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FUEL INPUT SUBSTITUTION UNDER TRADABLE CARBON PERMITS SYSTEM: EVIDENCE FROM FINNISH ENERGY PLANTS 2003 – 2007

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Abstract. Following the Kyoto protocol and the European Union climate policies larger than 20 MW energy plants are part of the EU's emissions-trading scheme (ETS). This greenhouse gas emission mitigation strategy, tradable carbon quota system, started in 2005. The scheme is not mandatory for the firms with size less than 20MW. Also the firms using renewable fuels will not pay for allowances. Advanced energy production technologies enable power and heating plants to use both non-renewable fossil fuels and renewable wood fuels in energy production. Wood fuel demand may constitute a substitute for fossil fuel demand if the price of tradable carbon allowances is relatively high. In this context plant level panel data from years 2003 – 2007 in Finland is analyzed with panel and mixed models. Econometric demand equations are specified for the ratio of wood and fossil fuel. The results show that high allowance prices in the years 2005 and 2006 compared to the years 2003 and 2004 decreased the use of fossil fuels and the demand for wood fuels increased. This increase was the larger the smaller proportional user of wood-fuel a plant was. However the downturn of allowance prices in year 2007 ended this process. The heterogeneity of energy plants in size, industry and location determines the intensity and extension of fuel use but their role is limited in the fuel substitution.

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1. Introduction

The European Union emissions trading scheme (EU ETS) started in 2005. The first phase ended in 2007 and the second one began in 2008 and will last until 2012. The scheme encompasses the whole EU region and it is designed to be the main instrument to reduce CO_2 emissions requested by the Kyoto Protocol. Energy plants with larger thermal input capacity than 20 MW are included within the scheme, as well as iron, steel, mineral, pulp and paper industries and oil refineries. In total, the first phase of the system covered approximately 12,000 installations, which correspond about 45% of EU´s aggregated CO_2 emissions. These installations are issued CO_2 emission permits. The emission allowances are each equivalent to a ton of CO_2 and they are provided from the initial allocation or purchased within the EU area. Power sector is the biggest and most active actor in EU's emission trading. (Point Carbon 2008; EC 2008.)

In a cap and trade system such as EU-ETS a target amount of CO_2 emission reductions set by policymakers can be reached in a cost efficient way (Menanteau et al. 2003). In particular, the system does not define a method or a place how the emission reductions should be made. To reach reductions in emissions, energy plants can (i) reduce their production, (ii) improve their energy efficiency by investments, (iii) invest in the carbon capture and storage (CCS) technology, or (iv) substitute low-carbon fuels, such as renewable fuels, for high-carbon fuels. Because of the nature of energy plants, (they serve municipalities or industries), the first option is not commonly available. As to the option of investments, Bailey and Ditty (2008) noticed that UK emissions trading scheme had only a minor impact on investment decisions of energy plants, which could be the case in EU ETS in short run. Also Kara et al. (2008) confirm the same finding in their study looking at the conditions of the Nordic electricity markets. Note that on the general level emission quotas and allowance markets set the firms in a complex and dynamic context wherein short and long run behaviour may be in conflict (e.g. see Harstad and Eskeland 2007, Boucekkine et al 2008, Zhang 2007 and references therein).

The fourth choice to reduce CO_2 emissions, substituting low-carbon fuels for high-carbon fuels, can be carried out without substantial risks or expenses in many circumstances. In this study we focus on this option, by investigating the substitution of wood fuels for fossil ones using Finnish firm-level data. Because renewable fuels such as wood fuels are considered as carbon neutral in the EU ETS, fuel input substitution between bio-fuels and fossil fuels may be favourable for energy producers. Even though emissions trading enhance the competitive advantage of renewable fuels in energy production in theory, empirical studies to confirm this are rare. Particularly, firm-level data on the fuel-mixes of energy plants that could be used in econometric analyses, are not commonly available. Tauchmann (2006) studied possible consequences of emissions trading by estimating the fuel price sensitivity of energy plants with German data. The analysis was based on a panel data set of major German electricity producers from 1968 until 1998. He concluded that German energy utilities have a low price sensitivity, which indicates that prices of CO_2 emission allowances may have only minor impact on the fuel mixes of energy plants. However some results (e.g. Arimura 2002) indicate that uncertainty concerning the trading rules and prices under allowance markets distort the firms' fuel input decisions.

Even though the fuel price sensitivity of energy plants may be low in German, it is not necessarily so in the Nordic countries, which is indicated by Brännlund and Lundgren (2004). They studied the fuel input substitution of Swedish heating plants under two different policy changes by using a cost share linear Logit model. In their simulations, the both policy instruments, a CO_2 taxation and a subsidy for wood fuel production, increased the demand for wood fuels substantially. The heterogeneity of energy plants affects the demand for wood fuels also within frontiers. Brännlund and Kriström (2001) found out that price elastisities for different fuels vary with plant size, while they studied the impacts of changes in Swedish energy taxation.

German and Finnish production structures in energy production differ from each other by their fuel-mix and also by their combustion technology. As noted in Tauchmann (2006) hard coal and lignite are dominant fuels in German, while bio-fuels, coal, natural gas and peat are the most significant fuels in Finland. In terms of combustion technology, pulverized fuel and fluidized bed combustion are the two main technologies for solid fuel utilization. The former is essentially a coal burning technology, while fluidized bed combustion is more suitable for multi-fuel utilization (Kangas et al. 2009). It is this latter combustion technology which is dominant in Finland, thus making the circumstances for fuel input substitution under the EU-ETS perhaps better in Finland as compared to Germany. Furthermore, peat is a relatively important fuel in energy production in Finland. Fuel properties of peat and wood are relatively similar, whereupon peat can be often substituted for wood also in unsophisticated boilers.

Finland is committed to increase its share of renewable energy source (RES) from 28,5% to 38% by 2020, which has led to the interest to promote wood fuel utilisation in the country. Currently, in the Finnish energy policy, the EU-ETS is the most important energy policy instrument to promote RES in the emissions trading sector, even though many other EU countries apply also either feed-in tariff systems or tradable green certificate systems to support RES. Thus, it is worthwhile to study how this EU wide climate policy tool affects the substitution between wood and the fossil fuels in Finland. This study focuses on wood fuel utilization excluding black liquor. Biomass is the most important RES in Finland, with the share of over 80%.

The aim of the paper is to study the impacts of the EU-ETS on the fuel substitution by using an econometric approach. We do this by taking into account the heterogeneity of energy plants with respect to their size, industry type and location. For example, the supply of wood fuels restricts the demand for wood fuels differently in different regions of the country. Furthermore, large energy plants are not often able to purchase extensive amount of wood fuels because of transportation costs combined with relatively low energy content of wood. Also, the type of energy plant is a determining factor in terms of the fuel substitution: an energy plant relating to the forest industry use naturally more wood fuels than e.g. a municipal energy plant. Additionally, the mechanism of emissions trading causes variation in wood fuel utilisation among different size categories of energy plants.

The rest of this paper is structured as follows. We first derive fuel input demand properties from a simple static model to motivate the econometric approach used in the empirical part of the study. In the following section the plant-level energy input and emission trading price data are presented. After this, the econometric specifications and estimation strategies are described together with the results. We end with conclusions and discussion.

2. Deriving fuel input demands with allowance permits

Consider a firm that is forced to internalize its greenhouse gas emission as a by-product of the production process. This happens with government issuing a limited number of pollution permits or allowances to the firms. Firms whose marginal abatement costs are larger than the allowance price can obtain extra allowances from less polluting firms. Typically the firm buys these allowances from tradable permission markets. An alternative way to control emissions is to use a less polluting technology or use low emitting inputs in the production process. Decreasing supply of the total number of polluting permits increases the allowance price making these alternative emission reduction methods more feasible. Over all, efficiently working emission permit market is seen as the least cost system to reduce greenhouse gases (Tietenberg 2006).

Assume that the firm *i* has two fuel inputs: one with high emission rate (*H*), and one with low emission rate (*L*) $e_H > e_L$. Only the former is controlled with tradable permissions. Let $e_H \bar{H} = \bar{m}_i$ be the number of allowances that the firm *i* obtains from the state in the first place. The emissions *e* from the input usage is

$$e(\bar{H}, L) = e_H \bar{H} + e_L L .$$

The government issues the fixed number of allowances for the firms, i.e. $\bar{M} = \sum_{i=1}^{N} \bar{m}_i$. Thus $\bar{M}$ is the total number of permissions for the firms that can be redistributed within the permission trade. Firm *i* can buy a number of permits to increase its emissions, $P_X [eH - e\bar{H}] = P_X [m_i - \bar{m}_i] > 0$ with tradable market price P_X .

Now the firm’s profit maximization problem is following

$$\underset{H,L}{MAX} \{ pf(H,L) - c(H,L) - P_X [e_H H - e_H \bar{H}] ,$$

where p is the fixed price of output and $c(H,L)$ is the convex cost function of fuel inputs. The first order conditions with a linear production function $f_H H + f_L L$ [1)] are

$$pf_H = c_H + P_X e_H$$
$$pf_L = c_L$$

The marginal products of inputs equal their marginal costs including the marginal costs of allowance rights. As $P_X e_H$ is positive the firm uses less *H* input compared to a firm that is not forced to internalize its emissions. Note also that if $f_H > f_L$ and $c_H < c_L$ the reduction in *H* is not necessarily large if the allowance trading price P_X is low. Some relevant comparative statics results are obtained by total differentiating the first order conditions with respect to *H*, *L*, and P_X :

$$\begin{bmatrix} -c_{HH} & -c_{HL} \\ -c_{LH} & -c_{LL} \end{bmatrix} \begin{bmatrix} dH \\ dL \end{bmatrix} = \begin{bmatrix} e_H dP_X \\ 0 \end{bmatrix}.$$

Solving with Cramer's rule for dL/dP_X and dH/dP_X gives

$$dH/dP_X = \frac{-e_H c_{LL}}{c_{HH}c_{LL} - c_{HL}^2} < 0 \qquad | \, c_{LL} > 0,$$

$$dL/dP_X = \frac{-e_H c_{LH}}{c_{HH}c_{LL} - c_{HL}^2} > 0 \qquad | \, c_{LH} < 0.$$

The increase of allowance price $(dP_X > 0)$ leads to decrease in high emission fuel *H* usage $(dH < 0)$. However the demand for low emission input *L* increase in response to an increase in the allowance price $dL/dP_X > 0$ if the raw material inputs are substitutes to each other in energy production, i.e. $c_{LH} = c_{HL} < 0$.

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[1]) f_H and f_L stand for partial derivates of *f(H,L)* with respect to *H* and *L*. These marginal products are measured as the constant unit efficiencies of the fuel inputs in power and heat production.

3. Data

The econometric analysis in this study relies on a regional firm-level data collected by Finnish Forest Research Institute (METLA). The data-set used compiles statistics on the solid wood fuel utilization between 2003-2007. The annual data consist of approximately 800 energy utilities with their nominal efficiencies, plant characteristics like regional location and industry type, and amounts of utilized wood fuels in energy content.

Since the firm-level data about fossil fuel consumption was not available, it was estimated through a representative energy plants approach. Energy plants were classified into four different groups, as the yearly utilization rates of different types of plants differ significantly. These four industry groups are: small community plants, large community plants, energy plants related to sawmills and energy plants related to pulp or paper industries. The annual observations of fuel-mixes were based on observations from 4 to 30 representative energy plants, depending on the industry group. The fossil fuel consumptions were estimated through a compiled statistics on utilised wood-based fuels and nominal efficiencies assuming that the annual utilization rates of energy plants are equal among different groups.

Allowance price level was estimated to be €5-20 per tonne in most predictions before the beginning of the EU-ETS (POMAR 2007). However, the volatility of allowance price was high during the first phase. In the beginning of the phase, the price level rose from €8 to over €30 per tonne by summer 2005. During autumn 2005 to spring 2006 the price settled on the level of €20-25. The information about realized CO_2 emissions in 2005 led to the collapse of allowance prices in late spring 2006 and decreased the price level from almost €30 to below €10. The price recovered slowly to the level of €15-20, before it started to sink again towards the end of 2006. The price depreciated steadily and went below €1 in spring 2007 and stood close to zero until the end of the first phase. Note that we don't have data on fuel input prices at firm level. However we know that aggregate price ratio of wood and fossil fuel inputs have been stable during the period analyzed. Thus the role of price ratio variable in the model is of second order importance.

4. Econometric Models and Results

In the following we specify three models to study the substitution between wood and fossil fuels. We estimate the response of ratio between wood and fossil based raw material inputs to changes in the CO_2 allowance prices. The models are augmented with energy production scale, industry, and regional specific effects.

Random and Fixed Effect Models

Consider the following Random Effect (RE) panel data model that estimates the response of ratio between wood and fossil based raw material inputs $(\ln(E_W / E_F))$ to changes in the CO_2 emission trading prices $(\ln EMISP_t)$

$$\begin{aligned}
\ln(E_W / E_F)_{it} = \alpha_0 + \beta_0 \ln TREND_t + \beta_1 D20MW_i + \beta_2 \ln EMISP_t \\
+ \beta_3 D20MW_i \times \ln EMISP05_t + \beta_4 D20MW_i \times \ln EMISP06_t \\
+ \beta_5 D20_i \times \ln EMISP07_t + c_1 DSAWMILL_i + c_2 DINDUSTRY1_i \\
+ c_3 DINDUSTRY2_i + d_1 \ln CAPACITY_{it} + \sum_{j=1}^{14} g_j REGION_{ij} + (\alpha_i + \varepsilon_{it})
\end{aligned}$$

Trading is obligatory for plants larger than $20MW$ using fossil based fuels in energy production. (Kara et al. (2008) estimated that 62% of Finnish installations that are producing CO_2 emissions are included into the scheme.) As all plants in the sample use wood-fossil fuel input mix in energy production, the ratio E_W / E_F is a natural fuel input adjustment measure when the emission trade prices vary. The trading system started in the year 2005. The annual differences of price responses for plants representing different industry types are modeled with the following variables

$$\ln EMISP_t = \text{emission trading price: } \begin{cases} 0, \text{ year } 2003 \\ 0, \text{ year } 2004 \\ \ln(28 Euro/ton), \text{ year } 2005 \\ \ln(23 Euro/ton), \text{ year } 2006 \\ \ln(9.5 Euro/ton), \text{ year } 2007 \end{cases}$$

$$D20MW_i = \begin{cases} 0, \text{ plant } i \text{ is smaller or equal to 20MW} \\ 1, \text{ plant } i \text{ is larger than 20MW} \end{cases}$$

$$D20MW_i \times \ln EMISP05_t = \text{emmision trading price for plants } > \text{ 20MW in year } 2005$$
$$D20MW_i \times \ln EMISP06_t = \text{emmision trading price for plants } > \text{ 20MW in year } 2006$$
$$D20MW_i \times \ln EMISP07_t = \text{emmision trading price for plants } > \text{ 20MW in year } 2007$$

The first variable measures the general emission price effect on fuel usage. The small plants may adjust toward greener fuel mix albeit they are not forced to pay emissions. The dummy variable $D20MW_i$ gives the size category effect on the fuel ratio. The last three variables give the year specific emission price effects for large plants, i.e. the plants which have to pay for CO_2 emissions if they use fossil based fuels.

The sample includes small plants that are connected closely to wood-processing industry. The dummy variable $DSAWMILL_i$ receives the value *1*, if the plant is part of a sawmill, otherwise it receives the value *0*. The dummy variable $DINDUSTRY1_i$ categorizes the plants between process industry and non-process industry classes. Similarly, the variable $DINDUSTRY2_i$ categorizes the plants between community energy utilities and other industry classes.

The scale of energy production determines the extension of fuel use. We use in this context $\ln CAPACITY_{it}$ as the size variable. It measures the average level (in %) of used nominal output capacity of the plant per year. Note that both E_w and E_F are measured also in MWh. Thus the ratio E_W / E_F is without units. However as we use the logarithmic transformation, $\ln(E_W / E_F) = \ln E_w - \ln E_F$, we can argue that its response to a change in some explanatory variable still has the MWh interpretation besides the typical elasticity interpretation connected to logarithmic variables.

Finally $\ln TREND_t = 0,1,2,3,4$ measures the general business condition in the energy sector during the years 2003-2007. The last fourteen dummy variables, $REGION_{ij}$, $j = 1,2,....,14$ select for each plant the region (measured as forest districts) where the plant is located. We argue that the different regions have different fuel supply profiles, especially concerning the wood based fuels. The reference region is the $REGION_{i0}$, the Åland archipelago in South-West Finland, where small wood based plants are common. α_0 is the general intercept of the model, α_i's are the random firm-specific effects, and ε_{it} is the normally distributed error term.

Note that the RE-specification requires that α_i's are uncorrelated with ε_{it}'s and with the explanatory variables (for more details, see Baltagi 2008). The Hausman test reported in Table 1 rejected this uncorrelation. The fixed effects (FE) panel data model can be estimated without this requirement but this alternative is not feasible in this context since the specified model includes several time-invariant variables. Instead we propose a 2-step or hierarchical FE_2-model: we first estimate the fixed effects with a panel model that excludes any other time-invariant variables than the cross-sectional dummies, i.e. idiosyncratic constants for the plants. The LSDV-estimates for these are regressed then in second step on all other time-invariant variables. Table 1 reports the results from RE and FE_2. Figure 1 gives the estimated fixed firm-level effects.

The negative sign for the variable $D20MW$ indicates that large plants use relatively more fossils fuels compared to small plants. On the average the effect is $E_W / E_F = \exp(-8.34)$ in the RE estimation and $E_W / E_F = \exp(-17.17)$ in the FE_2 estimation. The coefficient estimates of the emission price variables indicate that the use of wood based fuels has increased. The price effect is the largest in 2005 on the large fossil fuel using plants. In total the emission trading during 2005 - 2007 has increased the demand for wood fuel (on average, measured in MWh) with effect of

Table 1. RE and FE_2 estimation results. T = 5, N = 722, Total panel (unbalanced) = 2841. Dependent variable $\ln(E_W / E_F)$

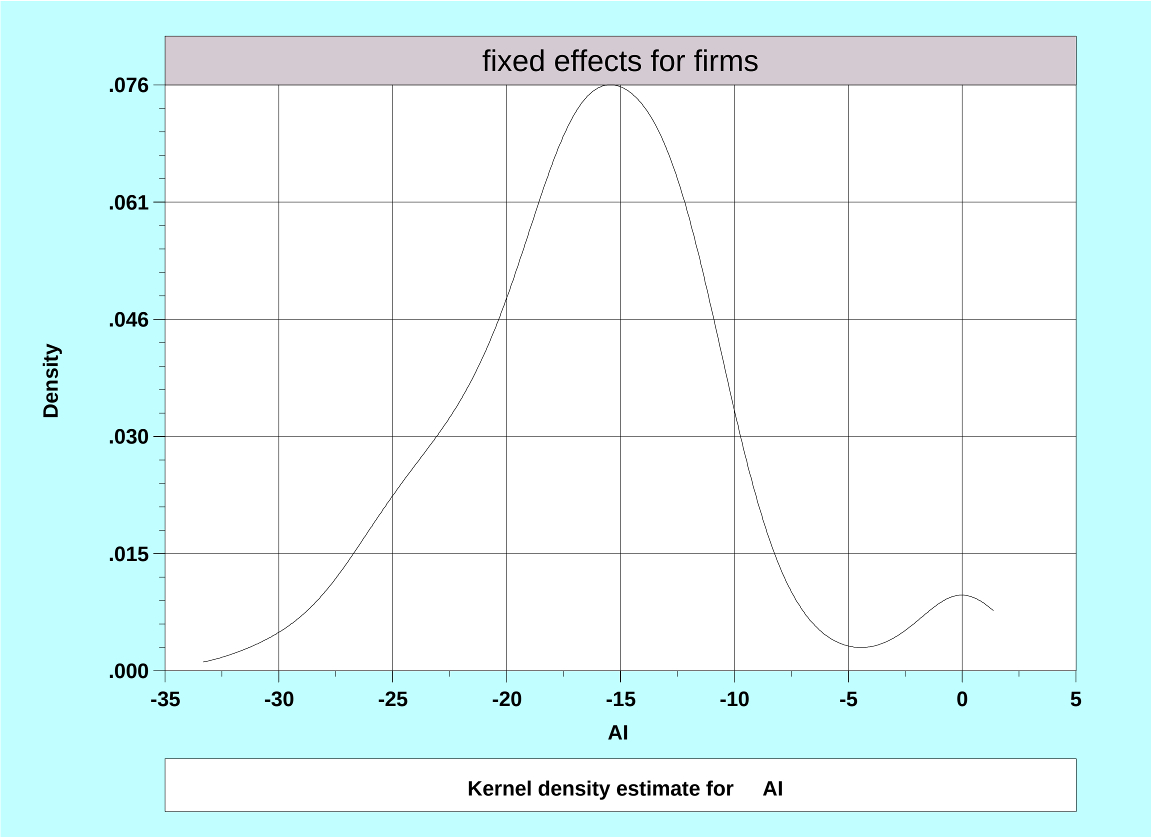
	RE MODEL		2-level FE MODEL	
	Coefficient	t_{HCSE}-value	Coefficent	t_{HCSE} value
C	**-14.85**	**-11.141**	**-18.41***	**-10.79**
lnTREND	0.089	0.78	0.044*	0.365
lnEMISP	**0.167**	**4.16**	**0.104***	**2.30**
D20MW	**-8.348**	**-19.52**	**-17.173**	**-18.52**
D20MWxlnP05	**0.429**	**3.60**	**0.312***	**4.18**
D20MWxlnP06	**0.294**	**2.48**	**0.261***	**3.59**
D20MWxlnP07	-0.025	-0.21	0.007*	0.01
DSAWMILL	**-1.649**	**-3.23**	**-5.078**	**-6.28**
DINIDUSTRY1	**-0.894**	**-3.71**	**7.382**	**2.77**
DINDUSTRY2	**-4.090**	**-6.56**	**9.012**	**3.32**
lnCAPACITY	**6.372**	**22.12**	**2.555***	**13.02**
REGION1	-1.812	-1.72	-0.574	-0.21
REGION2	**-1.978**	**-2.09**	1.265	0.73
REGION3	**-2.563**	**-2.73**	0.367	0.29
REGION4	**-2.356**	**-2.36**	0.035	.01
REGION5	**-0.567**	**-2.99**	-0.782	-0.55
REGION6	**-1.946**	**-2.06**	-1.565	-1.21
REGION7	**-3.397**	**-3.64**	0.386	0.32
REGION8	**-2.751**	**-2.92**	-0.529	-0.44
REGION9	**-2.795**	**-2.87**	-0.807	-0.62
REGION10	**-2.013**	**-2.07**	-1.640	-1.27
REGION11	-1.439	-1.42	-0.312	-0.23
REGION12	-1.840	-1.90	0.997	0.67
REGION13	**-3.846**	**-3.93**	-0.630	-0.50
REGION14	-35.650	**-2.48**	**-2.744**	**-2.01**
R^2	0.367		0.837*/0.404	
DW	1.61		2.01*/1.51	
JB-Normality	4.53		**130.11*/**4.23	
Hausman RE/FE-test	**104.48**			
F-test for fixed effects			**14.36***	

*) refers to the 1st step of FE_2 estimation

$E_W / E_F = \exp(0.17 + 0.43 + 0.29) = 2.43$ and $E_W / E_F = \exp(0.10 + 0.31 + 0.26) = 1.97$.

The negative sign of $DSAWMILL$ is unexpected.

Figure 1. The firm specific effects of $\ln(E_W/E_F)$



The results for industry dummies are opposite in the RE and FE_2 estimations. Note that the results are not comparable since the FE_2 estimation includes only a subset of the variables of RE-estimation in the first stage, and the second stage estimation (OLS on estimated firm specific fixed effects) also differs from the RE-estimation. The results from RE-estimation are as expected as the most of process industry and community energy plants are large units using relatively more fossil based fuels compared to small plants. Also the region dummies are negative. The plants are larger on the mainland regions compared to the Åland plants. Finally $\ln CAPACITY$ variable has a positive coefficient in both estimations indicating that the higher is the level of capacity the more wood fuel is used. Note that typically the large units have higher capacity level than the small ones. As our estimations include the variable $D20MW$ to capture the plant size effect we argue that the positive capacity effect on the fuel ratio stems from plants close to, but below, the size of 20MW.

The model fits are in statistical terms adequate. The residuals are normal in RE eatimation, the model explains close to 36% of the variation in $\ln(E_W / E_F)$, the random plant components explain 38% of the error variance, and the DW-value indicates that no residual autocorrelation is present. However the Hausman test rejects the RE-specification making the estimates inconsistent. This means that we have to emphasize the FE_2 results or use some other, a more general estimation approach, which would allow for controlling the evident random heterogeneity in $\ln(E_W / E_F)_{it}$ observations.

While the FE_2 results above are adequate, the 2-step FE-model can be considered to be a fairly restrictive and awkward approach to model and estimate both the plant-within and plant-between variability in the plants' fuel ratio $(E_W / E_F)_{it}$. Therefore we next introduce a model alternative, the Random Coefficient, or mixed 2-level model, which incorporates into one single model both aspects of the individual plant variability. This mixed model alternative is a general model approach that enables one to efficiently control and estimate the observed and unobserved heterogeneity among the plants. In addition we obtain some interesting estimates describing the evolution of the stochastic structure of the data and model coefficients that are not obtained from the RE- and FE-models.

Random Coefficient Model

In this model we used the following specifications in the two stages:

1 - level

$$\ln(E_W / E_F)_{it} = \alpha_i + \beta_i \ln TREND_t + d_1 \ln CAPACITY_{it} + \varepsilon_{it}$$

2 - level

$$\alpha_i = \alpha_0 + \alpha_1 D20MW_i + \alpha_2 \ln EMISP_t + \alpha_3 DSAWMILL_i + \alpha_4 DINDUSTRY1_i + \alpha_5 DINDUSTRY2_i + \sum_{j=6}^{19} \alpha_j REGION_{ij} + \zeta_{\alpha,i}$$

$$\beta_i = \beta_0 + \beta_1 D20MW_i + \beta_2 \ln EMISP_t + \beta_3 DSAWMILL_i + \beta_4 DINDUSTRY1_i + \beta_5 DINDUSTRY2_i + \sum_{j=6}^{19} \beta_j REGION_{ij} + \zeta_{\beta,i}$$

$$\varepsilon_{it} \sim N(0, \sigma_\varepsilon^2) \text{ and } \begin{bmatrix} \xi_{\alpha,i} \\ \xi_{\beta,i} \end{bmatrix} \sim N\left[\begin{pmatrix} 0 \\ 0 \end{pmatrix}, \begin{pmatrix} \sigma_\alpha^2 & \sigma_{\alpha\beta} \\ \sigma_{\beta\alpha} & \sigma_\beta^2 \end{pmatrix}\right].$$

The mixed model assumes that some of the first stage model parameters are random in the cross-sectional dimension. The α_i parameter measures the plant-between variability of $\ln(E_W / E_F)_{it}$ and β_i measures how this variability changes in time. However the plant-within variability is also modeled because we explain the first stage (random) coefficients with plant specific time-invariant controls. Finally we allow also for idiosyncratic randomness or unobserved heterogeneity for plant responses α_i and β_i, i.e. $\zeta_{\alpha,i}$ and $\zeta_{\beta,i}$. Note also that α_i and β_i can correlate with each other.

The composite form of the above model is called the conditional model that nicely shows the versatility of the mixed model approach that includes all the 2-way interaction terms with the $\ln TREND_t$ variable

$$\begin{aligned}\ln(E_W / E_F)_{it} &= \alpha_0 + \alpha_1 D20MW_i + \alpha_2 \ln EMISP_t + \alpha_3 DSAWMILL_i + \alpha_4 DINDUSTRY1_i \\ &+ \alpha_5 DINDUSTRY2_i + \sum\nolimits_{j=6}^{19} \alpha_j REGION_{ij\,i} \\ &+ (\beta_0 + \beta_1 D20MW_i + \beta_2 \ln EMISP_t + \beta_3 DSAWMILL_i + \beta_4 DINDUSTRY1_i \\ &+ \beta_5 DINDUSTRY2_i + \sum\nolimits_{j=6}^{19} \beta_j REGION_{ij}) \times \ln TREND_t \\ &+ d_1 \ln CAPACITY_{it} + (\zeta_{\alpha,i} + \zeta_{\beta,i} \times \ln TREND_t + \varepsilon_{it}).\end{aligned}$$

The model consists of 48 fixed effects parameters and of 4 random (covariance) parameters ($\sigma_\varepsilon^2, \sigma_\alpha^2, \sigma_\beta^2, \sigma_{\mathbf{a}\beta}$) that all can be estimated consistently with Maximum Likelihood (ML) or RESTRICTED Maximum Likelihood (REML) methods. Note that we cannot use $D20MW_i \times \ln EMISP05_t$ -type year specific variables in the model as they lack the needed cross-sectional variability in this context. However, augmenting the model with a more general interaction variable $D20MW_i \times \ln EMISP_t$ we receive all relevant information from the model concerning the emission price effects on $\ln(E_W / E_F)_{it}$. Table 2 presents relevant results after some preliminary estimations and model reductions.

Table 2. Mixed model estimation

Variable	Coefficient estimate	t-value
Intercept	**-15.202**	**-10.88**
lnTrend	**0.783**	**4.27**
D20MW	**-7.827**	**-12.92**
lnEMISP	**0.622**	**5.09**
lnTrend * D20MW	**-0.994**	**-2.14**
lnTrend * lnEMISP	**-0.460**	**-3.89**
D20MW * lnEMISP	**0.543**	**3.66**
DSAWMILL	-0.532	-1.02
DINDUSTRY1	-0.631	-1.82
DINDUSTRY2	**-4.520**	**-2.60**
lnTrend * DSAWMILL	**-1.156**	**-3.77**
lnTrend * INDUSTRY1	-0.226	-1.09
lnTrend * INDUSTRY2	0.494	0.44
lnCAPACITY	**6.337**	**34.98**
REGION1	-1.810	-1.24
REGION2	-1.954	-1.51
REGION3	-2.535	-1.95
REGION4	-2.331	-1.73
REGION5	**-0.568**	**-2.17**
REGION6	-1.902	-1.46
REGION7	**-3.375**	**-2.62**
REGION8	**-2.714**	**-2.07**
REGION9	**-2.816**	**-2.15**
REGION10	-1.971	-1.49
REGION11	-1.423	-1.05
REGION12	-1.842	-1.42
REGION13	**-3.812**	**-2.86**
REGION14	-35.342	-1.83

The results are interesting and close to the ones received earlier. Most interestingly $\ln TREND_t$ variable is now statistically significant with positive value of 0.78 and $\ln EMISP_t$ has many times larger value than earlier (0.62 compared to 0.16 and 0.104 in Table 1). Both are positive indicating that in the sample there has been a strong shift towards using more wood based fuels during the years 2003 - 2007. Note that the interaction variables $\ln TREND_t \times D20MW_i$ and $\ln TREND_t \times \ln EMISP_t$ are negative. The former has a natural interpretation: the large plants use relatively more fossil fuels compared to small plants during the study period. We argue that the trend effects dominate in the latter interaction variable since we control separately for emission prices with variables $\ln EMISP_t$ and $\ln EMISP_t \times D20MW_i$. Since these both are positive the emission prices have reduced the use of fossil fuels especially for large plants.

Table 3 shows that the random part of the model is statistically significant. There exists random variability among the plants' fuel ratio E_W / E_F both in the cross section and in time dimension. The variance in the growth of change of the initial state E_W / E_F is much smaller than the variance in the initial state E_W / E_F itself. The time dependent growth variation (the slope variation) between plants is more than five times less than the state (or intercept) level variation (1.814 and 8.622). Naturally firm size and technology conditions restrict its growth possibilities. Note also that the period between the years 2003 and 2007 in Finland was a period of steady economic growth. In spite of this the covariance between the intercept and time slope coefficients is negative and their correlation $\rho_{a,b} = \frac{\sigma_{\alpha\beta}}{\sqrt{\sigma_\alpha^2 \sigma_\beta^2}}$ is -0.447. This means that there exists a convergence among the random plant specific components $\zeta_{\alpha,i}$ in time, i.e. the smaller the plant level E_W / E_F initially was the faster it grew in time. This offers additional support to the result that substitution from fossil fuels to wood fuels has taken place among the sample plants during the period of 2003 – 2007.

Table 3. Estimates of Covariance Parameters

Parameter		Estimate	Std. Error	Wald Z	P-value
Residual	σ_ε^2	**3.148**	**0.114**	**27.484**	**0.000**
Intercept	σ_α^2	**8.622**	**0.704**	**12.245**	**0.000**
lnTrend	σ_β^2	**1.814**	**0.269**	**6.719**	**0.000**
	$\sigma_{\alpha\beta}$	**-1.766**	**0.358**	**-4.932**	**0.000**

A related and more precise information concerning the firm specific $\ln(E_W / E_F)_{it}$ evolution is obtained from the time dependent variance of the composite error, i.e. the time dependent cross-sectional variance

$$\sigma_t^2 = VAR[\zeta_{\alpha,i} + \zeta_{\beta,i} \ln TREND_t + \varepsilon_{i,t}]$$

$$= \sigma_\alpha^2 + \sigma_\beta^2 \ln TREND_t^2 + \sigma_\varepsilon^2 + 2\sigma_{\alpha\beta} \ln TREND_t \quad (t = 1, 2, ..., T).$$

Note that σ_t^2 is quadratic in time and it has a minimum value if $\sigma_{\alpha\beta} < 0$. i.e. $TREND_t^{MIN} = \exp(-\sigma_{\alpha\beta} / \sigma_\beta^2)$. The estimate for this time point is 2.65. i.e. the convergence stops after mid year 2005. The result is obvious as the emission trading started in year 2005 and the plants have to adjust their fuel mix under the new policy. In fact the cross-section error variance evolves in years 2003 – 2007 with the following values (11.77. 10.19. 10.08. 10.36. 10.78). Clearly the minimum is in year 2005. Thus the plot of the cross section variances is hump-shaped indicating that the plants have responded to introduction of emission trading homogenously. However after the year 2005 this tendency of unobserved heterogeneity among the firms has changed.

5. Conclusions and Discussion

Econometric studies on the impacts of the EU tradable CO2 permit system on the fuel demand have remained scarce. In this study we provided new results concerning the impacts of the EU-ETS cap and trade system on the fuel mix of energy plants. We used data from Finland, where the industrial and policy contexts suggest that the tradable CO2 permit system might have had larger impacts than perhaps in other European countries. The results indicate that the EU-ETS system has increased the wood energy consumption of the plants, and that wood fuels have been substituted for fossil fuels. However, over the period of 2005-2007 these impacts seemed to have decline.

There are a lot of energy-intensive industries. e.g. the forest and steel industries in Finland, which have driven the Finnish energy sector towards centralized units. Also the cold climate has affected that local district heating systems have penetrated considerably in the country (Ericsson et al 2004). The large units imply that the EU-ETS covers an exceptionally large share of the total CO_2 emissions in Finland, which increases the importance of the system in the Finnish conditions, and which may have contributed to the results received in this study.

Emission trading and possible high price level of the emission allowance in the future do not automatically guarantee an increased use of wood fuels in Finland. or in other countries with similar conditions. Because the energy contents of unprocessed wood fuels, e.g. forest chips, are relatively low, long transportation distances are not profitable. This means that wood-fuel markets remain regional. Another issue relates to the marketing position of energy producers. A district heat producer has usually a monopoly position on regional markets, which enables transferring the cost of purchasing CO_2 permits to the heat prices (Brännlund et al. 2004). This may reduce the substitution impact of emissions trading.

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