	0,0252	0,0324
	(0,55)	(-0,70)	(0,94)	(0,55)
Basic metals and fabricated metal	0,1794	0,0282	0,0111	0,2847
	(11,43)	(2,71)	(0,75)	(12,96)
Machinery nec	0,0072	0,0268	0,1220	0,0107
	(0,33)	(3,40)	(6,68)	(0,33)
Electrical and optical equipment	0,0521	0,0062	0,0997	0,0825
	(1,98)	(0,79)	(3,96)	(1,94)
Transport equipment	0,0407	0,0126	0,0575	0,0893
	(2,22)	(1,56)	(1,62)	(2,55)
Manufacturing nec and recycling	0,0825	-0,0039	-0,0013	0,1811
	(4,49)	(-0,45)	(-0,06)	(5,10)

Table 5. Parameter values for capital: Finland. (*: restricted; t-values in parenthesis)

	λ	ρ_{KE}	ρ_{KL}	γ_{KK}
Food, beverages and tobacco	0,0200	-0,0381	-0,0563	-0,3460
	(*)	(2,88)	(-3,23)	(-5,54)
Textiles, leather and footwear	0,0130	-0,0346	0,0437	0,0270
	(-0,60)	(-3,57)	(1,70)	(0,59)
Wood and of wood and cork	0,0834	-0,0005	-0,1288	0,3738
	(1,74)	(-0,03)	(-3,94)	(3,55)
Pulp, paper, printing and publishing	0,0912	0,0055	0,0331	0,2255
	(3,25)	(0,30)	(1,49)	(3,65)
Coke, refined petroleum, nuclear	0,1000	-0,0287	-0,0218	0,5022
	(*)	(-1,44)	(-0,82)	(3,55)
Chemicals and pharmaceuticals	0,0009	0,1275	0,0638	0,0041
	(0,08)	(7,51)	(3,34)	(0,08)
Rubber and plastics	0,0918	-0,0109	0,1245	0,2319
	(3,79)	(-1,02)	(5,07)	(3,72)
Other non-metallic mineral	0,1000	-0,0034	0,0022	0,3038
	(*)	(-0,20)	(0,08)	(8,86)
Basic metals and fabricated metal	0,1042	0,0702	0,0887	0,1780
	(4,33)	(5,92)	(5,38)	(5,62)
Machinery nec	0,1000	0,0108	0,3137	-0,6746
	(*)	(0,71)	(6,88)	(-6,29)
Electrical and optical equipment	0,0180	-0,0076	0,0002	0,0360
	(0,62)	(-0,63)	(0,01)	(0,62)
Transport equipment	0,1391	0,0155	-0,0044	0,2539
	(3,50)	(0,92)	(-0,16)	(3,65)
Manufacturing nec and recycling	0,1000	0,0157	0,1607	-0,4403
	(*)	(0,99)	(6,36)	(-5,68)

important (has a higher parameter value associated) than the price of energy and therefore has a larger impact on optimal capital stock and therefore on investment. This is an important result for the analysis outlined here of deriving the inducement of (embodied) technical change via energy prices. A low weight of the energy price in the investment decision necessarily gives a low inducement factor. As according to equation (20) the relationship ρ_{KE}/γ_{KK} determines the reaction of capital to energy price changes, the parameter γ_{KK} also plays an important role. As this parameter is mainly positive, energy prices only have a positive impact on capital accumulation in industries with energy-saving embodied technical change (*i.e.* negative values of parameter ρ_{KE}). Concerning the speed of adjustment (λ) for Italy and Spain, significant positive parameter values have been found for most industries. For Finland that was not the case and the parameter had to be restricted to positive values in some industries in order to guarantee a conversion towards equilibrium in capital stock adjustment. Generally the values of λ 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, $\frac{z_K x_K}{VC}$, from the share of the user cost of capital in the variable cost, $\frac{u_K x_K}{VC}$, in the past sample.

Table 6. Parameter values for capital: Spain. (*: restricted; t-values in parenthesis.)

	λ	ρ_{KE}	ρ_{KL}	γ_{KK}
Food, beverages and tobacco	0,1326	0,0224	0,0311	-0,0897
	(2,90)	(1,69)	(2,10)	(-2,49)
Textiles, leather and footwear	0,1525	-0,0105	-0,0261	-0,0829
	(1,37)	(-0,44)	(-1,28)	(-1,19)
Wood and of wood and cork	0,1628	-0,1412	0,0634	0,4199
	(4,57)	(-6,18)	(2,19)	(4,45)
Pulp, paper, printing and publishing	0,1671	0,1013	0,0661	0,4893
	(4,44)	(2,49)	(1,18)	(4,91)
Coke, refined petroleum, nuclear	0,0007	0,0549	-0,0527	0,0095
	(0,13)	(1,81)	(-3,32)	(0,13)
Chemicals and pharmaceuticals	0,0128	0,0073	0,1654	0,1203
	(1,83)	(0,39)	(9,71)	(3,26)
Rubber and plastics	0,1715	0,0361	-0,0371	0,4455
	(5,93)	(2,42)	(-1,58)	(7,86)
Other non-metallic mineral	0,0200	0,1336	0,1364	0,0615
	(1,16)	(3,79)	(5,04)	(1,20)
Basic metals and fabricated metal	0,0200	0,0865	0,3286	-0,4496
	(*)	(3,52)	(7,95)	(-4,99)
Machinery nec	0,1211	0,0798	0,1848	0,4351
	(4,36)	(3,48)	(5,46)	(5,05)
Electrical and optical equipment	0,2219	-0,0472	0,1028	0,3343
	(5,50)	(-3,03)	(4,70)	(5,15)
Transport equipment	0,1339	0,0036	0,0750	0,1314
	(3,64)	(0,61)	(3,40)	(3,89)
Manufacturing nec and recycling	0,2300	0,0163	0,0784	0,8682
	(6,19)	(1,25)	(4,12)	(9,79)

As **Figure 1** shows, energy intensity has decreased continuously in the manufacturing sector of the three 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 and Spain, Finland shows a slightly different development of a more continuous decrease over the whole sample. One explanation for this development could be found in embodied technical change, which as lined out in the theoretical model applied here is in turn influenced by energy prices. The generally rather low values of λ result in a long lasting impact of an energy price shock on energy intensity as adjustment takes time. This is counterbalanced by the relatively small importance of the energy prices for the investment decision, measured by the term ρ_{KE}/γ_{KK}. Obviously the optimal capital stock is also determined by other factor prices, scale effects and autonomous technical change.

The generally low or in some cases even positive values for $\bar{\varepsilon}_{EE}$ in **Table 7** 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 λ. In some industries one finds a considerable elasticity of past energy prices on energy intensity brought about by embodied technical change. On the other hand, to explain the stylized facts in the data one must combine the elasticities presented in Table 7 with the actual past energy price shocks, which were about +50% (1980) for the corresponding industries in Italy, about +30% (1980) in Finland, and about +20% (1981) in Spain. Given a 50% energy price shock in 1980 therefore means that for example the “non metallic mineral” industry in Italy had a 0.5% lower energy intensity in 1985 due to this price shock via embodied technical change. The full impact of embodied technical change is of course larger, as the results in Table 3 indicate, but only this small part can be traced back to the energy price shock.

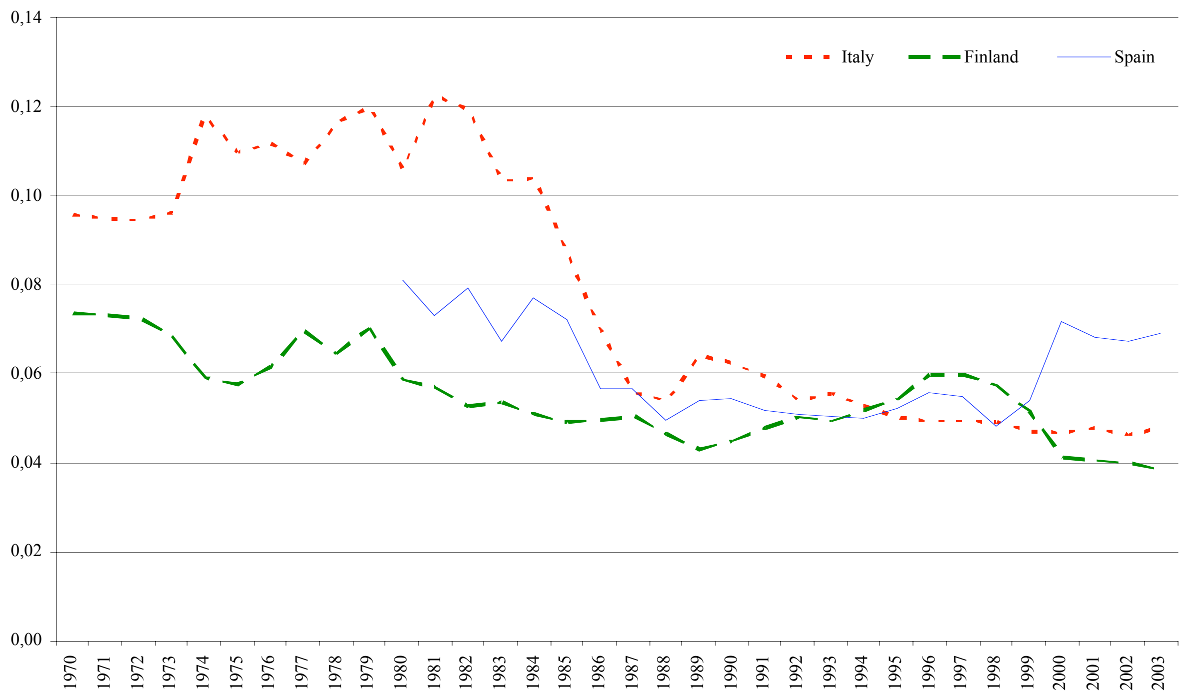

Figure 1. Energy Intensity (per unit of gross output) of Manufacturing. (Source: EU KLEMS database.)

Table 7. Price elasticitiy of energy intensity after 5 years (τ=5) due to embodied technical change, $\overline{\varepsilon}_{EE}$.

	Italy	Finland	Spain
Food, beverages and tobacco		0,021	
Textiles, leather and footwear		-0,134	0,033
Wood and of wood and cork	-0,001	-0,001	-0,830
Pulp, paper, printing and publishing	-0,003	0,008	
Coke, refined petroleum, nuclear	-0,001	-0,003	0,001
Chemicals and pharmaceuticals			0,000
Rubber and plastics		-0,009	
Other non-metallic mineral	-0,009	-0,001	
Basic metals and fabricated metal			
Machinery nec			
Electrical and optical equipment		-0,026	-0,213
Transport equipment			
Manufacturing nec and recycling	-0,002		

If we compare these results to those of Sue Wing and Eckaus (2004) for the US we find some similarities. Sue Wing and Eckaus (2004) 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. For the Translog model used in this study this long-run elasticity would be given by the expression $-\frac{\rho_{KE}}{\gamma_{KK}}\left[\frac{\rho_{KE}}{s_E}-\frac{z_K K}{VC}\right]$. Their results for the manufacturing sector also contain low differences between short- and long-run elasticities and in some cases even a reversion of the sign or higher short-run elasticities. This result is found for dealing with one aggregate capital stock as the fixed input. As Sue Wing and Eckaus (2004) also deal with different assets (information technology, electrical equipment, machinery, vehicles and structures) they find a significant and important contribution of certain assets to a long-run impact of energy prices via embodied technical change. This is especially the case (across different industries) for information technology and electrical equipment and could be seen as a strong indication for disaggregating the capital stock into single assets.

4. CONCLUSIONS

In this paper energy intensity for three selected EU countries (Italy, Finland and Spain) is analyzed by applying a Translog variable cost function setting to the new EU KLEMS dataset. The purpose is to trace back the impact of embodied technical change in capital goods to past energy price shocks. The central methodological innovation compared to existing studies is the incorporation of an explicit investment function into the model.

The main conclusion of the results presented here is that energy-saving embodied technical change plays a certain role in the case of European manufacturing, but cannot be mainly 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. Given the large price shocks at the beginning of the 1980s a considerable influence can still be found also with low elasticity values for induced technical change. As another study for the US (Sue Wing and Eckaus, 2004) also indicates, the results might improve when the impact of 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 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 for dealing with energy intensive activities separately. 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. Some of these aggregation problems can be resolved by using data at the NACE 2 digit level (which should in principle be available), some would require further disaggregation.

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