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The Effect of Energy Prices on Operation and Investment in OECD Countries: Evidence from the Vintage Capital Model

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Keywords energy efficiency, energy prices, investment, vintage capital model

JEL Classification D24, E22, Q41, Q43

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1 Introduction

Empirical analysis of the effect of energy prices on energy use has been so far limited by the ability of econometric models to reflect the adaptation of the capital stock to energy price changes. Griffin and Schulman (2005, p.5) describe the problem as follows: "In a properly specified econometric demand model, the stocks of energy-using equipment would be modeled with of a number of investment and depreciation equations for each type of energy using

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capital. Energy consumption would then depend on the utilization and efficiency characteristics of the stock of equipment. Such an elaborate model could then be simulated to describe the adaptation of the capital stock to energy price shocks. But given the absence of capital stock data needed to reflect the adjustment of the capital stock of energy using equipment, econometricians estimate reduced form single demand equations featuring a distributed lag on price to capture the adaptation of the capital stock."

This paper attempts to address this limitation in modelling the effect of energy prices on energy use. Our econometric model explicitly incorporates the capital stock, and separately accounts for operational and investment choices in different sectors. Specifically, we expand the traditional estimation of energy, materials, and labour responses to input price changes by including vintages for the capital stock. Each vintage of the capital stock has its own energy efficiency, which is a function of input prices at the time of investment, and exogenous technological change. In our vintage capital model, a rational cost-minimizing firm chooses both the optimal input quantities and the efficiency of new capital stock. The model therefore accounts separately for the flexibility of substitution between input factors to production (labour, energy and materials), and the potential for more efficient use of these inputs by choosing more efficient technologies at the time of investment. In doing so, our model allows for adaptation of the capital stock to energy price shocks.[1]

Our analysis is based on a new panel dataset, which covers 23 OECD countries and four sectors (agriculture, commerce, manufacturing, and transport) between 1990 and 2005. Compared to earlier studies, our analysis relies on more accurate energy prices in different sectors and countries based on the end-use fuel prices and sector-specific energy mix. As a result, this study is among the few to analyze the effect of energy prices from a cross-country, cross-sector perspective.[2]

We estimate the vintage capital model using a translog cost function approach suggested by Berndt and Wood (1975). However, our cost-share equations are non-linear in factor prices because of the composite effect of input substitution and changes in the efficiency of capital stock. This introduces additional complexity for the estimation of the relevant parameters of the model, and provides a better explanation of energy demand at the sector

[1] An alternative econometric approach, which allows for adaptation of capital stock to energy prices is the quasi-fixed input demand model (Berndt, Morrison, and Watkins 1981; Pindyck and Rotemberg 1983; Popp 2001; and Sue Wing 2008). This approach is based on entirely different assumptions about the nature of the adaptation of the capital stock, and should be treated complementary to our model. For comparison of these approaches (and defense of the vintage capital approach), see Atkeson and Kehoe (1999).

[2] A large number of studies have considered the effect of energy prices from a cross-country within-sector (typically, manufacturing and residential sectors) perspective. The only econometric study known to authors based on cross-country time-series data disaggregated by sector activity and fuel type, which uses theoretically appropriate measures of income and price is Pesaran, Smith, and Akiyama (1998)

level. The assumption of constant efficiency of capital stock is rejected for all sectors.

The results for all sectors indicate that rising energy prices result in substantial decline in the long-run energy use, and affect both the operation (input substitution) and the investment (energy efficiency of capital stock) components of energy demand. However, only the estimates for the manufacturing sector can be reconciled with the economic intuition. The vintage capital model predicts that between 1990 and 2005 the energy efficiency of capital stock in the U.S. manufacturing sector has improved by about 24 percent. Consistent with earlier findings (Linn 2008) the result of policy simulations for the manufacturing sector suggest that the size of operational response to energy prices is larger relative to the size of investment response. Interpretation of these results is however plagued by exogenous structural shifts within and across sectors, regulatory distortions, and measurement error. More robust results would require longer time series and less aggregation across sectors, covering more variation in energy prices.

The rest of this paper is structured as follows. The first section reviews existing literature on the effect of energy prices on energy efficiency. The second section outlines the vintage capital model and resulting stochastic specification. The third section describes the dataset. The fourth section presents the main findings of the research. The fifth section presents the results of policy simulations. The final section concludes, and suggests policy recommendations.

2 Literature Review

The effect of energy prices on energy use is a complex problem, which is still not well quantified. The economic literature identifies several channels through which prices influence energy demand in the short, medium and long-run. In the short-run, the main channel is input substitution, which captures the effect of relative energy prices on the optimal choice of inputs to production. An increase in real energy prices lowers the demand for energy services and their complements (e.g. capital), and raises the demand for substitutes to energy services (e.g. labor). This channel is well studied both theoretically and empirically based on capital-labor-energy-materials (KLEM) input demand model (Berndt and Wood 1975, Griffin and Gregory 1976, and Pindyck 1979).[3]

In the medium run, two important channels are the change in the industry structure of the economy, and improvements in energy efficiency of the capital stock. The change in the industry structure of the economy takes place because an increase in the real price of energy services raises the price of intermediate and final goods throughout the economy, leading to

[3]For a summary of subsequent studies on this topic, see e.g. Barker, Ekins, and Johnstone (1995), and Kilian (2008)

series of price and quantity adjustments, with energy-efficient goods and sectors likely to gain at the expense of energy-intensive ones (Sorrell and Dimitropoulos 2008, p.637). Though large number of studies in energy economics attempted to assess the scope of this channel[4], their findings are still difficult to reconcile. Two recent empirical contributions are studies by Metcalf (2008) and Sue Wing (2008). Both studies decompose changes in the aggregate energy intensity into shifts in the structure of sectoral composition and adjustments in the efficiency of energy use. Metcalf (2008) adapts an index number based theoretical approach, and finds that "roughly three-quarters of the improvements in U.S. energy intensity since 1970 results from efficiency improvements" (Metcalf 2008, p.1). Sue Wing's (2008) structural model attributes most of the changes in the U.S. energy intensity to adjustments of quasi-fixed inputs and disembodied autonomous technological progress. The study concludes that "price-induced substitution of variable inputs generated transitory energy savings, while innovation induced by energy prices had only a minor impact." (Sue Wing 2008, p.21).

In the medium-run, firms also respond to an increase in real energy prices by changing their investment decisions and improving the energy efficiency of their capital stock (achieving smaller energy input requirements per unit of capital). For example, firms in the commercial sector may insulate their office buildings, and firms in transport sector may adopt hybrid vehicles to achieve better mileage per gallon. Atkeson and Kehoe (1999) establish a theoretical foundation of this channel by analyzing energy efficiency in the context of a putty-clay model. In their model, each vintage of the capital stock has its own energy efficiency. In the short-run, capital and energy inputs are the complements, and energy demand elasticity is small. In the long-run, in response to permanent energy price changes, agents invest in capital goods with different energy efficiency. As a result, energy use becomes more responsive to energy prices.[5] Notwithstanding sound theoretical underpinnings, there is little empirical work on the effect of energy prices on the energy efficiency of capital stock.[6] This paper attempts to address this shortcoming in the empirical literature on energy efficiency.

In the long-run, a significant channel is technological change, both exogenous (e.g. resulting from autonomous scientific advance), and energy-price induced. This channel was studied empirically by Newell, Jaffe, and Stavins (1999), Popp (2002), Griffin and Schulman (2005), Frondel and Schmidt (2006), and Linn (2008). All of these research works use different methodologies and reach different conclusions. Newell, Jaffe, and Stavins (1999) develop a product-characteristics model of energy-saving consumer durables, and find that

[4] For a survey of these studies, see Ang and Zhang (2000).

[5] Diaz, Puch and Guillo (2004) relax some assumptions of Akeson and Kehoe (1999), and reach similar conclusions.

[6] A notable exception is a study by Newell, Jaffe, and Stavins (1999), but their analysis focuses only on three particular products (room air conditioners, central air conditioners, and gas water heaters).

the energy price has little effect on the rate of overall innovation, but it does affect the direction of innovation for some products. Popp (2002) estimates a structural model, using U.S. patent data as an instrument for scientific knowledge, and finds that both energy prices and the quantity of existing knowledge have very significant positive effects on innovation in the energy sector. Frondel and Schmidt (2006) compare energy-price elasticities of capital before and after the oil crisis of the early 1970s. The results of their counterfactual analysis indicate a substantial technological change, but its magnitude is unknown because of the change in economic circumstances. Griffin and Schulman (2005) argue that energy-saving technical change explains asymmetric price responses in econometric energy demand models.[7] Linn (2008) uses the U.S. plant-level data to compare the energy intensity of entrants and incumbents. The results of Linn's (2008) empirical analysis show that energy prices and technology adoption have a small effect on energy intensity.

3 Vintage Capital Model of Energy Demand

We introduce vintage capital model that separately accounts for investment and operational (production) decisions. We start with the firms' investment. Firms add new capital stock based on specific production technology. For each capital vintage firms choose the optimal level of factor efficiency of production technology given their expectations of future input costs.

We then consider production decisions, where firms minimise realized input costs to produce the desired output level given the level of input efficiency of installed production technology. The resulting equations are subsequently used to form stochastic specifications and estimate the input price elasticities of factor substitution and capital stock efficiency.

3.1 Investment Choice of Input Efficiency

We assume that economic behaviour in OECD country i at time t can be represented by that of a rational cost-minimizing firm assumed to operate in perfectly competitive product and factor markets. The firm is fully flexible in its choice of labor ($x^l_{i,t}$), energy ($x^e_{i,t}$), and materials ($x^m_{i,t}$) inputs. The capital stock ($x^k_{i,t}$) has vintage representation, and each vintage has its own technological efficiency with respect to each input to the production function. The investment in factor efficiency of a capital vintage is sunk. New capacity with a different production technology can be added, but all old vintages must depreciate before adjustment is complete. The production technology is thus inflexible in terms of the capital efficiency requirements.[8]

[7] Also see Gately and Huntington (2002), and Adeyemi and Hunt (2007).

[8] This assumption is consistent with "putty-clay" production technology models. For discussion of this assumption see Atkeson and Kehoe 1999. Other studies that adopt putty-clay models of energy use are

We assume that the efficiency of a capital vintage in period q with respect to input j is represented by an index $\gamma^j_{i,q}$. While firms make technology choices in period q, there is a lag between the firm's investment decision and plant commissioning. The technology is installed and becomes fully functional in period $q+1$. Firm's production decisions in period q are thus made based on production technology set up in period $q-1$.

The quantity of input j in period q, $x^j_{i,q}$, and the index of input efficiency of capital vintage, $\gamma^j_{i,q-1}$, determine the input service to production function, $\widetilde{x}^j_{i,q}$:

$$\widetilde{x}^j_{i,q} = \frac{x^j_{i,q}}{\gamma^j_{i,q-1}}, \quad \gamma^j_{i,q} > 0 \ . \tag{1}$$

Similarly, the relationship between the price of input in period q, $w^j_{i,q}$ and the price of service $\widetilde{w}^j_{i,q}$ is given by

$$\widetilde{w}^j_{i,q} = w^j_{i,q}\gamma^j_{i,q-1}. \tag{2}$$

The input efficiency that firms choose for energy, labour and materials is a function of the input prices and the exogenous technological change:

$$\gamma^j_{i,q} = (1-\zeta)^q \left(\frac{w^j_{i,q}}{\overline{w}^j}\right)^{-\phi^j}, \tag{3}$$

where $\overline{w}$ is the average price of input j across countries and all time periods[9], ϕ^j is the elasticity of input efficiency of capital stock with respect to input price changes, and ζ is the rate of exogenous Hicks-neutral technological change[10]. In appendix 1 we show this is the profit maximising (cost minimising choice) of a firm that faces a technology cost function.

Then, for all observed capital vintages we derive the index of input efficiency of capital stock $\widetilde{\gamma}^j_{i,t}$ as a sum of historic vintage efficiencies weighted by each vintage's q contribution to capital stock x^k_t :

$$\widetilde{\gamma}^j_{i,t} = \sum_{q=1}^{t} (1-\zeta)^q \left(\frac{w^j_{i,q}}{\overline{w}^j}\right)^{-\phi^j} \frac{I_{i,q}\,(1-\delta)^{t-q}}{x^k_{i,t}}, \tag{4}$$

Hawkins (1978), Abel (1983), Struckmeyer (1986), Struckmeyer (1987), and Wei (2003).

[9] We have chosen the OECD average input price across countries and all time periods to reflect the effects of globalization and industry migration. For sectors that are less globally integrated (e.g. agriculture, transport) we also considered the input price based on the country average across time: $\overline{w}^j_i = \sum_{t=1}^{T} w^j_{i,t}/T$. Estimation results are available from authors upon request.

[10] While there is an evidence that technological change responds endogenously to energy prices (see e.g. Popp 2002), endogenizing technological change is precluded by the numerical complexity of the model. Given this, our results should be interpreted as the lowest boundary of the effect of energy prices on energy efficiency of the capital stock.

where $I_{i,q}$ is the vintage investment in period q, and δ is the rate of economic depreciation of capital stock.

Because we do not know the values of the index of input efficiency of capital stock for vintages outside observation sample, we have to assume that they are the same as in the first period of observation sample. Under this assumption the index of input efficiency of capital stock becomes

$$\gamma_{i,t}^{j} = (1-\delta)^{t} x_{i,0}^{k} \left(\frac{w_{i,0}^{j}}{\overline{w}^{j}} \right)^{-\phi^{j}} + \sum_{q=1}^{t} (1-\zeta)^{q} \left(\frac{w_{i,q}^{j}}{\overline{w}^{j}} \right)^{-\phi^{j}} \frac{I_{i,q} (1-\delta)^{t-q}}{x_{i,t}^{k}}, \tag{5}$$

where the first term on the right hand side is the value of the index of input efficiency of capital stock in the first period of observation sample.[11]

3.2 Production Choice of Input Factors

We assume that firm minimises the costs of its inputs to deliver the output Y:

$$\min \sum_{j=k,l,e,m} w_{i,t}^{j} x_{i,t}^{j} \ s.t.\ f(\widetilde{x}_{i,t}^{k}, \widetilde{x}_{i,t}^{l}, \widetilde{x}_{i,t}^{e}, \widetilde{x}_{i,t}^{m}) = Y_{i,t}, \tag{6}$$

where $f(\cdot)$ is continuous, twice differentiable production function relating the flow of gross output $Y_{i,t}$ to the services of four inputs - capital $\left(\widetilde{x}^{k}\right)$, labor $\left(\widetilde{x}^{l}\right)$, energy $(\widetilde{x}^{e})$, and all other intermediate materials $(\widetilde{x}^{m})$.

Let $\widetilde{x}_{i,t}^{*}(Y_{i,t}, \widetilde{w}_{i,t}^{k}, \widetilde{w}_{i,t}^{l}, \widetilde{w}_{i,t}^{e}, \widetilde{w}_{i,t}^{m})$ be the set of optimal input services, and $C(Y_{i,t}, \widetilde{w}_{i,t}^{k}, \widetilde{w}_{i,t}^{l}, \widetilde{w}_{i,t}^{e}, \widetilde{w}_{i,t}^{m})$ be the expenditure function which corresponds to the production function. Following the economic literature on input demand starting from Christensen, Jorgenson, and Lau (1973) and Berndt and Wood (1975), we assume that the expenditure function can be approximated by the translog model:

$$\log C_{i,t} = \alpha_0 + \alpha_Y \log Y_{i,t} + \sum_{j} \alpha_{ij} \log \widetilde{w}_{i,t}^{j} + \frac{1}{2} \beta_{YY} \left(\log Y_{i,t}\right)^2 +$$
$$\frac{1}{2} \sum_{j} \sum_{k} \beta_{ijk} \log \widetilde{w}_{i,t}^{j} \log \widetilde{w}_{i,t}^{j} + \sum_{j} \beta_{Yj} \log Y_{i,t} \log \widetilde{w}_{i,t}^{j} + \lambda t + \varepsilon_{it}^{j}. \tag{7}$$

where ε_{it}^{j} is the error term. Differentiating (7) with respect to the logarithm of the prices of efficient inputs, and applying Sheppard's lemma yields four factor input cost share

[11] We attempted to estimate the joint efficiency of all unobserved capital stock vintages as a free parameter, but were unable to do so because of limited variation in data.

equations

$$S_{i,t}^{j} = \alpha_{ij} + \beta_{Yj} \log Y_{i,t} + \sum_{j} \beta_{ij} \log \widetilde{w}_{i,t}^{j} + \varepsilon_{it}^{j}, \tag{8}$$

where $S_{i,t}^{j} = \frac{\partial C}{\partial \widetilde{w}_{i,t}^{j}} \cdot \frac{\widetilde{w}_{i,t}^{j}}{C} = \frac{\widetilde{w}_{i,t}^{j} \widetilde{x}_{i,t}^{*}}{C} = \frac{w_{i,t}^{j} x_{i,t}^{*}}{C}$ is the share of each input j in firm's total cost.

3.3 Estimation of Vintage Capital Model

Combining equations (2), (5), and (8) yields a system of four equations to be estimated:

$$S_{i,t}^{j} = \alpha_{ij} + \beta_{Yj} \log Y_{i,t} + \sum_{j} \beta_{ij} \log \left(w_{i,t}^{j} \left[\psi \left(1-\delta\right)^{t-1} + \sum_{q=1}^{t-1} \left(\frac{w_{i,l}^{j}}{\overline{w}^{j}} \right)^{-\phi^{j}} \left(1-\zeta\right)^{q} \sigma_{i,q} \right] \right) + \varepsilon_{it}^{j}, \tag{9}$$

where α_{ij} are country-specific fixed effects, $\sigma_{i,q}$ is the last term in equation (4), and $\psi = x_{0}^{k} \left(\frac{w_{i,0}^{j}}{\overline{w}^{j}} \right)^{-\phi^{j}}$.[12] Following Griffin and Gregory (1976, p. 849) we treat input prices as purely exogenous, because the small sample bias from a set of constructed instrumental variables is not necessarily smaller than that obtained from actual prices.

The system of equations (9) is a conditionally linear seemingly unrelated regression[13], which is efficiently estimated by full information maximum likelihood (FIML). Because the share equations in the model (9) add to one, only 3 share equations are estimated.

The values of parameters ζ and ϕ^{j} are estimated to maximize the value of the model's goodness-of-fit criterion, and are obtained by the grid search. To minimize the computational burden of a multidimensional grid search, based on earlier empirical findings (e.g. Jorgenson and Fraumeni 1981; Raff and Summers 1987; Baltagi and Griffin 1988; Newell, Jaffe, and Stavins 1999; Li, Von Haefen, and Timmins 2008; and Sue Wing 2008) we restrict the parameter bounds for exogenous technological change ζ to lie between -0.01 and 0.04 and the elasticity of input efficiency of capital stock with respect to input price changes ϕ^{j} - between 0 and 1.5.

While the system (9) forms our basic empirical model we also estimate a restricted model, assuming that input efficiency of capital stock does not change, so $\gamma_{i,t}^{j}$ is set to 1 (or both

[12] Our econometric approach described by equation (9) is similar to Haas and Schipper (1998), who advocate calculating an index of energy efficiency, and using it directly in econometric specification for energy demand. The index of Haas and Schipper (1998) though is obtained through factor decomposition, and is thus purely exogenous.

[13] e.g. we still need to obtain the values of ζ and ϕ^{j} before estimating the model (9) as a linear problem.

ζ and ϕ^j are set to zero). Under this restriction the model becomes a conventional translog model of input demand of Berndt and Wood (1975) and Griffin and Gregory (1976). We then use the likelihood-ratio test to evaluate the significance of input efficiencies of capital stock in the models of energy demand.

To quantify factor response to current price changes holding all previous prices constant, we compute own-price and cross-price elasticities of substitution.[14] These elasticities are given by

$$\eta_{jj} = \frac{\partial \ln x_{i,t}^j}{\partial \ln w_{i,t}^j} = \frac{\beta_{jj} + \left(S_{i,t}^j\right)^2 - S_{i,t}^j}{S_{i,t}^j}, \; j = k, l, e, m. \tag{10}$$

and

$$\eta_{pj} = \frac{\partial \ln x_{i,t}^j}{\partial \ln w_{i,t}^p} = \frac{\beta_{pj} + S_{i,t}^p S_{i,t}^j}{S_{i,t}^j}, \; p, j = k, l, e, m, \; p \neq j. \tag{11}$$

Because analysis is based on the panel data across countries, the estimated elasticities have a standard interpretation of the long-run equilibrium effects (Griffin and Gregory 1976).[15] Inclusion of capital vintages does not affect this interpretation of computed elasticities, because capital stock adjusts fully to equilibrium in the long run.

4 Data

Our model is estimated using the panel data of 23 OECD countries separately for four sectors - agriculture (ISIC sector A), manufacturing (ISIC sector C), commerce (ISIC sector G), and transportation (ISIC sector H). The main data source for empirical analysis is the EU KLEMS database. The EU KLEMS database comprises of data on production inputs, labor and capital input prices[16], and output at the industry level for the European Union, United States, Korea, and Japan. The data is constructed based on the methodology set by Jorgenson, Gollop, and Fraumeni (1987) and Jorgenson, Ho, and Stiroh (2005).[17] The time coverage for different series varies significantly across countries and sectors. To ensure

[14] We have also estimated Allen's and Morishima's partial elasticities of substitution. Because these elasticities have less straightforward interpretation (Frondel 2004), and can be directly inferred from estimated cross-price elasticities, their estimates are not reported and available from authors upon request.

[15] Input substitution elasticities thus capture several separate substitution effects, including within-firm input substitution, within-industry, and cross-industry compositional changes. Sorting out between these effects is beyond the scope of this paper.

[16] Data on the price of capital services were not available for some countries. For these countries following Andrikopoulos, Brox, and Paraskevopoulos (1989) and Cho, Nam, and Pagán (2004) we computed the capital input prices (available from IMF International Financial Statistics Database) as a sum of the nominal interest rate on short-term government papers, and capital depreciation rate.

[17] For more details, see Timmer, O Mahony, and van Ark (2007).

best country coverage we estimate the system of share equations (8) based on an unbalanced panel over the period 1990-2005.[18]

In our dataset we only have data for capital stock $x_{i,t}^{k}$ and do not observe actual investment. Following large number of empirical studies on investment behaviour (for a survey see Jorgenson 1971) we assume geometric mortality distribution, (e.g. replacement is proportional to actual capital stock) and time-invariant rate of economic depreciation. Under these assumptions vintage investment in period q is given by

$$I_{i,q} = x_{i,q}^{k} - (1-\delta)x_{i,q-1}^{k}. \tag{12}$$

Based on earlier studies (e.g. Hubbard and Kashyap 1992; Hulten and Wykoff 1996; Nadiri and Prucha 1996; and Jorgenson 1996) we set economic depreciation rates as follows: economy level - 8%, agriculture - 12%, commerce - 20%, manufacturing - 5%, transport - 20%.

We obtain the end-use energy price data from the International Energy Agency database, and construct the average sector energy price by weighting energy carriers' prices by the consumption of each energy carrier in the sector.[19]

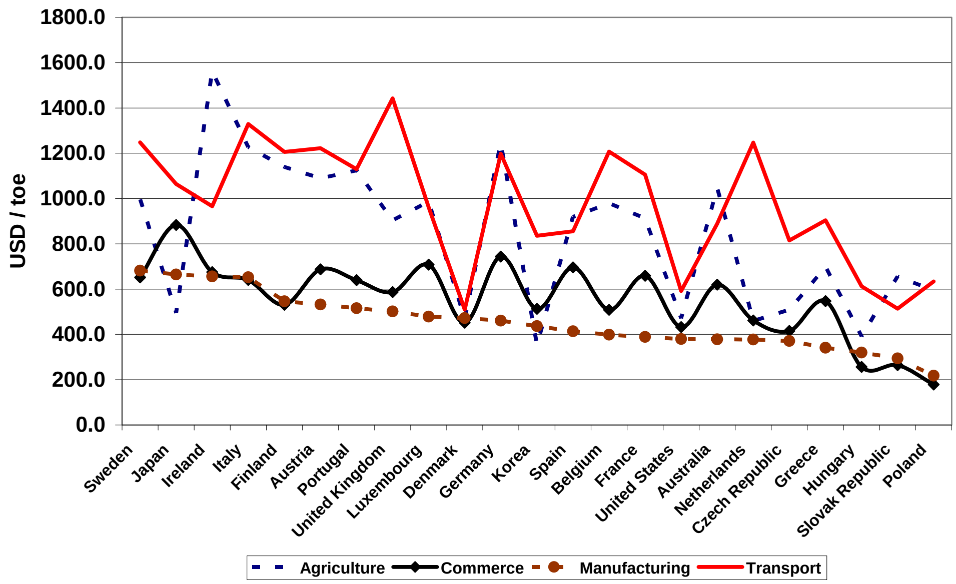
Figure 1 shows average energy prices across different sectors in OECD countries in 2000. There are large differences in energy prices across both OECD countries and sectors, because of variation in energy taxes, types of fuels used in the production process, and local distribution costs. Across sectors, the highest energy prices are in the transport sector, and the lowest are in the manufacturing sector. Across countries, the highest energy prices are in European countries (Italy, Ireland, Sweden, and the United Kingdom) and Japan, and the lowest are in Eastern European economies and the United States. Energy taxes appear to be the major factor explaining the energy price differences - for example, in 2008 gasoline tax accounted for nearly 60 percent of final energy price in Sweden, Germany and the United Kingdom, compared to just 13 percent in the United States (International Energy Agency 2008). In contrast, industrial energy prices are similar across OECD countries. This may reflect constraints on national energy tax policies in the manufacturing sector, posed by countries' concerns to maintain their international competitiveness (Brack, Grubb, and Windram 2000).

We construct the price of materials by weighting international commodity prices (from

[18] The panel is unbalanced because the data for Czech Republic, Poland, and Slovak Republic were available as of 1995.

[19] Specifically, we consider the following energy products - oil and petrolium products (high- and low-sulphur fuel oil, light fuel oil, automotive diesel, and gasoline), natural gas, coal, and electricity. Consumption of each product is measured in British thermal units (BTUs). More details are available in the technical appendix, available from authors upon request.

Figure 1: Average Real Energy Prices across OECD Countries and Sectors in 2005 (base year 1995, sorted by manufacturing sector in declining order)



IMF International Financial Statistics database) by sector consumption of each commodity (from UNIDO Industrial production database). The data series for labor, energy, and material costs, and for the value of output and capital stock are all deflated to their real values, using 1995 as a base year, and converted into United States dollars. Full list of variables, countries and the descriptive statistics for the final dataset are shown in Tables 1-3 (Appendix 2).

5 Results of Estimation of Vintage Capital Model

The results for the aggregate OECD economy level and for the four sectors are presented in Tables 4a-4e (Appendix 2). We present results for both the vintage capital model, and the standard translog model of energy demand, in which the indices of input efficiency of capital stock are set to 1[20]. Tables 1 and 2 present estimated own-price elasticities of input demand, cross-price elasticities of energy demand, and own-price elasticities of input efficiency of capital stock based on the vintage capital model.[21] Tables 5a-5e, Appendix 2 demonstrate variation of estimated elasticities across countries. Estimated cross-price elasticities of other input demands are presented in Table 6, Appendix 2. Figures 1a-1e, Appendix 3 show the

[20] This model is refered as a *restricted model* in Tables 4a-4e of Appendix II.

[21] Estimated elasticities of input demand based on the restricted model are not reported because their size and magnitude was not substantially different from the unrestricted model. The results are available from authors upon request.

values of the calculated indices of input efficiency of capital stock.

The vintage capital model provides a better explanation of energy demand at both economy and sector levels. The likelihood ratio test indicates that the restriction of input efficiencies of capital stock equal to 1 is rejected at the 1% level of significance for both the economy-level and sector-level estimates.

Table 1. Estimated Own-Price Elasticities of OECD Input Demand

Sector	Sector Share in OECD Gross Output	η_{LL}	η_{KK}	η_{EE}	η_{MM}	η_{LE}	η_{KE}	η_{ME}
Total Economy	100%	-0.27	-0.81	-0.10	-0.60	-0.05	-0.11	0.15
Agriculture	2.5%	-0.30	-0.85	-1.12	-0.67	0.01	1.74	0.07
Commerce	10.6%	0.07	-0.63	-1.51	-0.44	0.09	-0.09	0.19
Manufacturing	31.1%	-0.39	-0.89	-1.30	-0.57	0.18	-0.05	0.16
Transport	6.2%	-0.10	-1.02	-0.85	-1.13	0.45	0.59	0.28

Overall, the estimates of own-price and cross-price elasticities of input demand are consistent with their economic interpretation. Table 1 demonstrates that all but one of the estimated own-price elasticities for input demands across different sectors have the expected signs. The only exception is the commerce sector, where the own-price elasticity of labor demand does not have the expected sign. This outcome may result from endogeneity of wages and cost shares in labor-intensive commerce sector.

Estimated elasticities of own-price input demand generally have reasonable magnitudes. The results from the vintage capital model indicate that long-run energy demand is elastic in all sectors, except for the transport sector, with highest operational response in the manufacturing and commerce sectors. These estimates are higher compared to previous panel data studies (0.6-0.9). These differences could reflect a variety of reasons (e.g. technological change, energy and capital market liberalization, changed economic circumstances, and measurement error), and their empirical assessment is not possible without proper counterfactual analysis (Frondel and Schmidt 2006). At the economy-level, the estimated own-price energy demand elasticities are lower than expected. This may reflect the effect of the residential sector, where the medium term response to energy prices is highly inelastic.

Table 1 also shows estimated partial cross-price elasticities of energy demand. As expected, labor and materials are substitutes for energy at the sector level. At the economy level, the direct elasticities show that energy inputs are substitutes to materials, and complements to labor. Complementarity between labor and energy inputs at the economy level is puzzling, and is possibly the outcome of the aggregation bias, discussed earlier in this section.

The relation between energy and capital inputs varies across sectors. The elasticities indicate that capital and energy are the substitutes in the agriculture and transport sectors, comparable with the interpretation that larger capital intensity implies modern and energy efficient equipment. In the manufacturing and commerce sectors the elasticity is negative, indicating that capital and energy are compliments. This result is similar to previous findings (Thompson and Taylor 1995), and reflects the difficulties in measuring the elasticity of substitution in a multiple factor world.

Table 2. Own-Price Elasticities of Input Efficiency of Capital Stock,
Real Input Price Changes, and the Rate of Exogenous Technological Change
in OECD Countries, 1990-2005

Sector	γ_L	Change in Real Wages, %	γ_E	Change in Real Energy Prices, %	γ_M	Change in Real Materials Prices, %	ζ
Total Economy	0.65	-2.34	0.32	6.05	1.26	-26.82	0.028
Agriculture	0.04	59.72	0.73	34.45	0.03	-8.71	0.032
Commerce	0.01	8.05	0.90	-17.09	0.095	-30.27	0.022
Manufacturing	0.37	22.33	0.32	16.40	0.001	-6.29	0.025
Transport	0.31	20.82	0.82	8.04	0.57	-27.44	0.035*

* estimate did not meet the boundary condition

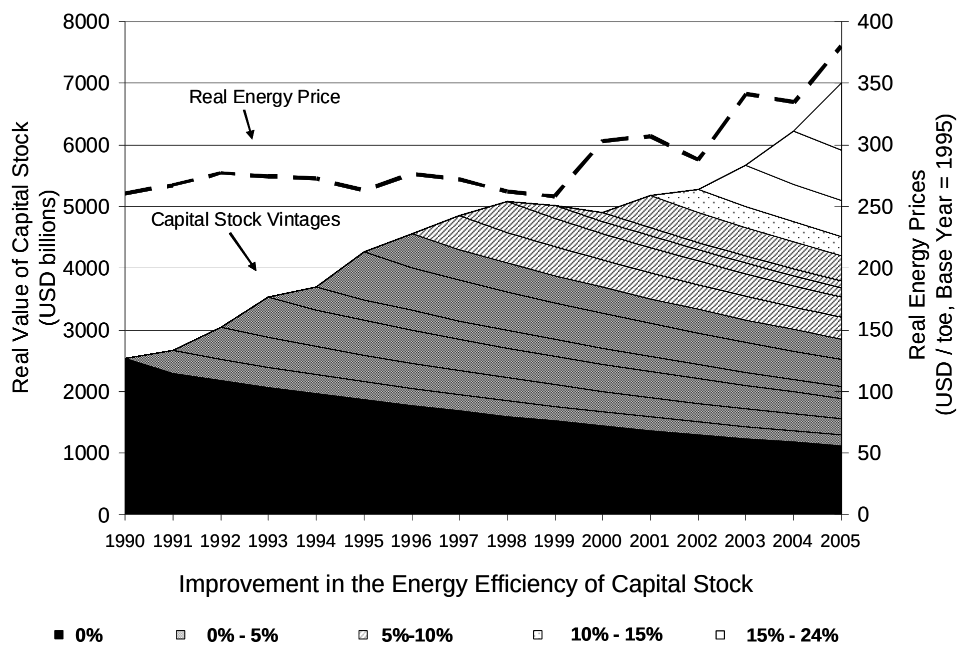
Table 2 illustrates the estimated elasticities of input efficiency of capital stock, corresponding real input price changes and the estimated rate of exogenous technological change in OECD countries between 1990 and 2005. At the sector level, only the estimates for the manufacturing sector can be reconciled with economic intuition. Estimated own-price elasticities of labor and energy efficiency of capital stock in the manufacturing sector have reasonable magnitudes. The own-price elasticity of materials efficiency of capital stock is close to zero in the manufacturing sector (and also in the agriculture and the commerce sectors). Table 3 shows that the real price of materials has fallen in all sectors. This result suggests that capital stock responds little to falling input prices and supports the hypothesis of asymmetric demand response to input prices (Borenstein, Cameron, and Gilbert 1997; Peltzman 2000; Gately and Huntington 2002).[22] The parameter ζ in the manufacturing sector (and all other sectors) is positive, indicating that autonomous technological change rises input efficiency of capital stock.[23]

Figure 2 illustrates the effect of energy prices on energy efficiency of capital stock, by showing estimated rate of improvement in energy efficiency in manufacturing sector across

[22] Because of little time series variation in data, this result should be taken with caution.

[23] It can be seen from Table 2 that the model failed to converge in transport sector with the specified range of boundaries. We have examined the model sensitivity to relaxing the range of estimation bounds. The model converged yielding no corner solutions but unreasonable estimate for the technological change parameter. Other parameters were little affected. Further details are available from authors upon request.

Figure 2: Real Energy prices and Energy Efficiency Improvements in the U.S. Manufacturing Sector



capital vintages in the United States in 1990-2005. The vintage capital model predicts that between 1990 and 2005 the energy efficiency of capital stock in the U.S. manufacturing sector has improved by about 24 percent. Real energy prices did not change much before 2000, and most improvements in the energy efficiency of capital stock were driven by exogenous energy-saving technological change. The major price-induced improvement in energy efficiency came between 2000 and 2005, following a sharp rise in real energy prices.

In other sectors of economic activity, the estimated elasticities of input efficiency of capital stock are not consistent with the economic theory and available evidence. Specifically, in the agriculture and the commerce sectors, the estimated elasticities of labor efficiency of capital stock are close to zero, and the estimated elasticities of energy efficiency of capital stock are 2.5-3 times larger than in the manufacturing sector. In the transport sector, the parameter for autonomous technological change failed to meet boundary conditions, casting doubts on the interpretation of estimated parameters. We believe that these results are the consequence of exogenous structural shifts (especially in the new member states of the

European Union)[24], regulatory distortions[25], and measurement error[26]. Further research at less aggregate level is required to explain these results better.

At the economy level, the estimated own-price elasticities of labor and energy efficiency of capital stock have reasonable values. The estimated elasticity of materials intensity of capital stock, however, is considerably higher than at the sector level, and is not consistent with our expectations. Another puzzling result is that the average real wages have declined at the economy level, and have increased at the sector level. These findings suggest that in addition to the problems discussed in the previous paragraph, the economy-level estimates reflect the effect of omitted sectors, and measurement error of non-linear aggregation across sectors.

6 Simulated Effects of Greenhouse Gas Emissions Tax

The results of the model discussed in the previous section indicate that capital stock is significant in determining the future energy efficiency of production. These findings imply that energy and climate policies providing incentives for early investment in energy efficient capital stock may reduce future energy (including fossil fuel) input consumption. To illustrate the outcome of such policies we use the vintage capital model predictions to evaluate the effect of a greenhouse emissions tax on energy consumption. Because of the difficulties with interpreting economy-level and most of the sector-level estimates described in preceding section, our analysis is restricted to the manufacturing sector. Specifically, we simulate the effect of the greenhouse gas (carbon dioxide, CO_2) emissions tax implemented in 2005.

We assume that all input prices except for the energy prices and output remain at their 2005 levels (e.g. $\Delta Y_{i,t} = \Delta w_{i,t}^{j=k,l,m} = 0, t > 2005$). The capital stock stays constant, and the vintage investment offsets capital stock depreciation (e.g. $x_{i,t>2005}^{k} = x_{i,2005}^{k}$, $\Delta I_{i,l>2005} = (1-\delta)\, x_{i,2005}^{k}$). Based on the results of the vintage capital model (see Table 3 and Table 5d, Appendix 2) we assume that the rate of exogenous technological change $\zeta = 0.025$, the own-price elasticity of energy efficiency of capital stock $\phi^{e} = 0.32$, and the own-price elasticity of energy demand for the U.K. manufacturing sector $\eta_{ee} = -1.44$.

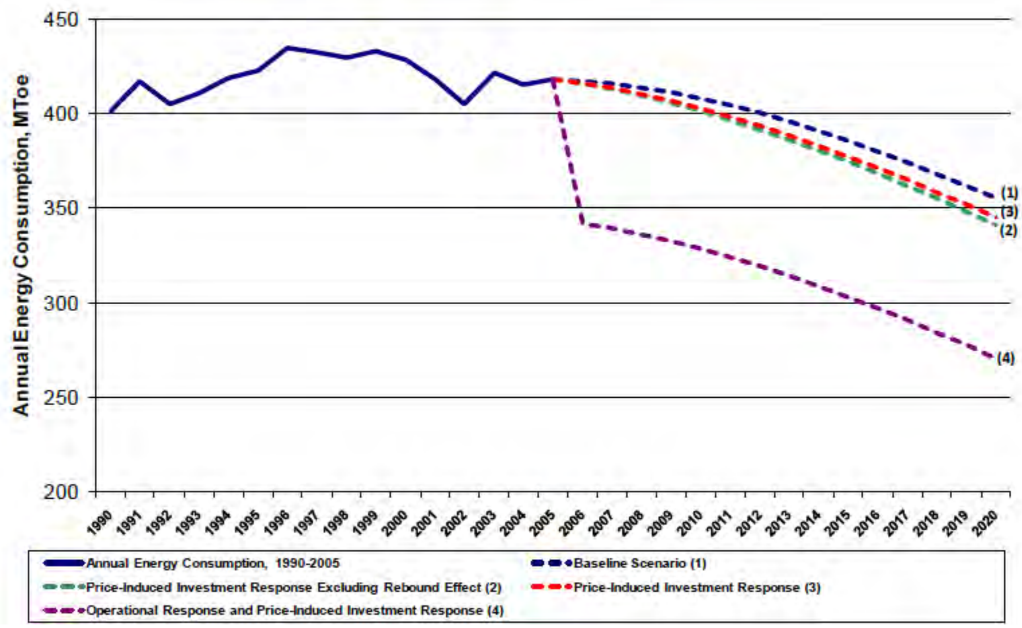
Figure 3 illustrates the simulation results. In the baseline scenario, we assume there is

[24] Havlik (2004) finds that productivity catching-up observed in the new member states of the European Union resulted overwhelmingly from massive shut-downs of unproductive labor- and energy- intensive firms, especially in the agriculture sector. The employment shifts among sectors had only a negligible effect on aggregate productivity growth.

[25] for example, Fulginiti and Perrin (1993) finds that subsidies distort wage-productivity link in the agriculture sector. Regulatory policies in the agriculture and transport sector may also affect the market structure, thus compromising model assumption that firms are perfectly competitive cost minimizers.

[26] For problem of measurement error in the empirical studies of the service sectors, see (Gordon 1996). (Timmer, O Mahony, and van Ark 2007) report a number of unresolved issues in the measurement of intermediate input prices, value added, and the capital stock in the EU KLEMS database.

Figure 3: Simulated Effect of $30 Carbon Tax on Energy Consumption in the UK Manufacturing Sector



no greenhouse emission tax, and energy price does not change. The change in the energy input consumption in the baseline scenario is determined by two factors. The first factor is the improvement in the energy efficiency of capital stock due to exogenous technological change. To quantify this effect we use the assumptions above to compute an index of energy efficiency of the capital stock for the simulation sample based on equation (5). The second factor is the change in the share of energy service due to the substitution effect between labor, energy, and materials services.[27] We compute the change in the share of energy service using the results from regression (9) for the manufacturing sector (see Table 4d, Appendix 2), and convert this change into energy units (*toe*). Our calculations show that in the baseline scenario, these factors account for 18 percent decline in energy input consumption by 2020.

In the counterfactual scenario, we assume there is $30 tax per ton of emitted greenhouse gas. Using the data for the UK manufacturing sector, we find that one ton of the fuel mix emits 2.5 tons of the CO_2 (computation details are available in Table 7, Appendix 2).[28]

[27] Given the assumptions above, the equation (9) implies that $\Delta S^E_{i,t} = \sum_{j=k,l,e,m} \beta_{ij} \Delta \log\left(w^j_{i,t}\gamma^j_{i,t}\right) = \sum_{j=k,l,e,m} \beta_{ij} \Delta \log(w^j_{i,t}) + \sum_{j=l,e,m} \beta_{ij} \Delta \log \gamma^j_{i,t} = \sum_{j=l,e,m} \beta_{ij} \Delta \log \gamma^j_{i,t} \neq 0.$

[28] The data on fuel mix composition in the UK manufacturing sector is obtained from the International Energy Agency database. The greenhouse emission coefficients per type of fuel (in million of British Thermal

Then, a \$30 tax per ton of greenhouse gas corresponds to \$75 per *toe*, or (given that average real energy price in the UK manufacturing sector was \$502 per *toe*) to 15 percent increase in energy input price.

The change in the energy input consumption in the counterfactual scenario relative to the baseline scenario depends on two factors. The first factor is price-induced change in the energy efficiency of the capital stock (or the price-induced investment response). As in the baseline scenario, we compute the index of energy efficiency of the capital stock for the simulation sample, now assuming a 15 percent increase in the energy input price. Our calculations show that the price-induced investment response results in 4 percent less energy consumption relative to that in baseline scenario by 2020. This analysis, however, excludes the rebound effect[29]. To quantify the rebound effect, we predict an increase in the share of energy service consumption $S_{i,t}^{j}$ due to greenhouse tax induced improvements in energy efficiency of capital stock (holding other factors constant), and convert these changes in level terms. The rebound effect is the difference in price-induced energy consumption with and without adjustments for changes in share of energy service. Our calculations show a long-run rebound effect of 26 percent, which is consistent with the findings from previous studies (see e.g. Small and Van Dender (2007) and references therein). In the presence of the rebound effect, energy consumption is 3 percent less than in the baseline scenario by 2020.

The second factor is the long-run change in the energy demand due to input substitution (or the operational response). Because prices of other inputs are assumed constant, the decline in the long-run energy demand depends solely on the own-price elasticity of energy demand. Our calculations show that the operational response to the greenhouse emissions tax results in 21 percent less energy consumption than energy consumption in the baseline scenario by 2020.

Bringing all effects together, a 15 percent increase in the energy input price due to the greenhouse gas tax lowers energy consumption by 24 percent relative to the baseline scenario. Price-induced efficiency improvements lower long-run energy consumption by 4 percent relative to baseline scenario. However, 26 percent of these price-induced efficiency improvements (or 1 percent of energy consumption in the baseline scenario) are reverted due to the rebound effect. The remaining 21 percent decline in long-run energy consumption relative to the baseline scenario is due to a reduction in the long-run energy demand. These

Units, BTU) are obtained from the US Department of Energy Voluntary Reporting of Greenhouse Gases Program website (http://www.eia.doe.gov/oiaf/1605/coefficients.html) and converted to tons of oil equivalent (*toe*, 1 *toe* $\approx 40 \times 10^6$ BTU).

[29] In this context the "rebound effect" is defined as a direct increase in demand for an energy service whose supply had increased as a result of improvements in technical efficiency in the use of energy (Khazzoom 1980; Greening, Greene, and Difiglio 2000; Sorrell and Dimitropoulos 2008).

results indicate that energy and climate policies that increase energy costs result in significant reduction in the energy use in the long-run.

7 Concluding Remarks

We have expanded the traditional estimation of energy, materials, and labour responses to input price changes by including vintages for the capital stock. The model allows for both substitution across production inputs (labour, energy and materials), and more efficient use of these inputs by choosing more efficient technologies at the time of investment.

In order to test the model, we develop a new dataset for 23 OECD countries, and calculate average final energy prices in different sectors and countries based on fuel prices and the energy mix within the sector. At the sector level, the explanatory value of the model with vintage capital stock is significantly improved, and the assumption of constant efficiency of capital stock is rejected for all sectors.

The results for all sectors indicate that rising energy prices result in substantial decline in the long-run energy use, and affect both the operation (input substitution) and the investment (energy efficiency of capital stock) components of energy demand. However, only the estimates for the manufacturing sector can be reconciled with the economic intuition. The vintage capital model predicts that between 1990 and 2005 the energy efficiency of capital stock in the U.S. manufacturing sector has improved by about 24 percent. Interpretation of the results for other sectors are plagued by exogenous structural shifts, regulatory distortions, and measurement error.

In further work it will be interesting to explore the robustness of our results by: (1) expanding the observation period beyond 1990-2005; (2) bringing the analysis to further disaggregated level of industry activities; and (3) including non-OECD countries in the data set.

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Appendix I - Derivation of Firm's Investment Choice of Capital Vintage Efficiency

The firm's choice of production technology depends on input cost savings from new technology and the costs of setting up new technology. For simplicity, let us assume that the index of input efficiency of capital vintage in time $q-1$ is equal to one. If in period q the firm installs the same technology, based on equation (1) the cost of input service to production function in period $q+1$, $F^j_{i,q+1}$, will be given by

$$F^j_{i,q+1} = E\left(w^j_{i,q+1}\widetilde{x}^j_{i,q+1}\right) = E\left(w^j_{i,q+1}x^j_{i,q+1}\right), \tag{13}$$

where $E(\cdot)$ denotes the expectations operator.

If in period q the firm installs more efficient technology with the index of input efficiency of capital vintage $\gamma^j_{i,q}$, based on equation (1) the cost of input service to production function in period $q+1$, $F'^j_{i,q+1}$, will be given by

$$F'^j_{i,q+1} = E\left(w^j_{i,q+1}\widetilde{x}^j_{i,q+1}\right) = \frac{1}{\gamma^j_{i,q}}E\left(w^j_{i,q+1}x^j_{i,q+1}\right) < F^j_{i,q+1}. \tag{14}$$

Based on the standard assumptions of the theory of the firm, we assume that the cost of installing technology with the index of input efficiency of capital vintage $\gamma^j_{i,q}$ can be represented by a continuos, twice-differentiable, and convex cost function $g\left(\gamma^j_{i,q}\right)$.

Given the assumptions above, firm's input cost savings from installing more efficient technology in period $q+1$ are

$$\pi^j_{i,t} = \left(1 - \frac{1}{\gamma^j_{i,q}}\right)E\left(w^j_{i,q+1}x^j_{i,q+1}\right) - g\left(\gamma^j_{i,q}\right). \tag{15}$$

Applying first order conditions to equation (15), setting them to zero and solving resulting equation yields firms' optimal index of input efficiency of capital vintage $\gamma^{*j}_{i,q}$:

$$\gamma^{*j}_{i,q} = \arg\max_{\gamma^j_{i,q}}\left[\frac{E\left(w^j_{i,q+1}x^j_{i,q+1}\right)}{g'\left(\gamma^j_{i,q}\right)\left(\gamma^j_{i,q}\right)^2}\right]. \tag{16}$$

To obtain a closed-form solution for $\gamma^{*j}_{i,q}$ one can use in an empirical specification, we assume that input quantities are predetermined and constant

$$x^j_{i,q} = x^j_{i,q+1} = \overline{x}^j, \tag{17}$$

and that the input prices exhibit a random walk[30], so that current input prices are the

[30]This assumption is consistent with evidence found in empirical studies (Ashenfelter and Card 1982;

best predictors of future input costs:

$$E\left(w_{i,q+1}^{j}\right) = w_{i,q}^{j}, \tag{18}$$

and the cost of installing technology with the index of input efficiency of capital vintage $\gamma_{i,q}^{j}$ is given by

$$g\left(\gamma_{i,q}^{j}\right) = \frac{h}{\varphi}\left(\gamma_{i,q}^{j}\right)^{\varphi}, \tag{19}$$

where h and φ are positive constants determining the curvature of the cost function. Using equations (18) and (19) in equation (16) yields the closed form solution for firm's investment choice of input efficiency of capital vintage $\gamma_{i,q}^{j}$:

$$\gamma_{i,q}^{*j} = \left(\frac{w_{i,q}^{j} x_{i,q}^{j}}{h}\right)^{\frac{1}{\varphi+1}}. \tag{20}$$

Let $h = \overline{x}^{j}\overline{w}^{j}$, where $\overline{w}^{j} = \frac{\sum_{i=1}^{n}\sum_{t=1}^{T} w_{i,t}^{j}}{nT}$ is the average price of input j across countries and all time periods.

Then equation (20) becomes

$$\gamma_{i,q}^{*j} = \left(\frac{w_{i,q}^{j}}{\overline{w}^{j}}\right)^{-\phi^{j}}, \tag{21}$$

where $\phi^{j} = -\frac{1}{\varphi+1} = \frac{\partial\gamma_{i,q}^{j}}{\partial w_{i,q}^{j}}\frac{w_{i,q}^{j}}{\gamma_{i,q}^{j}}$ is the elasticity of input efficiency of capital stock with respect to input price changes. Equation (21) implies that higher input prices result in a greater input efficiency of capital stock (and the smaller value of $\gamma_{i,q}^{j}$, meaning that smaller input quantities are required to produce the same amount of output holding capital stock constant). This result is consistent with theoretical works showing that firms respond to input price changes by choosing more efficient technologies for the production process (see e.g. Khazzoom 1980; Train 1986).

Pindyck 1999).

Appendix II - Tables

Table 1

List of Variables

Variable	Desctiption	Units
S_L	Share of Labor in the Total Cost	Percent
S_K	Share of Capital in the Total Cost	Percent
S_E	Share of Energy in the Total Cost	Percent
S_M	Share of Materials in the Total Cost	Percent
Y	Gross Output	Real USD million
w_L	Wage	Real USD / hour
w_K	Rate of Return on Capital	Percent
w_E	Price of Energy	USD / toe
w_M	Price of Materials	USD / metric ton

Table 2

List of Countries

Country ID	Country	Data Availability
1	Australia	1990-2005
2	Austria	1990-2005
3	Belgium	1990-2005
4	Czech Republic	1995-2005
5	Denmark	1990-2005
6	Finland	1990-2005
7	France	1990-2005
8	Germany	1990-2005
9	Greece	1990-2005
10	Hungary	1991-2005
11	Ireland	1990-2005
12	Italy	1990-2005
13	Japan	1990-2005
14	Korea	1990-2005
15	Luxembourg	1990-2005
16	Netherlands	1990-2005
17	Poland	1995-2005
18	Portugal	1990-2005
19	Slovak Republic	1995-2005
20	Spain	1990-2005
21	Sweden	1990-2005
22	United Kingdom	1990-2005
23	United States	1990-2005

Table 3a

Descriptive Statistics, Economy Level (1995)

Country	S_L	S_K	S_E	S_M	Y	w_L	w_K	w_E	w_M
Australia	0.40	0.24	0.05	0.31	752265	17.2	0.13	488.9	842.1
Austria	0.44	0.22	0.04	0.30	397074	26.4	0.11	774.6	1153.1
Belgium	0.39	0.21	0.05	0.35	566882	36.1	0.11	625.2	1221.2
Czech Republic	0.27	0.21	0.07	0.45	131888	3.3	0.09	371.0	800.4
Denmark	0.43	0.23	0.04	0.30	297992	29.0	0.12	719.5	1048.7
Finland	0.39	0.19	0.06	0.36	237054	26.0	0.13	675.0	1064.0
France	0.44	0.22	0.05	0.29	2702751	29.6	0.12	685.4	1219.7
Germany	0.46	0.22	0.05	0.28	4284886	31.4	0.10	729.3	1394.4
Greece	0.36	0.30	0.06	0.28	183821	13.9	0.21	642.1	1182.9
Hungary	0.34	0.21	0.08	0.37	89768	4.1	0.33	364.8	1398.9
Ireland	0.35	0.21	0.05	0.40	138429	19.5	0.12	644.2	1709.9
Italy	0.39	0.19	0.06	0.36	2103766	25.6	0.18	780.6	1296.2
Japan	0.39	0.26	0.04	0.31	9713929	31.9	0.07	1030.4	1162.5
Korea	0.39	0.13	0.05	0.43	1081649	10.8	0.16	411.4	1077.9
Luxembourg	0.39	0.30	0.07	0.24	38167	33.3	0.11	596.2	1709.5
Netherlands	0.41	0.20	0.05	0.34	787729	29.9	0.11	574.7	1281.0
Poland	0.41	0.15	0.06	0.37	264868	5.2	0.27	267.5	1085.3
Portugal	0.36	0.19	0.05	0.39	213649	9.4	0.16	671.0	1134.9
Slovak Republic	0.24	0.25	0.07	0.44	45299	2.4	0.14	265.5	899.9
Spain	0.37	0.22	0.05	0.36	1138641	18.5	0.13	636.1	1226.9
Sweden	0.40	0.22	0.05	0.33	455543	22.9	0.15	665.7	947.8
United Kingdom	0.43	0.18	0.06	0.33	2100778	19.1	0.13	600.2	1036.1
United States	0.46	0.26	0.05	0.23	12900000	20.2	0.11	355.9	1313.4

Table 3b

Descriptive Statistics, Agriculture (1995)

Country	S_L	S_K	S_E	S_M	Y	w_L	w_K	w_E	w_M
Australia	0.31	0.22	0.08	0.39	27333	9.2	0.13	606.7	1394.4
Austria	0.56	0.05	0.08	0.30	10963	10.0	0.11	797.0	1661.8
Belgium	0.28	0.14	0.17	0.41	9768	21.3	0.11	523.1	1360.9
Czech Republic	0.24	0.14	0.24	0.37	5723	2.1	0.09	590.6	1379.9
Denmark	0.25	0.25	0.10	0.40	11779	15.2	0.12	425.4	1279.2
Finland	0.52	0.04	0.11	0.33	9185	11.2	0.13	801.2	1586.6
France	0.44	0.08	0.05	0.42	95581	15.0	0.12	644.5	1335.6
Germany	0.53	0.06	0.07	0.34	62695	15.8	0.10	882.1	1594.9
Greece	0.44	0.23	0.09	0.25	15604	4.8	0.21	695.2	1388.2
Hungary	0.29	0.15	0.12	0.43	7479	3.5	0.33	528.3	1472.7
Ireland	0.42	0.10	0.07	0.41	8504	11.3	0.12	936.6	1876.3
Italy	0.53	0.10	0.09	0.28	53147	9.1	0.18	885.0	1505.8
Japan	0.32	0.28	0.06	0.35	175792	5.9	0.07	265.6	1472.9
Korea	0.65	0.09	0.07	0.19	43859	5.9	0.16	367.1	1280.9
Luxembourg	0.40	0.17	0.00	0.43	366	18.0	0.11	792.8	104.0
Netherlands	0.31	0.11	0.21	0.37	28429	19.0	0.11	267.7	1400.3
Poland	0.44	0.28	0.12	0.16	23337	4.9	0.27	309.1	1637.6
Portugal	0.58	0.01	0.07	0.33	9638	4.2	0.16	771.6	1448.9
Slovak Republic	0.21	0.18	0.11	0.50	2728	1.5	0.14	449.7	1043.4
Spain	0.28	0.36	0.07	0.29	47594	6.2	0.13	734.2	1447.8
Sweden	0.44	0.20	0.10	0.26	10015	14.4	0.15	674.2	1820.3
United Kingdom	0.35	0.19	0.03	0.43	41206	10.1	0.13	745.9	878.8
United States	0.27	0.25	0.09	0.39	309427	9.9	0.11	310.1	1557.4

Table 3c

Descriptive Statistics, Commerce (1995)

Country	S_L	S_K	S_E	S_M	Y	w_L	w_K	w_E	w_M
Australia	0.48	0.21	0.06	0.25	94820	10.6	0.13	544.9	842.1
Austria	0.53	0.26	0.02	0.18	46778	18.4	0.11	542.0	1153.1
Belgium	0.50	0.28	0.07	0.16	67604	24.6	0.11	362.3	1221.2
Czech Republic	0.46	0.22	0.07	0.25	11994	2.4	0.09	394.3	800.4
Denmark	0.59	0.23	0.03	0.16	36716	25.7	0.12	414.7	1048.7
Finland	0.55	0.18	0.04	0.24	19783	18.5	0.13	544.7	1064.0
France	0.61	0.23	0.05	0.12	269491	22.7	0.12	679.5	1219.7
Germany	0.75	0.13	0.02	0.09	409990	24.2	0.10	619.0	1394.4
Greece	0.38	0.46	0.03	0.14	23486	5.4	0.21	664.3	1182.9
Hungary	0.42	0.25	0.16	0.17	9732	2.8	0.33	252.3	1398.9
Ireland	0.65	0.20	0.04	0.11	9888	13.2	0.12	582.1	1709.9
Italy	0.52	0.19	0.05	0.24	282953	14.4	0.18	435.1	1296.2
Japan	0.57	0.31	0.01	0.11	1149129	22.1	0.07	1099.1	1162.5
Korea	0.77	0.01	0.02	0.20	68244	4.3	0.16	424.5	1077.9
Luxembourg	0.55	0.36	0.02	0.07	3072	22.3	0.11	818.0	1709.5
Netherlands	0.66	0.17	0.02	0.15	83304	21.4	0.11	333.3	1281.0
Poland	0.30	0.42	0.05	0.23	40693	2.3	0.27	125.8	1085.3
Portugal	0.53	0.24	0.04	0.19	24551	6.3	0.16	941.0	1134.9
Slovak Republic	0.24	0.31	0.09	0.36	5218	2.0	0.14	192.9	899.9
Spain	0.55	0.26	0.04	0.15	102238	10.4	0.13	372.4	1226.9
Sweden	0.67	0.20	0.03	0.09	37492	20.6	0.15	631.2	947.8
United Kingdom	0.59	0.20	0.03	0.19	210506	11.6	0.13	413.8	1036.1
United States	0.64	0.22	0.03	0.12	1309313	16.1	0.11	315.7	1313.4

Table 3d

Descriptive Statistics, Manufacturing (1995)

Country	S_L	S_K	S_E	S_M	Y	w_L	w_K	w_E	w_M
Australia	0.22	0.12	0.13	0.53	158893	15.0	0.13	333	842
Austria	0.29	0.12	0.07	0.52	112452	23.7	0.11	407	1153
Belgium	0.21	0.10	0.10	0.59	186698	32.7	0.11	327	1221
Czech Republic	0.15	0.11	0.15	0.58	47139	2.6	0.09	257	800
Denmark	0.28	0.11	0.05	0.57	76829	26.4	0.12	355	1049
Finland	0.21	0.15	0.10	0.55	90127	25.2	0.13	411	1064
France	0.24	0.10	0.08	0.58	782118	26.5	0.12	314	1220
Germany	0.34	0.08	0.08	0.49	1415681	32.1	0.10	433	1394
Greece	0.27	0.09	0.10	0.54	43592	7.6	0.21	354	1183
Hungary	0.18	0.09	0.21	0.51	31099	3.3	0.33	199	1399
Ireland	0.16	0.22	0.07	0.55	55360	14.8	0.12	373	1710
Italy	0.23	0.10	0.08	0.59	753102	17.4	0.18	405	1296
Japan	0.24	0.18	0.05	0.53	3295413	26.2	0.07	729	1163
Korea	0.18	0.10	0.11	0.61	500365	6.4	0.16	278	1078
Luxembourg	0.20	0.11	0.20	0.49	7603	29.3	0.11	361	1710
Netherlands	0.22	0.12	0.11	0.55	222714	26.1	0.11	334	1281
Poland	0.18	0.11	0.23	0.48	85411	2.8	0.27	165	1085
Portugal	0.18	0.10	0.10	0.63	68822	6.0	0.16	309	1135
Slovak Republic	0.14	0.14	0.21	0.52	16966	2.4	0.14	182	900
Spain	0.22	0.13	0.10	0.55	367655	16.3	0.13	319	1227
Sweden	0.23	0.15	0.08	0.54	149653	22.1	0.15	328	948
United Kingdom	0.27	0.12	0.08	0.53	602325	18.3	0.13	297	1036
United States	0.27	0.14	0.15	0.44	3556844	24.3	0.11	263	1313

Table 3e

Descriptive Statistics, Transport (1995)

Country	S_L	S_K	S_E	S_M	Y	w_L	w_K	w_E	w_M
Australia	0.28	0.24	0.35	0.14	66463	14.7	0.13	556.8	842.1
Austria	0.44	0.22	0.27	0.07	26245	22.4	0.11	1103.6	1153.1
Belgium	0.34	0.23	0.29	0.14	46022	28.3	0.11	999.2	1221.2
Czech Republic	0.21	0.36	0.29	0.13	10698	2.6	0.09	736.4	800.4
Denmark	0.40	0.25	0.27	0.08	26541	25.9	0.12	696.6	1048.7
Finland	0.34	0.31	0.26	0.10	18239	19.9	0.13	1053.2	1064.0
France	0.40	0.18	0.37	0.05	152692	27.6	0.12	1000.1	1219.7
Germany	0.39	0.16	0.38	0.06	246660	25.4	0.10	1065.3	1394.4
Greece	0.33	0.14	0.50	0.04	10467	9.0	0.21	729.4	1182.9
Hungary	0.28	0.12	0.49	0.11	5943	3.1	0.33	849.3	1398.9
Ireland	0.24	0.12	0.43	0.21	10637	18.7	0.12	933.2	1709.9
Italy	0.34	0.14	0.35	0.17	151683	19.5	0.18	1084.4	1296.2
Japan	0.45	0.23	0.21	0.11	574421	29.3	0.07	1006.3	1162.5
Korea	0.33	0.13	0.43	0.11	58809	8.0	0.16	557.9	1077.9
Luxembourg	0.21	0.18	0.57	0.04	2458	32.8	0.11	817.2	1709.5
Netherlands	0.35	0.20	0.34	0.12	51412	23.9	0.11	1066.0	1281.0
Poland	0.24	0.18	0.49	0.10	16156	3.0	0.27	565.8	1085.3
Portugal	0.29	0.20	0.44	0.07	12035	11.6	0.16	940.1	1134.9
Slovak Republic	0.20	0.32	0.36	0.12	3610	2.4	0.14	701.6	899.9
Spain	0.26	0.24	0.43	0.07	73727	14.5	0.13	787.3	1226.9
Sweden	0.36	0.24	0.26	0.13	43573	21.3	0.15	1075.6	947.8
United Kingdom	0.42	0.11	0.33	0.14	156058	20.9	0.13	943.5	1036.1
United States	0.20	0.14	0.62	0.04	737406	21.0	0.11	350.4	1313.4

Table 4a[31]

Parameter Estimates: Total Cost Function (Economy Level)

	Restricted Model		Unrestricted Model	
	est. coefficient	**standard error**	**est. coefficient**	**standard error**
Labor Share Equation: constant	1.170***	0.115	0.737***	0.092
Labor Share Equation: Output	-0.028***	0.008	0.004	0.005
Labor Share Equation: Wage	0.134***	0.013	0.130***	0.015
Labor Share Equation: Return on Capital	0.012***	0.003	-0.001	0.003
Labor Share Equation: Energy Price	-0.053***	0.010	-0.041***	0.012
Labor Share Equation: Materials Price	-0.042***	0.007	-0.071***	0.010
Capital Share Equation: constant	-0.623***	0.090	-0.248***	0.067
Capital Share Equation: Output	0.060***	0.006	0.036***	0.004
Capital Share Equation: Wage	-0.061***	0.010	-0.068***	0.011
Capital Share Equation: Return on Capital	-0.023***	0.003	-0.006**	0.002
Capital Share Equation: Energy Price	-0.026***	0.008	-0.034***	0.009
Capital Share Equation: Materials Price	0.026***	0.006	0.046***	0.007
Energy Share Equation: constant	-0.006	0.031	-0.079***	0.022
Energy Share Equation: Output	-0.003	0.002	-0.003**	0.001
Energy Share Equation: Wage	-0.025***	0.003	-0.047***	0.003
Energy Share Equation: Return on Capital	-0.001	0.001	-0.004***	0.001
Energy Share Equation: Energy Price	0.035***	0.003	0.046***	0.003
Energy Share Equation: Materials Price	-0.003	0.002	0.004*	0.002
Materials Share Equation: constant	0.459***	0.126	0.590***	0.098
Materials Share Equation: Output	-0.028***	0.008	-0.037***	0.006
Materials Share Equation: Wage	-0.048***	0.014	-0.015	0.016
Materials Share Equation: Return on Capital	0.012***	0.004	0.011***	0.004
Materials Share Equation: Energy Price	0.045***	0.011	0.029**	0.013
Materials Share Equation: Materials Price	0.019**	0.008	0.021**	0.010
Number of observations	351		351	
Labor Share Equation: R^2	0.94		0.93	
Capital Share Equation: R^2	0.94		0.94	
Energy Share Equation: R^2	0.88		0.90	
Materials Share Equation: R^2	0.95		0.94	
LR Test: $\gamma_L=\gamma_E=\gamma_M=\eta=0$, χ^2 (pval)	91.40 (0.00)			
note: *** p<0.01, ** p<0.05, * p<0.1				

[31] Estimates for country-specific fixed effects are not reported in Tables 4a-4e, and are available upon request.

Table 4b

Parameter Estimates: Total Cost Function (Agriculture)

	Restricted Model		Unrestricted Model	
	est. coefficient	standard error	est. coefficient	standard error
Labor Share Equation: constant	1.183***	0.193	1.061***	0.162
Labor Share Equation: Output	-0.083***	0.019	-0.081***	0.013
Labor Share Equation: Wage	0.101***	0.011	0.111***	0.009
Labor Share Equation: Return on Capital	0.041***	0.009	0.010	0.008
Labor Share Equation: Energy Price	-0.033**	0.013	-0.030***	0.010
Labor Share Equation: Materials Price	0.027	0.018	0.029***	0.011
Capital Share Equation: constant	-1.243***	0.252	-0.891***	0.211
Capital Share Equation: Output	0.179***	0.025	0.134***	0.016
Capital Share Equation: Wage	-0.120***	0.014	-0.129***	0.011
Capital Share Equation: Return on Capital	-0.050***	0.011	-0.000	0.011
Capital Share Equation: Energy Price	0.022	0.017	0.047***	0.013
Capital Share Equation: Materials Price	-0.100***	0.023	-0.079***	0.014
Energy Share Equation: constant	0.224**	0.095	0.017	0.097
Energy Share Equation: Output	-0.069***	0.009	-0.025***	0.007
Energy Share Equation: Wage	-0.010*	0.005	-0.018***	0.005
Energy Share Equation: Return on Capital	-0.017***	0.004	-0.026***	0.005
Energy Share Equation: Energy Price	0.006	0.006	-0.011*	0.006
Energy Share Equation: Materials Price	0.093***	0.009	0.059***	0.007
Materials Share Equation: constant	0.836***	0.155	0.812***	0.147
Materials Share Equation: Output	-0.027*	0.015	-0.028**	0.011
Materials Share Equation: Wage	0.029***	0.009	0.036***	0.008
Materials Share Equation: Return on Capital	0.026***	0.007	0.017**	0.007
Materials Share Equation: Energy Price	0.004	0.011	-0.006	0.009
Materials Share Equation: Materials Price	-0.019	0.014	-0.009	0.010
Number of observations	343		343	
Labor Share Equation: R^2	0.91		0.91	
Capital Share Equation: R^2	0.92		0.94	
Energy Share Equation: R^2	0.82		0.86	
Materials Share Equation: R^2	0.87		0.85	
LR Test: $\gamma_L=\gamma_E=\gamma_M=\eta=0$, χ^2 (pval)	67.03 (0.00)			
note: *** p<0.01, ** p<0.05, * p<0.1				

Table 4c

Parameter Estimates: Total Cost Function (Commerce)[32]

	Restricted Model		Unrestricted Model	
	est. coefficient	**standard error**	**est. coefficient**	**standard error**
Labor Share Equation: constant	3.953***	0.190	3.185***	0.174
Labor Share Equation: Output	-0.272***	0.016	-0.209***	0.012
Labor Share Equation: Wage	0.292***	0.017	0.273***	0.015
Labor Share Equation: Return on Capital	-0.008	0.007	-0.031***	0.008
Labor Share Equation: Energy Price	-0.001	0.010	0.025*	0.014
Labor Share Equation: Materials Price	-0.044***	0.013	-0.081***	0.012
Capital Share Equation: constant	-1.846***	0.214	-1.280***	0.192
Capital Share Equation: Output	0.190***	0.018	0.149***	0.013
Capital Share Equation: Wage	-0.178***	0.019	-0.181***	0.017
Capital Share Equation: Return on Capital	0.005	0.008	0.026***	0.009
Capital Share Equation: Energy Price	-0.013	0.011	-0.028*	0.015
Capital Share Equation: Materials Price	-0.004	0.015	0.018	0.013
Energy Share Equation: constant	-0.297***	0.082	-0.270***	0.076
Energy Share Equation: Output	0.023***	0.007	0.025***	0.005
Energy Share Equation: Wage	0.009	0.007	0.010	0.007
Energy Share Equation: Return on Capital	0.018***	0.003	0.015***	0.004
Energy Share Equation: Energy Price	-0.007*	0.004	-0.018***	0.006
Energy Share Equation: Materials Price	0.009	0.006	0.009*	0.005
Materials Share Equation: constant	-0.758***	0.170	-0.634***	0.178
Materials Share Equation: Output	0.064***	0.014	0.035***	0.012
Materials Share Equation: Wage	-0.100***	0.015	-0.101***	0.016
Materials Share Equation: Return on Capital	-0.007	0.007	-0.011	0.008
Materials Share Equation: Energy Price	0.034***	0.009	0.021	0.014
Materials Share Equation: Materials Price	0.002	0.012	0.055***	0.013
Number of observations	330		330	
Labor Share Equation: R^2	0.94		0.94	
Capital Share Equation: R^2	0.87		0.89	
Energy Share Equation: R^2	0.72		0.73	
Materials Share Equation: R^2	0.86		0.83	
LR Test: $\gamma_L=\gamma_E=\gamma_M=\eta=0$, χ^2 (pval)	25.85 (0.01)			
note: *** p<0.01, ** p<0.05, * p<0.1				

[32] Korea was excluded from the sample due to large measurement error in capital stock.

Table 4d

Parameter Estimates: Total Cost Function (Manufacturing)

	Restricted Model		Unrestricted Model	
	est. coefficient	standard error	est. coefficient	standard error
Labor Share Equation: constant	1.125***	0.086	1.055***	0.072
Labor Share Equation: Output	-0.065***	0.006	-0.068***	0.005
Labor Share Equation: Wage	0.049***	0.007	0.082***	0.007
Labor Share Equation: Return on Capital	0.021***	0.003	0.009**	0.004
Labor Share Equation: Energy Price	0.019***	0.006	0.017***	0.006
Labor Share Equation: Materials Price	-0.010	0.007	-0.010*	0.006
Capital Share Equation: constant	-1.050***	0.090	-0.837***	0.083
Capital Share Equation: Output	0.104***	0.007	0.091***	0.006
Capital Share Equation: Wage	-0.058***	0.007	-0.079***	0.008
Capital Share Equation: Return on Capital	-0.013***	0.003	-0.001	0.004
Capital Share Equation: Energy Price	-0.020***	0.007	-0.017**	0.007
Capital Share Equation: Materials Price	-0.013*	0.007	-0.007	0.007
Energy Share Equation: constant	0.626***	0.091	0.388***	0.089
Energy Share Equation: Output	-0.069***	0.007	-0.048***	0.006
Energy Share Equation: Wage	0.024***	0.007	0.013	0.009
Energy Share Equation: Return on Capital	-0.010***	0.003	-0.018***	0.004
Energy Share Equation: Energy Price	-0.034***	0.007	-0.034***	0.008
Energy Share Equation: Materials Price	0.091***	0.007	0.083***	0.007
Materials Share Equation: constant	0.299**	0.145	0.395***	0.136
Materials Share Equation: Output	0.030***	0.011	0.025***	0.010
Materials Share Equation: Wage	-0.015	0.012	-0.016	0.014
Materials Share Equation: Return on Capital	0.002	0.006	0.011	0.007
Materials Share Equation: Energy Price	0.035***	0.011	0.033***	0.012
Materials Share Equation: Materials Price	-0.068***	0.011	-0.066***	0.011
Number of observations	346		346	
Labor Share Equation: R^2	0.94		0.95	
Capital Share Equation: R^2	0.91		0.91	
Energy Share Equation: R^2	0.88		0.87	
Materials Share Equation: R^2	0.83		0.83	
LR Test: $\gamma_L=\gamma_E=\gamma_M=\eta=0$, χ^2 (pval)	27.51 (0.006)			
note: *** p<0.01, ** p<0.05, * p<0.1				

Table 4e

Parameter Estimates: Total Cost Function (Transport)

	Restricted Model		Unrestricted Model	
	est. coefficient	**standard error**	**est. coefficient**	**standard error**
Labor Share Equation: constant	1.515***	0.108	1.191***	0.108
Labor Share Equation: Output	-0.085***	0.009	-0.055***	0.005
Labor Share Equation: Wage	0.139***	0.012	0.177***	0.011
Labor Share Equation: Return on Capital	0.029***	0.005	0.006	0.005
Labor Share Equation: Energy Price	0.013	0.010	0.031***	0.011
Labor Share Equation: Materials Price	-0.084***	0.009	-0.135***	0.011
Capital Share Equation: constant	-0.889***	0.139	-0.639***	0.151
Capital Share Equation: Output	0.076***	0.011	0.044***	0.008
Capital Share Equation: Wage	-0.115***	0.015	-0.114***	0.016
Capital Share Equation: Return on Capital	-0.055***	0.007	-0.043***	0.006
Capital Share Equation: Energy Price	0.035***	0.013	0.044***	0.016
Capital Share Equation: Materials Price	0.005	0.012	0.021	0.015
Energy Share Equation: constant	0.666***	0.122	0.538***	0.132
Energy Share Equation: Output	-0.032***	0.010	-0.015**	0.007
Energy Share Equation: Wage	-0.010	0.014	-0.062***	0.014
Energy Share Equation: Return on Capital	0.009	0.006	0.021***	0.006
Energy Share Equation: Energy Price	-0.052***	0.011	-0.068***	0.014
Energy Share Equation: Materials Price	0.101***	0.010	0.135***	0.013
Materials Share Equation: constant	-0.291***	0.096	-0.090	0.104
Materials Share Equation: Output	0.041***	0.008	0.026***	0.005
Materials Share Equation: Wage	-0.014	0.011	-0.0004	0.011
Materials Share Equation: Return on Capital	0.017***	0.005	0.017***	0.004
Materials Share Equation: Energy Price	0.004	0.009	-0.006	0.011
Materials Share Equation: Materials Price	-0.022***	0.008	-0.021**	0.011
Number of observations	346		346	
Labor Share Equation: R^2	0.93		0.94	
Capital Share Equation: R^2	0.89		0.89	
Energy Share Equation: R^2	0.96		0.96	
Materials Share Equation: R^2	0.85		0.84	
LR Test: $\gamma_L=\gamma_E=\gamma_M=\eta=0$, χ^2 (pval)	63.95 (0.00)			
note: *** p<0.01, ** p<0.05, * p<0.1				

Table 5a

Estimated Energy Demand Elasticities by Country (Economy Level)

Country	η_{EE}		η_{LE}		η_{KE}		η_{ME}	
	mean	sd	mean	sd	mean	sd	mean	sd
Australia	-0.08	0.038	-0.05	0.004	-0.08	0.007	0.15	0.006
Austria	0.06	0.072	-0.05	0.004	-0.11	0.007	0.14	0.004
Belgium	-0.12	0.038	-0.05	0.002	-0.11	0.006	0.14	0.003
Czech Republic	-0.24	0.027	-0.08	0.003	-0.11	0.010	0.13	0.003
Denmark	0.16	0.084	-0.05	0.003	-0.12	0.005	0.14	0.003
Finland	-0.12	0.051	-0.05	0.010	-0.13	0.025	0.14	0.005
France	-0.02	0.046	-0.04	0.003	-0.10	0.006	0.15	0.004
Germany	-0.04	0.059	-0.04	0.003	-0.11	0.006	0.15	0.004
Greece	-0.20	0.042	-0.04	0.007	-0.05	0.013	0.17	0.017
Hungary	-0.33	0.037	-0.05	0.017	-0.11	0.034	0.15	0.008
Ireland	0.02	0.125	-0.07	0.013	-0.09	0.015	0.13	0.008
Italy	-0.13	0.036	-0.05	0.006	-0.12	0.018	0.14	0.004
Japan	0.13	0.036	-0.07	0.004	-0.08	0.009	0.13	0.006
Korea	-0.15	0.127	-0.05	0.007	-0.19	0.042	0.13	0.012
Luxembourg	-0.29	0.050	-0.03	0.010	-0.04	0.012	0.20	0.020
Netherlands	-0.04	0.057	-0.05	0.005	-0.12	0.008	0.14	0.008
Poland	-0.19	0.043	-0.04	0.004	-0.17	0.022	0.14	0.004
Portugal	-0.16	0.058	-0.05	0.008	-0.13	0.019	0.14	0.009
Slovak Republic	-0.32	0.029	-0.09	0.006	-0.06	0.007	0.14	0.005
Spain	-0.01	0.049	-0.06	0.004	-0.11	0.011	0.13	0.006
Sweden	-0.15	0.039	-0.04	0.005	-0.11	0.014	0.15	0.005
United Kingdom	-0.11	0.050	-0.03	0.005	-0.13	0.009	0.15	0.005
United States	-0.05	0.083	-0.03	0.005	-0.08	0.007	0.18	0.011

Table 5b

Estimated Energy Demand Elasticities by Country (Agriculture)

Country	η_{EE}		η_{LE}		η_{KE}		η_{ME}	
	mean	sd	mean	sd	mean	sd	mean	sd
Australia	-1.04	0.02	-0.01	0.02	0.31	0.08	0.07	0.008
Austria	-1.04	0.02	0.03	0.01	12.12	24.85	0.07	0.006
Belgium	-0.94	0.06	0.04	0.04	0.45	0.08	0.13	0.036
Czech Republic	-1.11	0.17	-0.02	0.06	0.35	0.10	0.07	0.068
Denmark	-0.95	0.03	0.02	0.02	0.59	0.71	0.12	0.017
Finland	-0.99	0.02	0.04	0.01	0.96	0.56	0.09	0.012
France	-1.16	0.02	-0.02	0.01	1.01	1.37	0.04	0.003
Germany	-1.03	0.03	0.03	0.01	5.02	10.36	0.07	0.011
Greece	-1.01	0.02	0.04	0.01	0.55	0.33	0.08	0.006
Hungary	-0.96	0.03	0.00	0.03	0.42	0.07	0.12	0.015
Ireland	-1.09	0.02	-0.01	0.02	0.64	0.34	0.05	0.005
Italy	-1.04	0.03	0.03	0.01	4.63	14.99	0.06	0.010
Japan	-1.09	0.03	-0.04	0.01	0.23	0.02	0.05	0.009
Korea	-1.05	0.07	0.04	0.03	0.96	1.05	0.05	0.031
Luxembourg	-3.31	0.42	-0.06	0.01	1.23	1.42	-0.01	0.002
Netherlands	-0.85	0.02	0.12	0.02	4.88	13.33	0.19	0.015
Poland	-1.04	0.07	0.02	0.03	0.23	0.05	0.04	0.038
Portugal	-1.07	0.05	0.02	0.02	1.94	3.47	0.05	0.018
Slovak Republic	-1.09	0.08	-0.08	0.03	0.29	0.08	0.06	0.024
Spain	-1.08	0.05	-0.03	0.01	0.21	0.02	0.05	0.016
Sweden	-1.01	0.03	0.03	0.01	0.43	0.08	0.08	0.012
United Kingdom	-1.34	0.06	-0.05	0.01	0.40	0.12	0.01	0.004
United States	-1.06	0.05	-0.03	0.02	0.27	0.05	0.06	0.018

Table 5c

Estimated Energy Demand Elasticities by Country (Commerce)[33]

Country	η_{EE}		η_{LE}		η_{KE}		η_{ME}	
	mean	sd	mean	sd	mean	sd	mean	sd
Australia	-1.29	0.092	0.10	0.014	-0.10	0.016	0.15	0.014
Austria	-1.66	0.066	0.08	0.004	-0.08	0.006	0.14	0.008
Belgium	-1.34	0.196	0.11	0.018	-0.05	0.029	0.17	0.054
Czech Republic	-1.33	0.143	0.10	0.024	-0.07	0.036	0.15	0.034
Denmark	-1.53	0.042	0.07	0.002	-0.13	0.022	0.17	0.005
Finland	-1.34	0.096	0.10	0.016	-0.12	0.068	0.14	0.013
France	-1.29	0.032	0.09	0.005	-0.09	0.028	0.23	0.010
Germany	-1.62	0.127	0.06	0.006	-0.20	0.035	0.25	0.016
Greece	-1.65	0.081	0.09	0.009	-0.04	0.008	0.19	0.019
Hungary	-1.17	0.161	0.14	0.050	-0.05	0.044	0.20	0.085
Ireland	-1.77	0.475	0.07	0.015	-0.07	0.028	0.28	0.039
Italy	-1.32	0.064	0.10	0.006	-0.12	0.017	0.14	0.024
Japan	-2.23	0.051	0.06	0.001	-0.08	0.007	0.19	0.014
Luxembourg	-1.75	0.118	0.07	0.004	-0.05	0.004	0.33	0.027
Netherlands	-2.06	0.095	0.06	0.003	-0.11	0.023	0.16	0.013
Poland	-1.32	0.057	0.14	0.009	-0.02	0.005	0.13	0.006
Portugal	-1.34	0.131	0.09	0.017	-0.10	0.029	0.16	0.017
Slovak Republic	-1.27	0.073	0.13	0.030	-0.04	0.021	0.14	0.010
Spain	-1.41	0.059	0.09	0.005	-0.07	0.009	0.18	0.012
Sweden	-1.49	0.033	0.07	0.001	-0.15	0.066	0.29	0.026
United Kingdom	-1.47	0.098	0.08	0.009	-0.10	0.017	0.16	0.012
United States	-1.51	0.048	0.07	0.003	-0.09	0.017	0.22	0.009

Table 5d

Estimated Energy Demand Elasticities by Country (Manufacturing)

Country	η_{EE}		η_{LE}		η_{KE}		η_{ME}	
	mean	sd	mean	sd	mean	sd	mean	sd
Australia	-1.18	0.04	0.19	0.01	-0.02	0.01	0.18	0.01
Austria	-1.41	0.04	0.14	0.01	-0.06	0.02	0.13	0.01
Belgium	-1.20	0.04	0.19	0.01	-0.05	0.01	0.17	0.01
Czech Republic	-1.33	0.17	0.20	0.03	-0.06	0.04	0.14	0.04
Denmark	-1.63	0.08	0.11	0.01	-0.11	0.02	0.11	0.01
Finland	-1.31	0.09	0.17	0.01	-0.03	0.02	0.15	0.02
France	-1.40	0.04	0.15	0.01	-0.10	0.01	0.13	0.01
Germany	-1.33	0.04	0.14	0.01	-0.10	0.02	0.15	0.01
Greece	-1.21	0.10	0.17	0.02	-0.06	0.06	0.17	0.03
Hungary	-1.11	0.14	0.26	0.04	-0.04	0.05	0.21	0.06
Ireland	-1.45	0.16	0.19	0.01	0.00	0.00	0.14	0.02
Italy	-1.39	0.04	0.15	0.01	-0.10	0.01	0.13	0.01
Japan	-1.57	0.08	0.13	0.01	-0.04	0.01	0.12	0.01
Korea	-1.21	0.03	0.21	0.01	-0.05	0.02	0.16	0.01
Luxembourg	-1.01	0.04	0.27	0.02	0.02	0.03	0.24	0.02
Netherlands	-1.16	0.03	0.20	0.01	-0.03	0.01	0.18	0.01
Poland	-1.10	0.13	0.25	0.04	-0.02	0.04	0.21	0.05
Portugal	-1.26	0.03	0.19	0.01	-0.07	0.01	0.15	0.01
Slovak Republic	-1.10	0.11	0.27	0.04	0.02	0.04	0.21	0.05
Spain	-1.26	0.07	0.18	0.01	-0.04	0.01	0.16	0.01
Sweden	-1.45	0.07	0.13	0.01	-0.07	0.03	0.13	0.01
United Kingdom	-1.44	0.07	0.12	0.01	-0.10	0.03	0.13	0.01
United States	-1.11	0.05	0.20	0.02	0.02	0.01	0.22	0.02

[33] The results for Korea are not reported (see footnote above).

Table 5e

Estimated Energy Demand Elasticities by Country (Transport)

Country	η_{EE}		η_{LE}		η_{KE}		η_{ME}	
	mean	sd	mean	sd	mean	sd	mean	sd
Australia	-0.89	0.04	0.43	0.02	0.50	0.03	0.28	0.02
Austria	-0.97	0.04	0.36	0.03	0.46	0.04	0.20	0.04
Belgium	-0.92	0.03	0.39	0.02	0.51	0.02	0.26	0.02
Czech Republic	-0.94	0.05	0.42	0.03	0.42	0.03	0.23	0.03
Denmark	-0.99	0.06	0.34	0.03	0.44	0.06	0.19	0.03
Finland	-1.09	0.06	0.31	0.02	0.35	0.04	0.16	0.03
France	-0.86	0.04	0.42	0.02	0.57	0.04	0.25	0.02
Germany	-0.78	0.03	0.48	0.02	0.65	0.05	0.31	0.02
Greece	-0.71	0.09	0.54	0.06	0.71	0.16	0.28	0.07
Hungary	-0.69	0.03	0.57	0.02	0.80	0.18	0.41	0.03
Ireland	-0.70	0.03	0.57	0.02	0.86	0.07	0.42	0.02
Italy	-0.93	0.05	0.38	0.02	0.60	0.12	0.26	0.02
Japan	-1.07	0.05	0.30	0.03	0.41	0.03	0.18	0.02
Korea	-0.78	0.04	0.48	0.03	0.72	0.06	0.35	0.02
Luxembourg	-0.59	0.04	0.69	0.04	0.74	0.05	0.41	0.04
Netherlands	-0.89	0.04	0.41	0.02	0.53	0.04	0.28	0.02
Poland	-0.75	0.08	0.53	0.06	0.65	0.11	0.37	0.05
Portugal	-0.75	0.03	0.51	0.02	0.64	0.04	0.34	0.02
Slovak Republic	-0.92	0.05	0.45	0.04	0.44	0.04	0.26	0.03
Spain	-0.76	0.02	0.52	0.02	0.59	0.03	0.34	0.01
Sweden	-1.08	0.05	0.30	0.02	0.40	0.03	0.18	0.02
United Kingdom	-0.98	0.08	0.34	0.04	0.63	0.07	0.23	0.04
United States	-0.54	0.05	0.73	0.05	0.86	0.08	0.44	0.02

Table 6

Estimated Cross-Price Elasticities of Input Demand

Sector	η_{KL}	η_{EL}	η_{ML}	η_{LK}	η_{EK}	η_{MK}	η_{LM}	η_{KM}	η_{EM}
Total Economy	0.07	-0.46	0.35	0.22	0.15	0.25	0.15	0.55	0.41
Agriculture	-0.51*	0.05	0.51	0.18	-0.36	0.21	0.44	-2.42	1.51
Commerce	-0.28	0.86	-0.18	0.19	0.73	0.16	0.01	0.24	0.45
Manufacturing	-0.46	0.38	0.20	0.16	-0.09	0.14	0.50	0.49	1.52
Transport	-0.28	0.14	0.32	0.23	0.28	0.40	-0.33	0.22	0.52

* medians reported

Table 7

Greenhouse Gas Emissions in UK Manufacturing Sector in 2005

Fuel Type	Fuel Consumption (toe)	Fuel Share (%)	CO2 Emission per toe	CO2 emission per Share
Gas/Diesel Oil	3641939	0.09	2.90	0.25
Motor Gasoline	0	0.00	2.82	0.00
Naphtha	2074889	0.05	2.87	0.14
Kerosene type Jet Fuel	0	0.00	2.81	0.00
Residual Fuel Oil	763697	0.02	3.13	0.06
Liquefied Petroleum Gases	3329969	0.08	2.50	0.20
Other Petroleum Products	7177334	0.17	2.90	0.50
Coal	1814070	0.04	3.70	0.16
Natural gas	12786713	0.31	2.17	0.66
Electricity	10219552	0.24	2.17*	0.53*
Total	41808164	1.00		2.51

* Assuming Natural Gas as a Base Load Factor in Electricity Generation

Appendix III - Charts

Figure 1a

Capital Stock Efficiency Indexes, U.S. Economy, 1991-2005

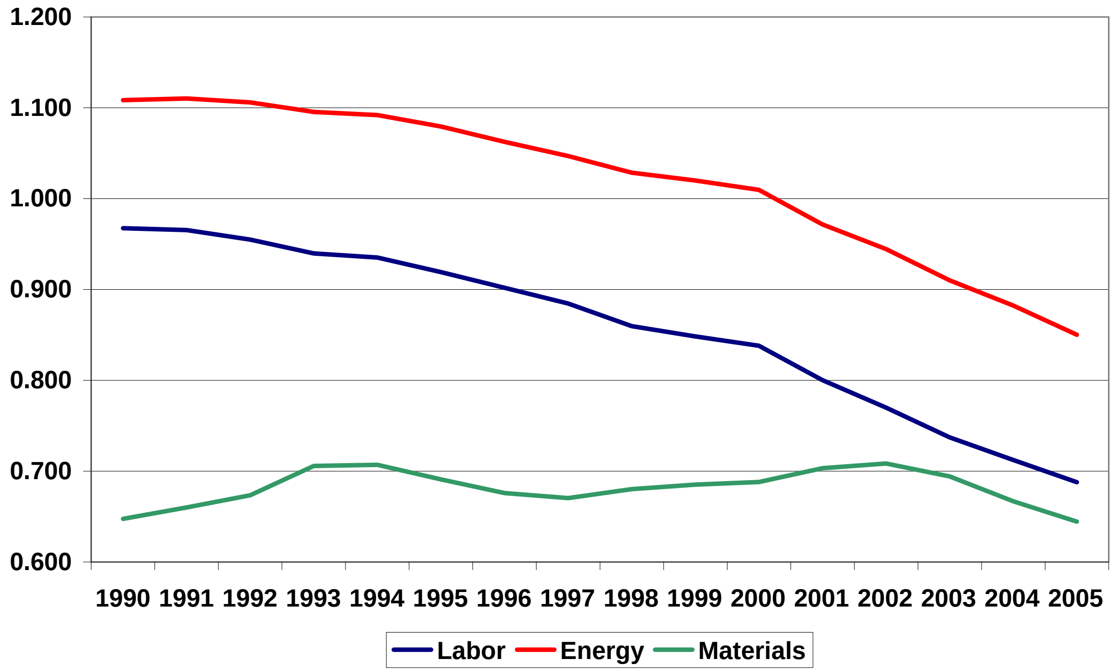

Figure 1b

Capital Stock Efficiency Indexes, U.S. Agriculture Sector, 1991-2005

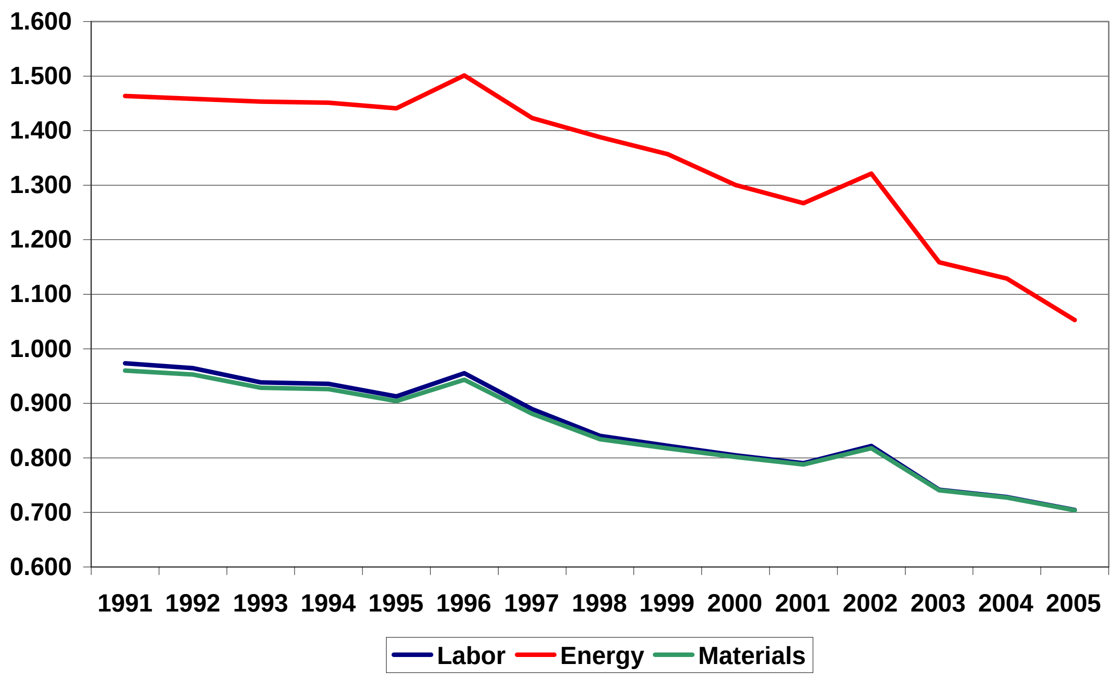

Figure 1c

Capital Stock Efficiency Indexes, U.S. Commerce Sector, 1991-2005

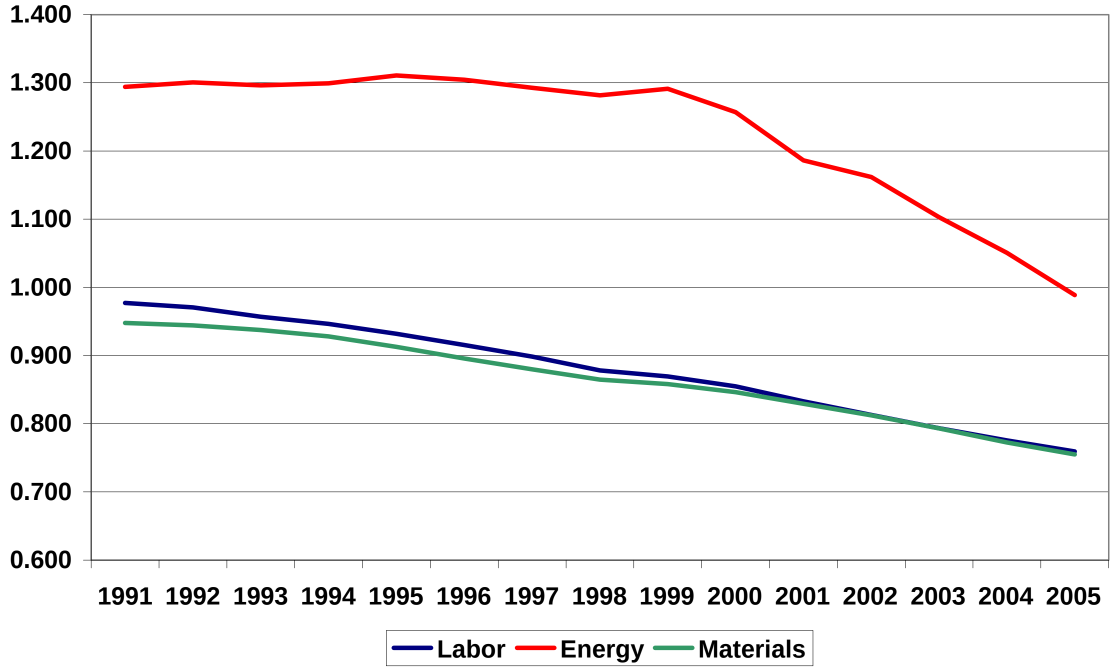

Figure 1d

Capital Stock Efficiency Indexes, U.S. Manufacturing Sector, 1991-2005

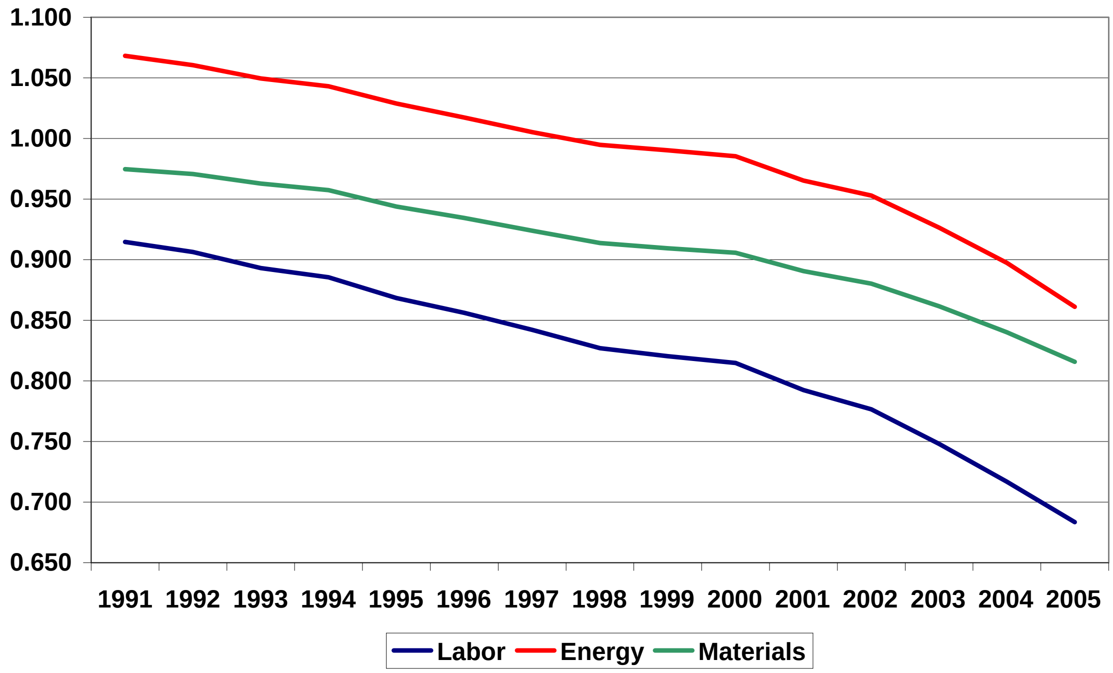

Figure 1e

Capital Stock Efficiency Indexes, U.S. Transport Sector, 1991-2005