Capital-Energy Substitution for Climate and Peak Oil Solutions?

An International Comparison Using the EU-KLEMS Database

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Abstract

The simultaneous influence of increasing oil scarcity, greenhouse gas control and diffusion of renewable energy will push energy prices up. Whether a smooth path away from oil exists for modern economies is a fundamental socio-economic and political question, which according to economics depends on the degree of substitution between energy and capital. We study this issue by modelling the manufacturing sector of seven major OECD countries during 1970-2005, using the EU-KLEMS database. Based on a brief literature survey, various production structures are considered, and cross-price and direct capital and energy elasticities are calculated. Our results support the hypothesis of complementarity, or weak substituability, between energy and capital in the manufacturing sector. This suggests that less cheap energy will go along with less capital in production, which could ultimately lead to a lower level of manufacturing output.

Keywords: complementarity, cross-price elasticity, KLEM

1. Introduction

Within neoclassical-economic production theory the dependence of the current economic system on non-renewable resources can be relieved in two ways, namely through input substitution and technical change. The first is often assessed by estimation of elasticities of substitution, which quantify the 'flexibility' of an economy to produce a given output with different combinations of inputs. The second can be captured through variables quantifying improvements in energy efficiency. While the motivation of early studies of substitution in production was to assist governments in determining optimal energy taxes and the impact of oil price shocks due to political factors, at present physical-geological scarcity of fossil fuels and climate change influence the research agenda (Kerr 2011; Salameh 2010).[1] Both peak oil and global warming contribute to increasing energy prices and a need to substitute away from fossil energy.

Input substitution has long been an issue of strong disagreement, as highlighted by the Daly versus Solow/Stiglitz debate (Daly a,b; Solow 1997; Stiglitz 1997). The focus of the controversy was about whether substitution or complementarity characterizes the relation between energy and capital inputs in the production process at the national level. This concern goes back to the theoretical work of Georgescu-Roegen (1971) and exercises with the system dynamics model of Meadows et al. (1972). In response, neoclassical economics developed an approach to include resource depletion within theoretical growth models, focusing on substitution and technical change as growth factors. Generally, economists have been confident about the reduction of the energy (as well as scarce material) intensity of the economy through these two factors, driven by price mechanisms (Dasgupta and Heal 1974; Stiglitz 1974, 1997; Daly 1997a; Solow 1997). However, Stiglitz (1997 p. 269) admitted the shortcomings of growth models:

[1] The IEA (2010) notes "a decreasing output from existing fields", stressing that data mark a *plateau* of regular oil production since 2005, somehow disguised by the growth of unconventional oil and natural gas liquids (Alekett 2009). Nevertheless, the assessment of reserves and global forecasts by the IEA have been strongly criticized (Miller 2011; Sorrell et al. 2010a,b). It is not a matter of oil ending, but a cheap-oil peak, confirmed by a significant decrease in the energy return on energy invested (Gagnon et al. 2009).

“We write down models as if they extend to infinity, but no one takes these limits seriously [...] In this intermediate run, capital can substitute for natural resources–and this is true even though capital itself uses resources. […] Technical change – some of which is the result of investment in R&D, a form of capital, can reduce the amounts of physical capital and resources required to produce the unit of output, were output is measured not in physical units, but in the value of the services associated with it.”

The recent degrowth vs. a-growth debate (Kallis 2011; van den Bergh 2011) can also be interpreted in terms of different degrees of confidence in input substitutability, as substitution can be seen as a measure of ‘robustness’ of an economy to higher energy prices, whether due to resource scarcity or climate policy (carbon pricing). The period after 2008, characterized by energy price volatility and a worldwide financial crisis, confirms this.

Here we quantify the substitution potential between energy and capital by estimating the cross-price elasticity with a translog cost function from the EU-KLEMS database to estimate capital/energy substitution during 1970-2005. We specify five translog cost functions for France, Germany, Italy, Japan, Spain, UK and USA. This represents a flexible approach in the sense that it incorporates both returns to scale (RTS) and technical change (TC).

The article is organized as follows. Section 2 provides a brief review of the literature on production and cost functions, and associated elasticity formulations. Section 3 describes the models used, the EU-KLEMS database, and the elasticity definitions used to assess substituability between energy and capital inputs. Section 4 presents and discusses the results, including model parameters relating to energy/capital substitution, returns-to-scale (RTS) and technical change (TC). Section 5 concludes and discusses the implications of the results for potential responses to peak oil and global warming.

2. The interrelated history of production functions and elasticity of substitution

Early production function formulations related total production to the amount of labour, capital and land employed in the economic process. Even though the merit of formulating this relation straightforwardly - production is a function of factors of production - is credited to Wicksteed (1894), the intuition of the mathematical relation might go back to Turgot's "partial derivatives of total product schedules", or to Malthus and Ricardo's "logarithmic and quadratic implicit functions" (Humphrey 1997). The Cobb-Douglas specification came into play when the economist Paul Douglas asked the mathematician Charles Cobb to develop an equation describing the time series of U.S. manufacturing output, labour and capital input he had assembled for the period 1889–1922. The result is the well-known expression: $P = bL^{k}C^{1-k}$, with P = production, L and C labour and capital respectively, b and k parameters; a function without land and raw material inputs, constant RTS and fixed technology.

In the middle of the 20th century the search for flexible functional forms in the production specification was motivated by two conceptual needs. The first was to measure the 'ease' of substitution between production factors with no a priori restrictions (as imposed by the Cobb-Douglas). The second was the inclusion of other inputs, like different energy sources, the distinction skilled/unskilled labour force and raw materials. Thus, progress on production functions occurred *because* researchers looked for flexibility in input substitution.

One major step was the constant elasticity of substitution (CES) production function (Arrow et al. 1961), which encompasses the Leontief, linear and Cobb-Douglas production functions as special cases.[2] It writes: $Q=F[aK^{r} +(1-a)L^{r}]^{1/r}$, where, Q = *Output*, F = *Factor productivity*, a = *Share parameter*, K, L = *inputs*, $r = (s-1)/s$, $s = 1/(1-r)$ = *Elasticity of substitution*. Additional, essential contributions of duality theory by Diewert (1974) and Fuss and McFadden (1978) led to modern input demand

[2] When $s \rightarrow 1$ the function becomes the Cobb-Douglas, as $s \rightarrow \infty$ we get the linear (perfect substitutes) function; for s approaching 0, we get the Leontief (perfect complements) function.

estimation practice via cost and, to a lesser extent, profit functions. The first to use the dual cost function to derive input demand was Nerlove (1963), whose models to estimate RTS and substitution between capital, labour, and fuels in the U.S. electric sector employed a cost function with non-constant RTS, rather than a production function. Nerlove, unsatisfied with the Cobb-Douglas specification, directed Daniel McFadden to work on both duality theory and flexible functional forms. While McFadden focused on duality theory, Erwin Diewert (a student of McFadden) devoted himself to the application of Shephard's theorem and the development of flexible functional forms with more than two inputs. In the early seventies, the very flexible translog function was introduced by Christensen, Jorgenson and Lau (1971, 1973), although similar functional forms were produced a decade before.[3] The translog production function is written as:

$$\ln Q = \alpha_0 + \sum_{i=1}^{n} \alpha_i \ln x_i + \frac{1}{2} \sum_{i=1}^{n} \sum_{j=1}^{n} \alpha_{ij} \ln x_i \ln x_j \qquad (1)$$

with Q = output and *i,j = inputs.* Function (1) has the merit of relaxing both the Cobb-Douglas unitary elasticity of substitution and the CES constraints, where all production factors are substitutes by definition (Uzawa 1962).[4]

The history of the elasticity of substitution (ES) began with the first measures of factor substitution proposed by Hicks (1932) and Robinson (1933). Hicks introduced the elasticity of substitution to analyse the "ease of substitution" between capital and labour, while studying the effect of changes in income distribution in England. Robinson defined the elasticity of substitution more rigorously as the relative change in the demand for labour caused by a change in the relative price of factors. Shortly after,

[3] Heady and Dillon (1961) explicitly considered the second-degree polynomial expansion in logarithms (later called translog) and a square root transformation, which took on as a special case the generalized linear production function introduced by Diewert in 1971.

[4] An additional drawback of the CES specification is that its elasticity of substitution is the same for all inputs, which is quite unrealistic.

Hicks and Allen (1934) defined the elasticity of substitution as a measure of the responsiveness of relative inputs to relative input prices. Among the main challenges related to the elasticity of substitution are: inputs measurability in monetary and physical units; input separability (Frondel and Schmidt 2004) and the choice of substitution measure among a multitude of elasticity formulas.[5]

The research on energy/capital substitution set a milestone with the econometric work of Berndt and Wood (1975): they used the translog production function to derive the dual cost function and the input shares from Shephard's lemma and they estimated the *E-K* elasticities employing an original database of labour, capital services, energy and materials for the U.S. manufacturing sector.[6] Their study indicated a clear complementarity between *K* and *E* with an estimated Allen elasticity of substitution (*AES*) between energy and capital of *-3.53* in 1971, corresponding to a cross-price elasticity (CPE_{ke}) of *-0.16*. After this study, a vivid debate on *K-E* substituability emerged a since further research provided different estimates of substitution elasticities at national, industrial and inter-country levels, even for the same country and sector.

Several explanations for the variety of findings have been offered: first of all time-series capture short-term (low) substitution, resulting in a bias towards *K-E* complementarity, while cross-section data represent long-term input equilibria,[7] showing substituability between the factors (Apostolakis 1990) ; then the inclusion of material inputs in the specification increases *E-K* complementarity (Frondel 2001, p.49). Finally, separating between physical and working capital results in an increased complementarity between physical capital and energy (Field and Grebenstein 1980). Solow (1987) raised doubts about possible aggregation bias in substitution estimates at

[5] For more details, the interested reader might check the extensive surveys by Frondel (2001), Stern (2007), Sorrell et al. (2008) and Koetse et al. (2008).

[6] Since Berndt and Wood's contribution, the K-L formulation, the Cobb-Douglas and the Constant Elasticity of Substitution (Arrow et al. 1961) production functions lost research appeal in favour of the 4-inputs translog cost specification.

[7] For a given capital equipment, the energy input per unit of time is rather constant (*E-K* complementary) in the short run, thus an increase in energy prices is likely to lead to an increase in labour input (*L-E* and *L-K* substitutes) instead of capital, while, in the long run, energy-saving capital can be added, so *K* and *E* might turn into substitutes (as well as E and L).

the aggregate manufacturing level as, *stricto sensu*, *K-E* substitution is a microeconomic phenomenon determined by engineering and organizational constraints. In a sharp critique, Miller (1986) pointed at the role and bias induced by the different output composition between countries and sectors. In any case, it became increasingly clear that what mostly affects the results is the definition of capital input.

Capital input is mainly calculated from national accounting data as the residual value added, after subtracting labour payments and the energy bill from national income.[8] A narrower approach to measure capital, denoted *capital services*, develops a physical index of capital, using the perpetual inventory method (PIM) where, starting with an estimated initial capital stock, yearly investment flows are added and a depreciation rate is subtracted.[9] One shortcoming of the PIM approach is the constant capital depreciation rate and variations determined by investment flows. In fact, investment flows are a function of business cycles and are inversely correlated with energy prices. So, in times of cheap energy, machines scrapping is likely to accelerate (high investment cycle) and this is not accounted for (constant depreciation), leading to capital overestimation. Historically, cheap energy and large investments characterized the U.S economy in the post WW2 – pre 1973 timeframe, when *E-K* complementarity was assessed by Bernd and Wood (1975). Thus, in the cost function formulation, the evidence for *E-K* complementarity is limited to acknowledging that "investment lowers when energy prices grow or vice versa" (Miller 1986, p.755). Finally, as the PIM is a rent-weighted measure of capital services, if investments to an industry slow down (or stop) then the capital input does not just stop growing but actually declines.

A literature review (Broadstock et al. 2007) of empirical *E-K* substitution studies covering more than 100 scientific papers found that 40% of the estimates assess complementarity between *E* and *K*, and within the remaining 60%, around two thirds

[8] The value added includes the contribution to production of a heterogeneous set of capital inputs, like residential buildings and financial products; these are joined into reproducible capital inputs (instead of being attributed to rent).
[9] Baldwin and Gu (2007) review studies that estimate capital services.

are less than unity; hence, 75% of the estimates suggest that *E* and *K* are either complements or weak substitutes. Concerning the inclusion of material inputs in the specification, the review finds half of the studies using KLE and the other half a KLEM (or similar) specification, with a clear distinct effect on the results: the average *ES* between in KLE specifications is between *0.4* and *0.5* (suggesting *K-E* substitution), while KLEM specifications result in an average *ES* of *-0.5* and median *-0.1*, indicating complementarity. These results mean that investment in production capital (including innovation) is probably not an effective way to reduce energy use, contrasting the decoupling hypothesis. The level of aggregation is also an important cause of variability, since at the higher level a sector may still exhibit factor substitution due to changes in product mix, even if the mix of factors required at a lower level is relatively fixed.

Other reasons for variation in the *K-E* elasticity are the assumptions made about the technology (homothetic or not), the inclusion of returns to scale parameters and the specification (or lack thereof) of technical change. In the next section we present five models to analyse *E/K* substitution; returns to scale and technical change are evaluated by adding output and a time variable in the estimated equation.

3. Data, models and measures

The EU-KLEMS database offers an opportunity to analyse the production structure at the sector level for different countries. It provides volumes and prices of capital, labour, energy and intermediate materials, from 1970 onwards.[10] It is the main outcome of a research project financed by the European Commission to analyse productivity at the industrial level, "embedded in a clear analytical framework, rooted in production functions and the theory of economic growth" (Timmer et al. 2007, p. 7). The database includes 30 countries, but due to lack of data on energy and materials we limited the

[10] We use the 2008 EU-KLEMS release, as the 2009 update does not include energy and materials.

analysis to the manufacturing sector of seven OECD economies. The 2008 EU-KLEMS release stops in 2005, while the coverage begins in 1970 for Italy, UK and USA, in 1973 for Japan, in 1978 for Germany, in 1980 for Spain and in 1981 for France. To our knowledge, this database has not been used to estimate cost functions or to derive measures of input substitution, returns to scale and technical change.

The EU-KLEMS aggregation, over products or industries, uses the Tornqvist quantity index, a discrete time approximation to a Divisia index. Labour compensation (LAB), is derived by applying the ratio of total hours worked by total persons engaged to hours worked by employees to compensation. Capital compensation (CAP) is derived as value added minus LAB. Energy, materials and services inputs are calculated by applying the shares of *E*, *M* and *S* from the Use-tables to total intermediate inputs from the national account series. While for many countries nominal Supply-Use Tables (SUT) are available since 1995, few countries have SUT extending back to 1980 or earlier. In this case Input-Output tables have been used to derive measures of *E*, *M* and *S*. Energy input is defined as all energy mining products (10-12), oil refining products (23) and electricity and gas products (40). All products from industries 50-99 are included as services; the remaining products are classified as materials.

The input shares of capital, energy, labour and materials for the manufacturing sector in the countries analysed are presented in *Figure 1*. The USA have the highest capital share (16%, followed by France at 10%); the share of labour is the highest in UK and the lowest in France and Spain, while the energy shares lie in the 4-5% range except for Spain and Japan; materials share is between 40% in the UK and 53% in France, Italy and Spain.

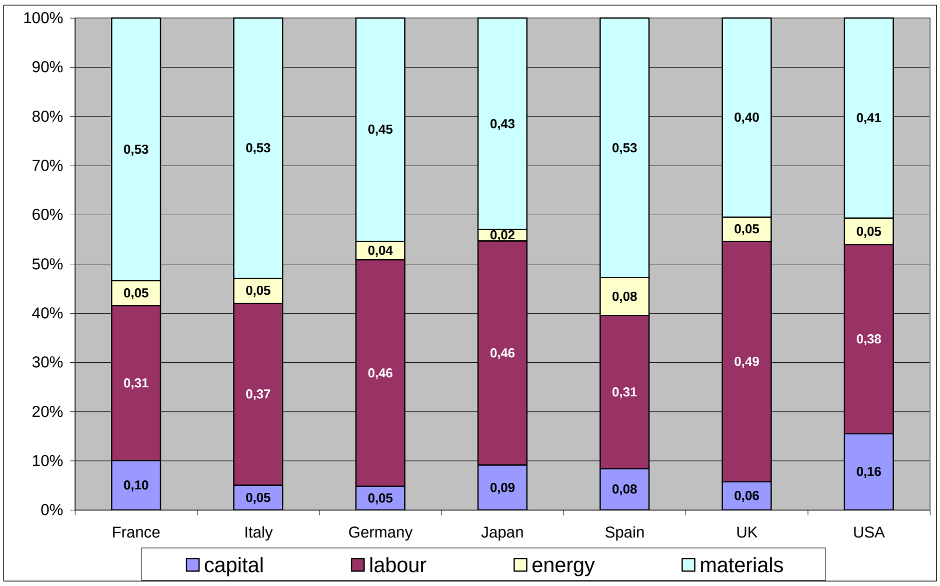

Figure 1. Manufacturing sector input shares in year 2000

Models. The seven countries under scrutiny are comparable in terms of both wealth and industrialization criteria. We independently estimated five translog cost specifications (*Table 1*) from which to derive direct and cross-price elasticities with a focus on energy and capital substitution (*Table 2*). The main reason to use a cost function, instead of a production function, being to circumvent the general problem that input quantities are not likely to be exogenous, at the aggregate level, violating the necessary conditions for unbiased parameters (Binswanger 1973). The use of prices in the estimation solves the endogeneity problem, since they are more likely to be exogenous than the quantities. No separability assumption between inputs is made as there is no nested structure and the cost function is estimated straightforwardly.

A first issue concerns the homotheticity of the cost function. A function is homothetic if and only is it can be written as a separate function in output and input prices (the relative factor shares are independent of the level of output). A necessary and sufficient condition for a production technology to be homothetic is that $\beta_{iY} = 0$ for all i. Model 1 cost function expresses homothetic technology imposing $\sum\beta_i = 1$ and $\sum\beta_{ij} = 0$, a testable null hypothesis. Model 1 uses the simplest translog cost function specification, suitable to assess inputs substitution. The specification is considered to be well-behaved if the first derivatives are positive and the Hessian is negative semi definite. Since unconstrained model often verify $\sum\beta_{ij} \neq 0$, a further direct test for homothetic cost function is to include output as an independent variable in the estimated equations. Model 2 includes linear, quadratic and input-specific RTS structures, to verify the hypothesis of non-homothetic technology by including gross output of the manufacturing sector (y) as an exogenous variable with the constraint $\sum\beta_{iY} = 0$.[11,12]

Table 1. Estimated models

Model	Equation	Remarks
1	$\ln C_t = \beta_0 + \sum_{i=1}^{n}\beta_i \ln p_i + \frac{1}{2}\sum_{i=1}^{n}\sum_{j=1}^{n}\beta_{ij} \ln p_i \ln p_j$	Cost function
2	$\ln C_t = \beta_0 + \beta_Y \ln y_t + \frac{1}{2}\beta_{YY} \ln y_t^2 + \sum_{i=1}^{m}\beta_i \ln p_{it} + \frac{1}{2}\sum_{i=1}^{m}\sum_{j=1}^{m}\beta_{ij} \ln p_{it} \ln p_{jt} + \sum_{i=1}^{m}\beta_{iY} \ln p_{it} \ln y_t$	CF with RTS
3	$\ln C_t = \beta_0 + \beta_T t_t + \frac{1}{2}\beta_{TT} t_t^2 + \sum_{i=1}^{m}\beta_i \ln p_{it} + \frac{1}{2}\sum_{i=1}^{m}\sum_{j=1}^{m}\beta_{ij} \ln p_{it} \ln p_{jt} + \sum_{i=1}^{m}\beta_{iT} \ln p_{it} t_t$	CF with TC
4	$\ln C_t = \beta_0 + \beta_Y \ln y_t + \beta_T t_t + \sum_{i=1}^{m}\beta_i \ln p_{it} + \frac{1}{2}\sum_{i=1}^{m}\sum_{j=1}^{m}\beta_{ij} \ln p_{it} \ln p_{jt}$	CF constant RTS, neutral TC
5	$\ln C_t = \beta_0 + \beta_Y \ln y_t + \frac{1}{2}\beta_{YY} \ln y_t^2 + \beta_T t_t + \frac{1}{2}\beta_{TT} t_t^2 + \sum_{i=1}^{m}\beta_i \ln p_{it}$ $+ \frac{1}{2}\sum_{i=1}^{m}\sum_{j=1}^{m}\beta_{ij} \ln p_{it} \ln p_{jt} + \sum_{i=1}^{m}\beta_{iY} \ln p_{it} \ln y_t + \beta_{YT} \ln y_t t_t + \sum_{i=1}^{m}\beta_{iT} \ln p_{it} t_t$	CF with input specific RTS and TC

Another investigation path, concerning magnitude and quality of TC, is detailed in Model 3, where linear, quadratic and input specific TC parameters (by a time trend) are added. In aggregate analysis ‘technology’ represents the set of possible combinations of

[11] Failure to reject the null hypothesis $\beta_{iY} = 0$ indicates homothetic production. If the coefficient β_{iY} is significant but all of the β_{ij} terms are not, factor shares are constant along production isoquants implying unit own factor price elasticities.

[12] Koetse (2006) noted how not including RTS parameters in the cost function systematically affects the elasticity. In particular, if constant returns to scale do not hold in reality, primary studies that do not allow for non-constant returns to scale will underestimate substitution potential.

factor inputs that can produce a given level of output. [13] Analytically, a change in technology t shifts the isoquant structure through a change in parameter β_0 in the cost function; Model 3 and 5 include input-specific technical change parameters β_{iT} under the usual constraint $\sum\beta_{iT} = 0$. The assumption of neutral technical change is generally rejected in empirical studies (Hesse and Tarkka 1986; Hunt 1986). A diagrammatic interpretation of energy-saving/using technical change is given in *Figure 2*, where the shift to the green (red) isoquants leads to a new energy saving (resp. using) equilibrium. Since empirical studies often assume an homogeneous cost function, with constant RTS and neutral TC (i.e. $\beta_{iy} = \beta_{it} = 0$), we specify Model 4, with constant and neutral RTS and TC parameters, while Model 5 gathers both flexible RTS and TC structures.

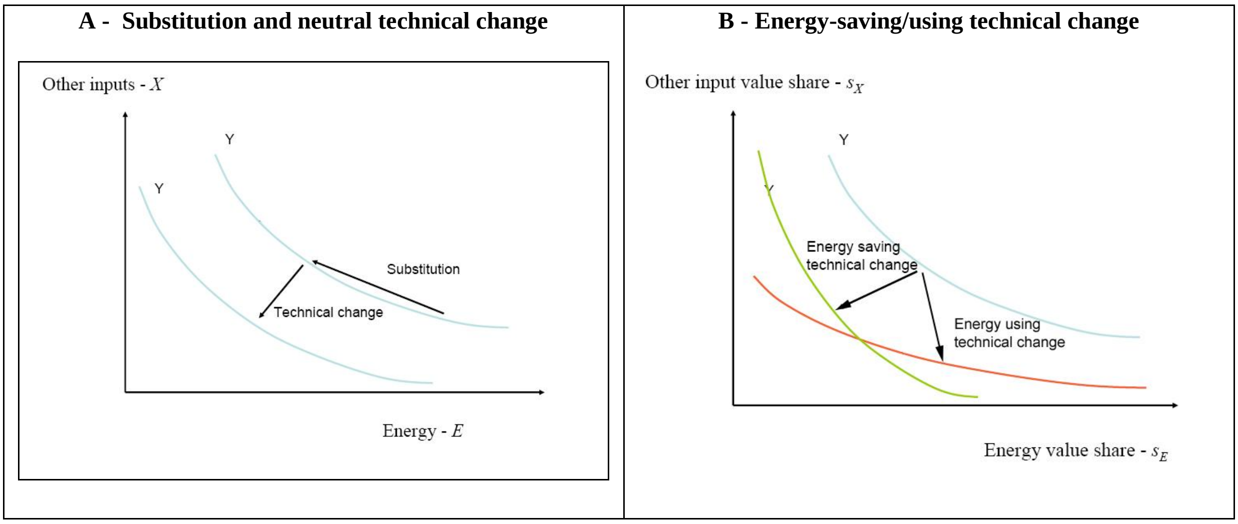

Figure 2. Substitution and technical change (adapted from Sorrell and Dimitropoulos 2007)

In our estimations we assume constant time trend t, so that a negative value of β_{it} implies that the share of factor i in total costs will fall over time, a positive value an increase. The cross-price elasticity CPE_{ij}, the direct price elasticity PE_{ii} and their variances are computed from the parameters as indicated in *Table 2*.

[13] Binswanger (1974) proposed a definition of biased technical change suitable for functions with many inputs, called *factor price bias*, giving a measure of the rate of change in the share of factor costs in the value of output, holding input prices constant. If this factor price effect is negative, technical change is factor-saving for factor i, if positive, is 'factor-using'.

Table 2 - Elasticities and their variances

Elasticity	**Variance**
$CPE_{ij} = \eta_{ij} = s_j + \frac{\beta_{ij}}{s_i}$	$\mathrm{var}(CPE_{ij}) = \frac{\mathrm{var}(\hat{\beta}_{ij})}{\hat{s}_i^2}$
$PE_{ii} = \eta_{ii} = \frac{\beta_{ii} + s_i^2 - s_i}{s_i}$	$\mathrm{var}(PE_{ii}) = \frac{\mathrm{var}(\hat{\beta}_{ii})}{\hat{s}_i^2}$

4. Results

The estimated elasticities, presented in *Table 3*, result from the joint estimation of cost function and input shares by three-stage iterated least squares, while cost function estimates are presented in the Annex. The materials cost share is eliminated and the remaining inputs prices are expressed relative to P_M, to avoid redundancy. The adequacy of the translog model is evaluated by multiple criteria: first of all negative direct price elasticities (PE_{ij}) are expected, then we checked the (eventual pattern of) residuals and the significance of parameters β_{ke}, β_k and β_e; finally, the model diagnostics (RMSE, R^2 and D-W) are used to select the best specification for each country and relative energy/capital cross-price elasticities CPE_{ij}.

The PE_{ij} are correct for all models in **France**, the CPE_{ke} ranging from *-0.94* to *0.04* and significant *β's* over each model. The residuals pattern and regression diagnostics lead us to retain Model 5, with a $CPE_{ke} = -0.04$ and $CPE_{ek} = -0.06$; direct elasticities are $PE_k = -0.33$ and $PE_e = -0.22$. The technological structure of French manufacturing sector indicates complementarity between *K* and *E*, significant input-specific RTS parameters (negative for Labour) and positive input-related TC (negative for energy). Comparison of our CPE estimates with the existing literature is hard to perform for France: Griffin and Gregory (1976) obtain a $CPE_{ke} = 0.11$ (not significant) and $CPE_{ek} = 0.27$ (significant) with a KLEM model using panel data for 1965; estimates by Hesse and Tarkka (1986) result in a $CPE_{ek} = 0.023$ between capital and fossil fuels in 1977, while we considered aggregate energy as input (and France has a high nuclear share).

Both cross-price elasticities are steadily negative in **Germany**, while positive PE_e appear in Model 2, 3 and 5; the regression diagnostics lead us to retain Model 5 with $CPE_{ke} = -0.372$ and $CPE_{ek} = -0.36$. Direct capital elasticity is *-0.35* (*PEe* not significant). German estimates by Welsch and Ochsen (2005) find $CPE_{ke} = -0.13$ and $CPE_{ek} = -0.32$ between 1976 and 1988; the only other significant estimates for Germany are by Falck and Koebel (1999), who obtain $CPE_{ke} = 0.01$ and $CPE_{ek} = 0.03$ (they analyzed 27 German industries using a normalized quadratic cost function, distinguishing between three types of labour over the 1978-1990 timeframe). Both capital and energy direct elasticities are correctly negative for **Italy**; positive *CPE* arise in models 1 and 3, where β_{ke} are non-significant. Based on the significance of the parameters, residuals and diagnostics, we retain Model 5 with $CPE_{ke} = -0.02$ and $CPE_{ek} =-0.007$; direct energy and capital price elasticities are *-0.50* and *-0.41*, respectively. These results can be compared with Pindyck (1979) $CPE_{ke} = -0.05$ and $CPE_{ek} = -0.28$ (in a KLE model with panel data for 1965-1973). Italian CPE_{ke} and CPE_{ek} estimates have also been provided by Apostolakis (1990), resulting in *0.58* and *0.3* (KLE model, evaluated in 1984, no standard error provided). Medina and Vega-Cervera (2001) find a $CPE_{ke} = -0.02$ in 1988 (low significance) and, finally, Hesse and Tarkka (1986) obtain a slightly-significant estimate of *CPE* between capital and fossil fuels of *0.027* in 1977.

As the direct elasticities for both energy and capital input are constantly negative for **Japan**, we restrict our choice by looking at significance of the parameters β_{ke}, β_k and β_e. This lead us to retain Model 4 where, accepting a lower D-W compared to Mod. 5, all relevant β are significant. So, Japan $CPE_{ke} = 0.34$ and $CPE_{ek} = 0.40$, indicating weak substitution between E and K; direct capital and energy price elasticity are high: *-1.25* and *-1.29* respectively. Norsworthy and Malmquist (1983) Japan CPE_{ke} estimates is *-0.37* for 1977 (no standard error) in a model with constant returns to scale and biased technological change; estimates by Pindyck (1979) show complementarity between energy and capital in the Japanese manufacturing sector. The five specifications result in positive energy price elasticity in **Spain**, this is probably due to the lack of variations in Spanish energy prices, making it impossible for the model to capture the mechanism of price reaction. Negative cross-price elasticities are generally reported though, supporting the hypothesis of a complementarity relation between energy and capital. Lack of significance of the β_k and β_e parameter in, respectively, Model 5 and 3 is compensated by the strong significance of the β_{ke} parameter, further regression diagnostics check leaves a degree of uncertainty between Model 2 and 5, so that Spanish CPE_{ke} might range between *-0.80* and *-0.83,* while the CPE_{ek} is between *-1.04* and *-1.20* (*PEk = -0.3,* while *PEe* is not significant). The Spanish results can only be compared with those obtained from models without material input by Apostolakis (1987), $CPE_{ke} = 0.49$ in 1984, (no standard error given) and Medina and Vega-Cervera (2001) $CPE_{ke} = -0.0023$ for 1988 (not significant). All five specification tested have positive autocorrelation in the case of **UK**, with the D-W statistic constantly below one; the analysis of cost function parameters significance restricts our choice to Model 2, retaining $CPE_{ke} = -0.69$ and $CPE_{ek} = -0.58$: *K/E* complementarity in the UK; direct capital and energy elasticities are *-0.20* and *-0.27* respectively. United Kingdom estimates by Hunt (1986) are positive, significant and < 1 ($CPE_{ke} = 0.17$ in 1980, in a model with input-specific technical change), with labour-saving and K, E-using TC. In our estimation, both linear and quadratic returns to scale are highly significant, while negative β_{lY} mean labour-saving RTS. The **USA** estimation produces the correct price elasticity for all specifications considered, the pseudo-R2 and D-W statistics make us opt for model 5 to describe the manufacturing technology of the US, even though β_e is not significant, thus weakening the validity of results. Finally, USA cross-price elasticities are $CPE_{ke} = -0.08$ and $CPE_{ek} = -0.10$. Significant energy and capital saving TC are estimated, as well as neutral RTS and TC. In the past USA input substitution have been assessed by many studies at the subsector (2 digit) level, only few treating the aggregate manufacturing sector; between them Garofalo and Malotra (1984) and Moghimzadeh and Kymn (1986), who distinguish between electric and non-electric energy. The results of both refer the 1970's and, generally, find weak substitution or complementarity in all cases.

Koetse et al (2008) meta-analysis of the literature estimates finds CPE_{ke} for North America and Europe around *0.38* and *0.34* respectively, which can be interpreted as weak substitution characterizing the relation between energy and capital in the aggregate manufacturing sector. In general, estimates of cross-price elasticities not significantly different from zero mean that the production structure is quite rigid and inputs cannot be easily substituted for one another. Our results show that energy and capital are not substitutes since no $CPE > 1$, most countries feature $CPE < 1$ and the retained $CPE < 0$ for six of the seven countries analyzed. This result should be carefully interpreted, as the results do change with the estimated model. Nevertheless, the translog KLEM specifications employed are rather straightforward and the elasticities generally significant.

The overall poor substitution supports the hypothesis of a strong reliance of advanced economies on (fossil fuels based) energy inputs, in contrast with mainstream economics message, suggesting much potential for substitution away from energy and a long and smooth energy transition toward renewable energy.

Table 3. Energy and capital Cross-price and direct elasticities

	Model 1				Model 2				Model 3				Model 4				Model 5			
	CPEke	CPEek	PEk	PEe	CPEke	CPEek	PEk	PEe	CPEke	CPEek	PEk	PEe	CPEke	CPEek	PEk	PEe	CPEke	CPEek	PEk	PEe
France	0,012	0,009	-1,08	-0,93	-0,09	-0,12	-0,45	-0,02	0,041	0,073	-0,87	-0,772	-0,94	-0,16	-0,34	-0,86	-0,04	-0,06	-0,33	-0,23
	0,000	0,000	0,001	0,000	0,001	0,002	0,001	0,006	0,000	0,001	0,000	0,002	0,008	0,000	0,010	0,001	0,003	0,005	0,003	0,009
Germany	-0,466	-0,214	-0,638	-0,723	-0,915	-0,896	-0,202	2,132	-0,229	-0,477	-0,648	1,781	-0,764	2,663	-0,599	-6,814	-0,372	-0,357	-0,319	0,934
	0,001	0,000	0,000	0,002	0,014	0,013	0,002	0,158	0,005	0,020	0,000	0,484	0,001	0,017	0,001	0,085	0,015	0,014	0,001	0,309
Italy	0,136	-0,017	-1,444	-1,137	-0,059	-0,030	-0,425	-0,739	0,251	0,121	-0,712	-0,916	0,078	-0,011	-1,450	-1,054	-0,015	-0,007	-0,409	-0,496
	0,037	0,001	0,014	0,002	0,001	0,000	0,001	0,006	0,002	0,000	0,001	0,003	0,033	0,001	0,014	0,002	0,002	0,000	0,001	0,007
Japan	-0,008	-0,033	-1,090	-0,548	-0,057	-0,201	-1,077	-0,299	0,141	0,500	-0,873	-0,782	0,336	0,398	-1,246	-1,292	0,013	0,050	-0,596	-0,396
	0,000	0,001	0,000	0,005	0,000	0,001	0,001	0,016	0,000	0,006	0,001	0,006	0,000	0,000	0,000	0,001	0,001	0,017	0,004	0,020
Spain	-1,294	-3,259	-0,047	5,880	-0,803	-1,038	-0,298	2,579	-0,684	-9,206	-0,514	24,449	-0,829	-0,635	-0,353	0,409	-0,832	-1,205	-0,284	3,342
	0,004	0,023	0,001	0,126	0,004	0,007	0,001	0,084	0,002	0,429	0,000	6,118	0,002	0,001	0,000	0,008	0,007	0,014	0,001	0,112
UK	-0,509	-0,059	-0,339	-1,340	-0,693	-0,581	-0,196	-0,266	0,033	0,074	-0,712	-0,789	-0,404	-0,269	-0,739	-0,411	-0,175	-0,151	-0,258	-1,479
	0,004	0,000	0,002	0,000	0,012	0,008	0,002	0,158	0,002	0,012	0,000	0,658	0,003	0,001	0,001	0,014	0,028	0,021	0,002	0,466
USA	-0,362	0,885	-1,338	-1,136	-0,387	-0,635	-0,470	-0,563	-0,070	-0,156	-0,856	-0,776	-0,119	0,875	-1,573	-1,440	-0,077	-0,105	-0,544	-0,964
	0,000	0,001	0,000	0,001	0,002	0,006	0,005	0,010	0,001	0,005	0,001	0,016	0,000	0,007	0,000	0,007	0,004	0,007	0,003	0,042

5. Conclusions

In this article, we aimed to provide an updated estimation of energy-capital substitution for various countries. The overall purpose was to examine whether energy efficiency and technological change have played an important role in advanced economies, thus supporting the decoupling hypothesis, and providing input for public policy responses to increasing fossil fuel scarcity and climate change. Our results find that a complementarity relation between energy and capital characterizes the technology of the manufacturing sector in seven major OECD economies for the period 1970-2005 (starting date differs between countries). This means a strong reliance of manufacturing in all these countries on energy and mineral resources.

In particular, strong complementarity is found for Germany, Spain and the UK, while negative, close-to-zero crossed elasticities are estimated for France, Italy and the USA. The weak substitution of Japan, consistent with the neutral, linear returns to scale (RTS) and technological change (TC) specification (Model 4), comes out as statistically performing the best. The specification with both linear and quadratic input-specific RTS and TC terms (Model 5) turns out to best describe the manufacturing technologies of France, Germany, Italy, Spain (Model 2 also performs well here) and the USA. An input-specific RTS specification without TC (Model 2) best fits the UK. These differences in "best models" can be explained by differences in the composition and technologies of manufacturing in these various countries.

Significant capital-using TC in France, Italy and the USA and energy-saving TC in France, Germany Japan and the USA were found. Furthermore, significant energy-using RTS was found to apply to the UK, and significant labour-saving RTS for France, Germany and Spain, while France and Germany also showed labour-using TC. Finally, labour-saving RTS were found to characterize UK manufacturing, while significant neutral TC and RTS characterize Japan. These results indicate few opportunities for decoupling between production (GDP) and energy in Italy, Spain and the UK.

The world is facing a trend of increasing resource scarcity (notably peak oil) and environmental problems (notably climate change). The solution that can count on most support is relieving the dependence on fossil fuels by developing renewable energy. However, increasing the share of renewable energy in total energy provision also mean less available energy and more expensive energy, mainly because of a considerably lower energy return on energy investment (EROI) for renewable sources compared to fossils (Murphy and Hall, 2010). Higher energy prices, given the energy-capital complementarity relation found here, in turn imply less capital use, which is likely to result in a lower output in the manufacturing sector.

This suggests the need for a deep restructuring of OECD economies that goes beyond an increase in the share of renewable energy efficiency improvements. A steady policy focus on lowering net energy consumption is needed, both on a national and per-capita basis. This will be impossible without considerably increasing energy prices through climate-energy policies which assures that all energy-intensive goods and services provide adequate signals to producers, consumers and innovators alike. This will set in motion the “deep restructuring”, which will particularly affect energy-intensive manufacturing activities like consumer electronics, plastics, cement and glass production.

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Annex 1 – Model estimates

Model 1	France		Germany		Italy		Japan		Spain		UK		USA	
Variable	Coef.	t-val.	Coef.	t-val.	Coef.	t-val.	Coef.	t-val.	Coef.	t-val.	Coef.	t-val.	Coef.	t-val.
lnpk	0,169	64,96	0,108	180,7	-0,027	-14,81	0,165	65,43	0,073	104,9	0,059	33,03	0,463	184,6
lnpl	0,615	153,0	0,656	142,1	0,812	492,9	0,795	274,11	0,898	294,6	0,427	62,67	0,727	289,0
lnpe	0,216	110,0	0,236	53,27	0,215	75,04	0,040	28,61	0,029	10,02	0,513	69,23	-0,190	-87,56
lnpkpk	0,014	3,62	0,051	21,47	0,013	3,98	0,012	5,42	0,075	34,09	0,043	18,49	0,058	5,81
lnplpl	0,006	0,69	0,020	2,31	0,034	9,56	0,016	5,39	0,082	11,78	0,010	1,08	-0,041	-4,85
lnpepe	0,061	12,97	0,121	12,50	0,017	1,72	0,020	7,32	0,200	19,49	0,089	8,56	0,062	8,97
lnpkpl	0,020	3,56	0,025	14,45	-0,015	-5,91	-0,004	-1,76	0,022	8,42	0,018	7,38	0,023	3,07
lnpkpe	-0,034	-11,28	-0,076	-20,22	0,002	0,41	-0,008	-7,37	-0,096	-21,97	-0,061	-15,42	-0,080	-11,96
lnplpe	-0,027	-5,83	-0,045	-5,34	-0,019	-3,46	-0,012	-6,04	-0,104	-13,93	-0,028	-3,06	0,018	3,24
one	12,65	3254	14,05	1422	12,36	1850,0	18,84	2064,7	12,59	659,8	13,19	540,1	14,98	1107,3
RMSE	0,350		0,455		0,421		0,192		0,418		0,560		0,314	
"R2"	-3,120		-8,086		-1,660		0,486		-2,674		-19,66		-0,507	
D-W stat.	0,002		0,004		0,008		0,042		0,010		0,008		0,014	

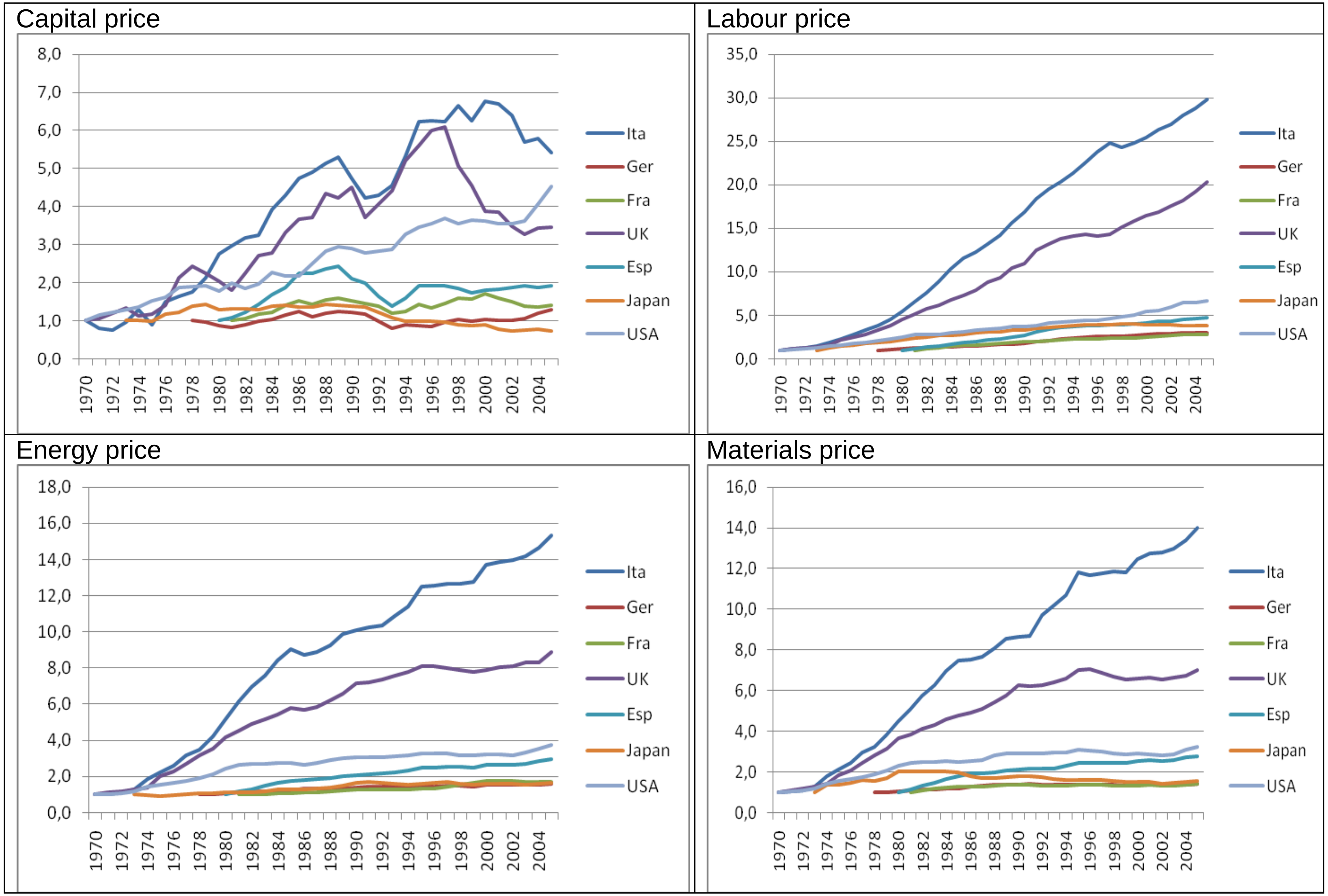
Model 2	France		Germany		Italy		Japan		Spain		UK		USA	
Variable	Coef.	t-val.	Coef.	t-val.	Coef.	t-val.	Coef.	t-val.	Coef.	t-val.	Coef.	t-val.	Coef.	t-val.
lnpk	-0,467	-15,69	-0,091	-1,97	-0,084	-14,28	0,535	4,86	0,056	2,80	-0,172	-5,81	-0,117	-2,79
lnpl	1,562	40,67	1,655	9,28	0,856	38,28	0,422	3,43	1,278	18,92	0,821	7,81	0,862	13,68
lnpe	-0,095	-2,94	-0,564	-2,89	0,228	10,37	0,043	0,95	-0,334	-4,30	0,351	2,74	0,255	6,15
lnpkpk	0,053	18,95	0,048	18,70	0,030	21,15	0,003	0,83	0,085	31,72	0,054	21,36	0,078	9,15
lnplpl	0,093	19,66	0,122	7,55	0,050	7,16	0,006	1,29	0,196	12,99	0,018	0,96	0,005	0,33
lnpepe	0,065	13,86	0,184	8,03	0,034	4,81	0,021	5,76	0,297	12,60	0,060	2,03	0,037	5,11
lnpkpl	-0,040	-14,54	0,007	1,43	-0,023	-14,49	0,006	1,77	0,008	1,67	-0,006	-1,18	-0,023	-2,35
lnpkpe	-0,013	-4,72	-0,055	-8,28	-0,008	-4,43	-0,009	-8,05	-0,093	-13,46	-0,048	-7,08	-0,055	-10,05
lnplpe	-0,052	-12,89	-0,129	-6,97	-0,027	-3,88	-0,012	-3,66	-0,204	-11,11	-0,012	-0,52	0,018	2,08
lny	1,774	123,52	1,684	32,18	0,039	0,22	1,495	90,46	-9,019	-17,29	-4,918	-8,14	-2,181	-4,34
lny2	-0,119	-54,52	-0,101	-13,25	0,004	0,33	-0,052	-30,15	0,708	18,16	0,348	7,83	0,160	4,86
lnpky	0,050	22,80	0,014	2,93	0,014	6,35	-0,017	-3,17	0,020	5,92	0,008	1,65	0,023	7,49
lnply	-0,090	-32,79	-0,102	-7,68	-0,017	-3,41	-0,008	-1,35	-0,046	-6,94	-0,043	-3,01	-0,017	-4,01
lnpey	0,040	15,27	0,088	5,43	0,003	0,55	0,025	10,51	0,027	2,84	0,035	1,97	-0,007	-1,65
one	(dropped)		(dropped)		11,91	9,72	(dropped)		69,54	19,97	47,31	11,46	29,18	7,60
RMSE	0,010		0,029		0,040		0,030		0,041		0,115		0,100	
"R2"	0,996		0,964		0,976		0,988		0,964		0,131		0,847	
D-W stat.	0,815		0,570		0,296		0,474		0,318		0,321		0,074	

Model 3	France		Germany		Italy		Japan		Spain		UK		USA	
Variable	Coef.	t-val.	Coef.	t-val.	Coef.	t-val.	Coef.	t-val.	Coef.	t-val.	Coef.	t-val.	Coef.	t-val.
lnpk	0,247	175,86	0,099	193,9	0,081	51,71	0,173	77,32	0,146	171,9	0,104	59,70	0,178	139,17
lnpl	0,614	526,48	0,856	386,2	0,749	337,8	0,778	226,61	0,849	335,5	0,850	132,6	0,741	311,42
lnpe	0,139	80,25	0,045	17,50	0,170	56,23	0,049	23,86	0,005	1,53	0,046	6,10	0,080	45,39
lnpkpk	0,089	19,44	0,044	24,35	0,030	14,09	0,052	7,96	0,091	33,21	0,041	26,06	0,057	10,21
lnplpl	0,092	22,75	0,123	5,23	0,085	10,49	0,097	8,97	0,163	9,34	0,050	1,46	0,028	1,48
lnpepe	0,049	8,82	0,133	4,06	0,042	4,25	0,013	3,57	0,272	10,29	0,012	0,32	0,024	2,40
lnpkpl	-0,066	-20,14	-0,017	-3,28	-0,037	-10,44	-0,068	-9,19	0,009	1,84	-0,039	-7,89	-0,031	-3,40
lnpkpe	-0,022	-5,40	-0,027	-4,03	0,007	1,88	0,016	4,37	-0,100	-14,27	-0,001	-0,27	-0,026	-4,89
lnplpe	-0,026	-7,27	-0,106	-3,86	-0,049	-5,85	-0,029	-5,50	-0,172	-8,16	-0,011	-0,30	0,002	0,19
t	-0,013	-2,64	0,042	9,43	0,042	20,16	0,053	7,20	-0,003	-0,49	0,015	4,48	0,058	12,78
t2	0,001	3,28	0,000	1,06	0,000	-2,83	-0,001	-1,85	0,003	9,77	0,001	2,22	-0,001	-3,02
lnpkt	0,009	1,75	0,002	0,48	0,012	5,42	-0,002	-0,34	0,007	1,11	0,015	8,43	0,016	4,75
lnplt	-0,014	-3,00	-0,025	-2,95	-0,023	-5,91	-0,033	-5,27	-0,035	-3,13	-0,011	-1,54	-0,004	-0,99
lnpet	0,005	0,58	0,023	2,02	0,011	2,49	0,034	3,79	0,028	1,82	-0,004	-0,54	-0,012	-2,49
one	13,16	1121,8	12,84	1023	12,56	467,1	18,63	981,0	12,08	484,9	12,2	331,2	13,55	870,77
RMSE	0,081		0,365		0,072		0,153		0,063		0,339		0,464	
"R2"	0,781		-4,847		0,923		0,676		0,917		-6,555		-2,303	
D-W stat.	0,042		0,015		0,119		0,052		0,190		0,020		0,012	

Model 4	France		Germany		Italy		Japan		Spain		UK		USA	
Variable	Coef.	t-val.	Coef.	t-val.	Coef.	t-val.	Coef.	t-val.	Coef.	t-val.	Coef.	t-val.	Coef.	t-val.
lnpk	0,033	17,06	0,099	170,0	-0,026	-13,74	0,292	92,15	0,105	156,5	0,101	47,01	0,599	207,1
lnpl	0,768	231,9	0,929	319,0	0,838	492,3	0,461	59,31	0,758	199,7	0,746	123,60	0,483	176,2
lnpe	0,199	94,63	-0,029	-10,24	0,187	64,72	0,247	45,68	0,137	37,2	0,152	22,42	-0,082	-52,3
lnpkpk	0,023	6,80	0,050	21,23	0,012	3,96	0,013	7,37	0,079	35,2	0,037	12,73	0,016	1,81
lnplpl	0,015	1,97	0,070	10,66	0,043	12,36	0,054	6,10	0,088	8,78	0,037	2,73	0,013	1,56
lnpepe	0,068	12,15	0,167	20,09	0,025	2,96	-0,011	-1,79	0,212	16,80	0,113	6,29	0,043	6,34
lnpkpl	0,015	3,41	0,023	13,42	-0,015	-6,92	-0,040	-10,76	0,022	8,66	0,020	5,30	0,007	0,90
lnpkpe	-0,038	-12,66	-0,073	-19,48	0,003	0,61	0,026	8,81	-0,101	-22,47	-0,056	-11,13	-0,023	-3,32
lnplpe	-0,030	-6,12	-0,093	-14,17	-0,028	-5,70	-0,015	-2,30	-0,110	-10,66	-0,057	-3,70	-0,020	-4,28
t	-0,008	-4,68	-0,035	-10,97	-0,009	-6,13	-0,002	-4,19	0,053	7,11	-0,016	-5,76	0,001	0,37
lny	0,044	0,99	0,654	6,91	0,061	4,49	0,386	26,27	-0,675	-5,72	0,091	2,47	0,289	10,24
one	11,35	19,37	4,174	3,23	11,305	64,25	11,691	41,06	19,20	13,12	10,66	21,93	8,028	19,33
RMSE	1,092		0,580		0,738		0,027		1,258		0,896		2,151	
"R2"	-39,03		-13,80		-7,154		0,990		-32,21		-51,99		-69,864	
D-W stat.	0,001		0,001		0,002		0,489		0,002		0,002		0,000	

Model 5	France		Germany		Italy		Japan		Spain		UK		USA	
Variable	Coef.	t-val.	Coef.	t-val.	Coef.	t-val.	Coef.	t-val.	Coef.	t-val.	Coef.	t-val.	Coef.	t-val.
lnpk	-0,245	-2,44	0,251	4,93	-0,077	-10,26	0,588	8,36	0,029	0,36	0,000	0,00	0,341	5,27
lnpl	1,069	14,41	1,105	3,88	0,692	26,33	0,323	3,81	1,482	8,16	1,193	6,85	0,720	5,42
lnpe	0,176	1,49	-0,355	-1,14	0,385	14,10	0,089	1,69	-0,511	-2,27	-0,193	-0,90	-0,062	-0,53
lnpkpk	0,066	14,39	0,043	21,99	0,032	22,35	0,054	8,54	0,083	21,42	0,050	18,56	0,059	10,64
lnplpl	0,099	33,92	0,115	4,70	0,082	10,25	0,069	8,01	0,209	14,42	-0,010	-0,27	0,035	1,61
lnpepe	0,052	9,04	0,122	3,59	0,061	7,34	0,018	4,42	0,309	13,20	-0,029	-0,60	0,009	0,56
lnpkpl	-0,056	-21,23	-0,018	-3,31	-0,026	-12,32	-0,053	-7,95	0,009	1,64	-0,035	-4,04	-0,043	-4,72
lnpkpe	-0,009	-2,10	-0,025	-3,57	-0,006	-2,74	-0,002	-0,43	-0,091	-11,15	-0,015	-1,49	-0,016	-2,54
lnplpe	-0,043	-12,99	-0,097	-3,40	-0,056	-7,02	-0,016	-3,99	-0,217	-12,38	0,045	1,07	0,007	0,43
lny	1,343	18,01	1,428	15,76	2,074	1,09	1,300	63,44	2,108	14,70	1,926	0,68	1,829	27,25
t	0,260	3,07	-0,274	-4,38	-0,036	-0,16	0,062	2,42	-0,951	-8,19	-0,306	-1,57	-0,330	-6,98
lny2	-0,053	-4,61	-0,063	-4,70	-0,152	-1,03	-0,031	-14,31	-0,180	-7,69	-0,167	-0,78	-0,114	-12,28
t2	0,001	2,95	-0,001	-2,29	0,001	0,30	0,002	15,87	-0,006	-4,60	-0,001	-0,94	-0,003	-4,47
lnpky	0,020	2,57	-0,016	-3,48	0,010	1,86	-0,035	-8,60	0,037	3,08	-0,011	-1,88	-0,020	-2,28
lnply	-0,062	-8,74	-0,068	-3,07	0,007	0,43	0,008	1,85	-0,082	-4,22	-0,039	-1,80	0,007	0,44
lnpey	0,042	4,35	0,084	3,42	-0,017	-1,13	0,026	8,32	0,046	1,86	0,050	2,13	0,013	1,01
lnyt	-0,021	-3,28	0,019	3,89	0,004	0,21	-0,005	-4,04	0,075	7,67	0,023	1,58	0,022	6,67
lnpkt	0,011	3,06	0,004	1,51	0,011	2,42	0,013	9,65	-0,013	-1,44	0,013	3,84	0,023	2,98
lnplt	0,011	2,83	0,013	2,18	-0,010	-0,84	0,001	0,82	0,041	2,53	-0,010	-0,92	0,003	0,42
lnpet	-0,022	-4,81	-0,018	-2,26	-0,001	-0,05	-0,014	-8,80	-0,027	-1,73	-0,003	-0,29	-0,026	-2,83
one	(dropped)		(dropped)		-1,383	-0,11	(dropped)		(dropped)		1,894	0,10	(dropped)	
RMSE	0,009		0,012		0,024		0,007		0,024		0,107		0,025	
"R2"	0,998		0,993		0,991		0,999		0,988		0,252		0,991	
D-W stat.	0,902		1,359		0,940		0,931		0,976		0,274		0,807	

Annex 2 – EU-KLEMS Input prices



Annex 3 – EU-KLEMS Input shares

	France				Germany				Italy				Japan				Spain				UK				USA			
	sk	sl	Se	sm	sk	sl	se	sm	sk	sl	se	sm	sk	sl	se	sm	sk	sl	se	sm	Sk	sl	se	sm	sk	sl	se	sm
1970									0,046	0,437	0,092	0,425									0,065	0,488	0,031	0,416	0,102	0,403	0,076	0,418
1971									0,039	0,462	0,088	0,411									0,062	0,456	0,071	0,411	0,114	0,397	0,076	0,413
1972									0,037	0,459	0,090	0,413									0,067	0,456	0,067	0,410	0,113	0,392	0,074	0,420
1973									0,043	0,446	0,095	0,417	0,103	0,366	0,029	0,502					0,064	0,429	0,090	0,417	0,105	0,391	0,074	0,430
1974									0,047	0,425	0,096	0,432	0,089	0,373	0,023	0,515					0,047	0,423	0,115	0,414	0,101	0,377	0,075	0,448
1975									0,030	0,452	0,099	0,418	0,089	0,401	0,020	0,490					0,041	0,444	0,099	0,415	0,120	0,372	0,080	0,428
1976									0,042	0,441	0,097	0,419	0,094	0,393	0,012	0,501					0,043	0,431	0,124	0,402	0,115	0,378	0,078	0,429
1977									0,041	0,444	0,090	0,424	0,092	0,394	0,022	0,492					0,056	0,415	0,104	0,424	0,122	0,374	0,075	0,429
1978					0,058	0,473	0,056	0,414	0,040	0,440	0,090	0,430	0,100	0,398	0,023	0,479					0,059	0,417	0,118	0,406	0,115	0,382	0,072	0,430
1979					0,053	0,472	0,056	0,419	0,042	0,429	0,091	0,438	0,096	0,381	0,022	0,501					0,054	0,465	0,064	0,417	0,109	0,388	0,077	0,427
1980					0,046	0,471	0,063	0,420	0,050	0,422	0,076	0,453	0,075	0,388	0,019	0,517	0,101	0,292	0,085	0,523	0,047	0,475	0,069	0,409	0,102	0,389	0,089	0,420
1981	0,084	0,352	0,061	0,503	0,043	0,469	0,069	0,419	0,048	0,423	0,075	0,453	0,077	0,403	0,018	0,502	0,097	0,286	0,079	0,537	0,042	0,497	0,052	0,408	0,108	0,396	0,080	0,416
1982	0,081	0,357	0,051	0,510	0,047	0,466	0,071	0,416	0,047	0,427	0,072	0,454	0,079	0,414	0,016	0,490	0,097	0,278	0,086	0,539	0,050	0,487	0,045	0,418	0,109	0,397	0,081	0,413
1983	0,086	0,358	0,048	0,509	0,052	0,464	0,067	0,417	0,044	0,436	0,067	0,453	0,077	0,425	0,017	0,481	0,102	0,270	0,075	0,554	0,059	0,480	0,059	0,403	0,113	0,387	0,071	0,429
1984	0,084	0,353	0,048	0,515	0,052	0,456	0,069	0,423	0,048	0,416	0,065	0,471	0,081	0,421	0,017	0,481	0,105	0,253	0,084	0,558	0,057	0,484	0,050	0,409	0,121	0,388	0,072	0,419
1985	0,093	0,349	0,047	0,512	0,056	0,455	0,066	0,422	0,048	0,417	0,060	0,474	0,084	0,427	0,016	0,473	0,110	0,247	0,077	0,566	0,063	0,475	0,053	0,408	0,120	0,404	0,067	0,409
1986	0,101	0,351	0,044	0,505	0,062	0,472	0,053	0,412	0,052	0,427	0,060	0,461	0,088	0,454	0,017	0,442	0,127	0,262	0,058	0,553	0,069	0,489	0,066	0,377	0,122	0,419	0,057	0,403
1987	0,096	0,356	0,043	0,505	0,055	0,480	0,063	0,402	0,052	0,429	0,052	0,466	0,090	0,465	0,017	0,428	0,123	0,270	0,058	0,549	0,067	0,506	0,049	0,379	0,129	0,402	0,060	0,409
1988	0,102	0,343	0,042	0,513	0,059	0,475	0,061	0,405	0,051	0,419	0,050	0,480	0,093	0,456	0,018	0,433	0,125	0,267	0,050	0,558	0,073	0,495	0,052	0,380	0,136	0,390	0,060	0,414
1989	0,102	0,337	0,041	0,520	0,060	0,466	0,063	0,412	0,050	0,416	0,052	0,482	0,092	0,447	0,019	0,442	0,124	0,268	0,054	0,553	0,068	0,511	0,047	0,373	0,138	0,396	0,060	0,405
1990	0,099	0,347	0,042	0,512	0,058	0,475	0,060	0,407	0,044	0,433	0,051	0,473	0,092	0,426	0,021	0,461	0,109	0,294	0,055	0,542	0,074	0,513	0,046	0,367	0,139	0,395	0,065	0,400
1991	0,097	0,353	0,044	0,506	0,055	0,484	0,056	0,405	0,040	0,461	0,050	0,449	0,093	0,430	0,022	0,455	0,104	0,307	0,053	0,537	0,060	0,514	0,045	0,380	0,140	0,398	0,062	0,399
1992	0,093	0,362	0,043	0,502	0,048	0,503	0,045	0,403	0,039	0,443	0,052	0,467	0,093	0,448	0,021	0,438	0,089	0,334	0,052	0,525	0,063	0,488	0,043	0,406	0,136	0,402	0,058	0,405
1993	0,084	0,376	0,045	0,495	0,042	0,521	0,046	0,391	0,041	0,441	0,054	0,465	0,089	0,463	0,022	0,426	0,078	0,352	0,052	0,519	0,066	0,476	0,044	0,414	0,136	0,402	0,055	0,408
1994	0,085	0,365	0,046	0,504	0,046	0,511	0,044	0,399	0,044	0,415	0,053	0,488	0,085	0,471	0,023	0,421	0,082	0,324	0,052	0,541	0,074	0,462	0,044	0,421	0,145	0,393	0,052	0,410
1995	0,092	0,352	0,046	0,510	0,043	0,499	0,047	0,411	0,046	0,384	0,052	0,517	0,087	0,465	0,023	0,425	0,097	0,322	0,057	0,524	0,076	0,449	0,045	0,430	0,148	0,378	0,052	0,422
1996	0,087	0,359	0,048	0,506	0,044	0,505	0,042	0,409	0,047	0,400	0,051	0,502	0,090	0,461	0,024	0,425	0,095	0,325	0,059	0,521	0,081	0,440	0,053	0,426	0,156	0,377	0,051	0,416
1997	0,093	0,348	0,048	0,511	0,049	0,490	0,040	0,421	0,046	0,396	0,051	0,506	0,087	0,457	0,024	0,432	0,093	0,328	0,059	0,520	0,083	0,444	0,050	0,423	0,161	0,381	0,045	0,413
1998	0,100	0,332	0,053	0,515	0,051	0,482	0,041	0,426	0,050	0,385	0,051	0,515	0,088	0,467	0,024	0,421	0,090	0,329	0,052	0,529	0,072	0,475	0,045	0,409	0,157	0,387	0,044	0,411
1999	0,097	0,328	0,053	0,521	0,050	0,482	0,036	0,431	0,048	0,386	0,049	0,518	0,089	0,473	0,023	0,415	0,087	0,328	0,058	0,527	0,067	0,485	0,045	0,403	0,162	0,385	0,045	0,408
2000	0,101	0,315	0,051	0,534	0,048	0,460	0,037	0,454	0,050	0,370	0,051	0,529	0,092	0,455	0,024	0,429	0,084	0,312	0,077	0,527	0,057	0,488	0,050	0,405	0,155	0,384	0,054	0,406
2001	0,095	0,315	0,050	0,539	0,048	0,460	0,034	0,458	0,050	0,371	0,052	0,527	0,083	0,463	0,024	0,430	0,084	0,312	0,074	0,530	0,059	0,490	0,044	0,407	0,165	0,394	0,046	0,395
2002	0,092	0,326	0,048	0,534	0,049	0,467	0,041	0,443	0,048	0,375	0,050	0,527	0,086	0,463	0,025	0,426	0,087	0,317	0,072	0,524	0,054	0,499	0,046	0,401	0,167	0,397	0,047	0,389
2003	0,088	0,337	0,047	0,527	0,052	0,462	0,044	0,442	0,043	0,383	0,051	0,523	0,093	0,448	0,024	0,435	0,088	0,318	0,074	0,520	0,050	0,500	0,048	0,402	0,167	0,403	0,044	0,387
2004	0,085	0,332	0,049	0,534	0,056	0,443	0,038	0,463	0,043	0,379	0,052	0,526	0,096	0,431	0,024	0,449	0,082	0,308	0,083	0,527	0,051	0,493	0,053	0,403	0,176	0,384	0,045	0,395
2005	0,088	0,320	0,048	0,545	0,058	0,426	0,037	0,479	0,040	0,376	0,056	0,528	0,093	0,415	0,024	0,467	0,081	0,304	0,096	0,519	0,052	0,495	0,054	0,400	0,185	0,378	0,046	0,391
Mean	**0,092**	**0,345**	**0,047**	**0,515**	**0,052**	**0,475**	**0,052**	**0,422**	**0,045**	**0,418**	**0,066**	**0,470**	**0,089**	**0,432**	**0,021**	**0,458**	**0,098**	**0,300**	**0,067**	**0,535**	**0,061**	**0,473**	**0,061**	**0,405**	**0,134**	**0,391**	**0,063**	**0,413**