The impact of energy taxes on competitiveness, output, and exports: a panel regression study of 56 European industry sectors

1. Introduction.

The original Porter hypothesis states that high national environmental standards will encourage domestic industries to innovate and hence improve competitiveness, in particular when the regulatory standards anticipate requirements that will spread internationally (Porter, 1990; 1998). The main reason, according to Porter and van der Linde, is that environmental regulation puts a pressure on industry to innovate new and greener products that, in turn, create better demand conditions for the industry. Moreover, environmental standards encourage industries to find less resource intensive ways of production, thereby counteracting the initial rise in production costs caused by the regulatory demands. The earlier such regulatory pressures are introduced within a given country vis-à-vis other countries, the higher the chance that the innovative experiments arising from the pressure will lead to a competitive edge.[1]

The critics of the Porter hypothesis reject the argument that environmental regulation should lead firms down more profitable, innovative avenues. If such opportunities existed, they would have been pursued anyway by rational firms, and, in this light, the regulation is just another distortion that may hamper efficient allocation of resources. Hence, the controversy involves intriguing questions on economic rationality and institutional factors which are very difficult to answer *a priori*. This paper makes no attempt to resolve the theoretical question. It merely provides some empirical evidence that can be used to indicate if, and to what extent there is, a Porter effect in one special area of environmental regulation.

It is recognized that not all environmental regulation will have the desired effect. Porter agrees that traditional environmental regulations have often violated the principles for a positive impact on competitiveness by imposing rigid pollution abatement technologies, rather than leaving room for adaptation, flexibility and innovation (Porter, 1991). From this point of view, market-based environmental regulation, including environmental taxes, would be better suited to fulfil the Porter "prophecy". On the other hand, emission taxes (at least those without revenue recycling) introduce an out-of-pocket

[1] Although, of course, if regulations are introduced too early, it may cause severe problems for industry thus hampering innovative efforts.

tax expense to the polluting firms on top of the extra abatement costs they experience from their attempts to reduce the tax burden. It brings us to the interesting question whether a Porter effect is in fact associated with environmental taxes and, if so, whether environmental taxes have better or worse effects on competition than environmental standards.

The focus of this paper is the extent to which energy taxes – via the resulting increase in real energy prices, or in their own right – reduce or enhance industrial competitiveness. From a panel data set covering 56 industry sectors throughout Europe over the period 1990-2003, we estimate how changes in real energy taxes and real energy prices affect, on the one hand, competitiveness measured in terms unit energy costs and unit wage costs and, on the other hand, economic performance expressed in terms of output (value added) and exports. Accordingly, the paper distinguish between competitiveness as an economic potential, for example low unit energy costs, and the effects of that potential which, for example, could be higher economic output and exports. If the industries experience significantly lower exports and output as a consequence of a tax-imposed increase in real energy prices it is a clear indication that this outcome resulted because the energy taxes reduced their competitiveness. Such findings would give us reason to reject the Porter hypothesis in this specific case.

2. Modelling the Porter effects associated with energy taxes

A good theoretical model is required in order to estimate the causal subtleties associated with the possible Porter effect of an environmental tax on energy. According to economic theory, the effect of an energy tax will be exactly the same as the equivalent increase in energy prices. Energy price elasticities with respect to energy consumption and output has been extensively documented through a variety of statistical methods in the energy economics literature (for an overview see Atkinson and Manning, 1995, plus numerous articles in the Energy Economics journal).Panel regression and cointegration analyses have been more successful than older methods in capturing the long-term relation between energy prices and energy consumption. Typically the studies report long-term own-price elasticiticies of industrial energy consumption in the range between -0.3 and -0.6 (Barker et. al, 1995). This evidence tells us that energy taxes will have a strong environmental effect in the form of reduced energy consumption and hence less combustion of fossil fuels and lower emission of air pollution.

But what is the impact of energy taxes on competitiveness and economic performance? Energy is not just some environmental problem, but a major input factors into industrial production. Most evidence indicate that rising energy prices have an adverse impact on economic performance (Longva et. al, 1988; Smyth, 1993). The two oil crises during the 1970s speak for themselves (Nasseh and Elyasiani, 1984). Hence, it appears unlikely that energy taxes should be the carrier of a true Porter effect. Indeed, it is hard to believe that energy taxes will make room for so much innovation that it more than offsets the problem of rising input prices. But even if the net effect of an energy tax is a reduction in output, a mitigating Porter effect of substantial size may be involved.

Figure 1. A causal model of the Porter effects

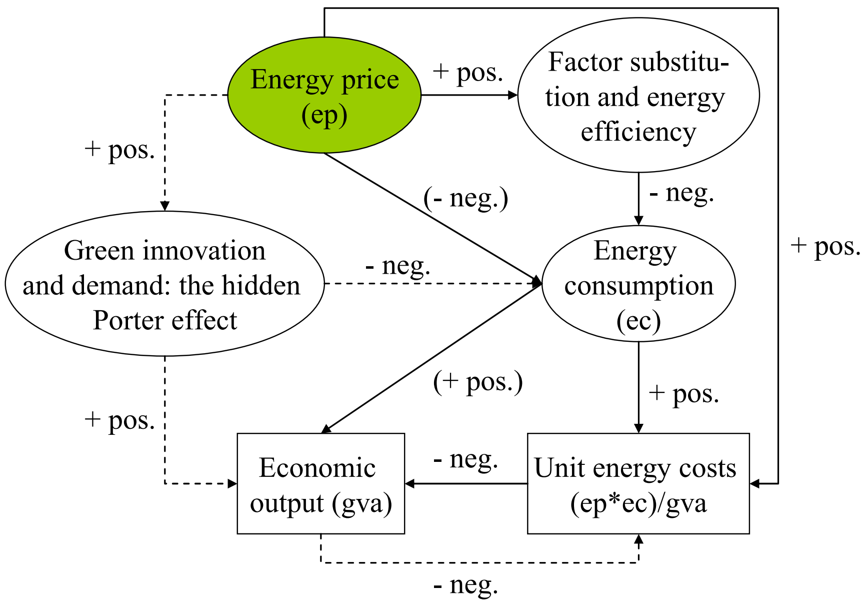

Figure 1 shows the basic reasoning. Variables that later appear as dependent variables in the analysis are indicated by rectangular boxes and variables that appear as independent variables, or unobserved intermediary causes, are indicated by oval boxes. A number of relevant independent variables are omitted from the figure, for example government regulation and subsidies to stimulate energy savings, the cost conditions of competitors, etc. The omitted factors are assumed to remain unaltered. There are two separate streams of influences, the first marked by solid lines and the other by dotted.

In the first stream, or chain of effects, the following logic applies. Rising taxes and energy prices will induce firms to substitution towards other input factors (mainly labour and capital) including energy efficiency improvements, which again will lead to lower energy consumption. If the possibilities for innovation and factor substitution are very limited, rising energy prices and taxes may even reduce output since lower energy consumption is not compensated for by other input factors (cf. the bracket relations) Factor substitution will, in turn, decrease unit energy costs. On balance, however, unit energy costs are expected to rise because of the higher energy price. The net impact is therefore a reduction in competitiveness on the assumption that competitors (especially foreign) do not experience a similar or higher increase in energy costs. The further implication of increasing unit energy costs (vis-á-vis competitors) is reduced economic output. Overall, the stronger the effect of the mitigating influences in the form of energy savings through factor substitution, the less negative impact on economic performance – and the more support to the supply-related elements of the Porter idea.

On the other hand, there is a second chain of effects in which rising energy prices and taxes may induce firms to product innovations that minimize the use of resources and other kinds of environmental initiatives that ensure more effective pollution abatement. This may, in turn, stimulate growth either because demand for the specific industrial products increase, or because the initiatives helps to create a strong green image, which improves the general economic conditions for the firm. This broader green innovation effect is the core of the Porter hypothesis, but it is much more difficult to observe and measure than the first chain of effects.

In the first chain of effects, the Porter element reduces to the mitigating influence that factor substitution has on the original negative economic impact of higher energy prices. One would never expect factor substitution to be so high that unit energy costs actually decline and output grows as a result of higher energy prices and taxes. However, the second chain of effects – the demand-related green innovation effect – introduces the possibility that, on balance, green energy taxes reduce competitiveness and output only slightly or perhaps even lead to improvements.

In the subsequent statistical analyses, we will test whether Porter hypotheses of various degrees are supported by the evidence relating to energy taxes. One of the most interesting questions is, of course, whether the hidden Porter effect is strong enough to offset the expected adverse impact of energy prices on economic performance. Hence, if we find a positive relation between energy taxes, competitiveness and output, it would indicate the existence of a *radical Porter effect*. This would indeed be contrary to ordinary economic reasoning and move the scope of the Porter hypothesis beyond its usual application to non-fiscal instruments of environmental regulation.

More likely, there is a chance that Porter effects working through the factor substitution channel and the demand-related innovation channel strongly reduce the original negative effects of energy taxes on unit energy costs and output. If that turns out to be the case, it will indicate the existence of a *mitigating Porter effect* even with respect to tax instruments of environmental regulation. Finally, if economic performance is severely harmed by rising energy prices and taxes as assumed by mainstream theory, it indicates the *absence of Porter effects* in this area.

3. Data and method

The analysis is based on the COMETR WP3 data set covering 8 industrial sectors in 7 different European countries for the period 1990-2003. This amounts to a maximum number of 784 observations on each variable. The countries included are Denmark, Finland, Germany, Netherlands, Slovenia, Sweden and the UK. The following sectors are included:

Table 1. The industry sectors in the WP3 data set

Sector (NACE 3-digit):
15.1 Meat industry
21.2 Paper and cardboard articles
24.1 Basic chemicals industry
24.4 Pharmaceuticals industry
26.1 Glass industry
26.5 Cement, lime and plaster
27.1-27.3 Basic ferrous metals
27.4 Basic Non-ferrous metals

Accordingly the data set contains a mixture of energy intensive (24.1, 26.1, 26.5, 27.1-3 and 27.4) and medium energy intensive sectors (15.1, 21.2 and 24.4). Data on a large number of energy-related and economic variables has been collected for each of the industry sectors by teams in the respective countries. In Table 1, we provide a list of the subset of variables that we included in the panel regressions. All economic variables are in fixed 2000 prices.

From the causal model in Figure 1, we note that endogeneity problems apply to the set of variables that, as a minimum, would be required to estimate both unit energy costs and economic output. Unit energy costs are influenced by economic output as economies of scale give rise to less energy use per unit when production increases and, in the other way around, economic output is influenced by unit energy costs as competitiveness influence the output level.

In deciding about the appropriate statistical methods to use for estimating the causal relations, we were limited by data availability. It was not feasible to extend the time series beyond the 14 year period 1990–2003. The relatively short time series ruled out the application of VAR and cointegration techniques, which would have been preferred (in combination with panel data techniques) given the challenge with endogeneous variables, the supposed dynamic character of the interrelations and the often reported cointegrating nature of the central variables (energy prices, energy consumption and output).[2]

Table 2. List of variables applied in the panel regressions.

Variable	Description
gva	Gross value added (€ in fixed 2000 prices). Deflated by the producer price index (PPI)[3], GVA measures real economic output and is also used as a proxy measure of industrial production volume in economic terms
yvol	The value of total industrial output (€ in fixed 2000 prices).It is used as a proxy measure of industrial production volume in physical terms.
encon	Total energy consumption (GJ)
uec	Unit energy costs. Total energy costs (€) per value added (€). Total energy costs are divided by GVA
ulc	Unit labour costs. Labour costs (€) per value added (€). Total compensation of employees is divided by GVA.
urc	Unit raw materials costs. Total intermediate consumption (€) exclusive energy costs per value added (€).
uic	Unit input costs. Total factor input costs (€) per value added (€).
ep	Real energy price (€ in fixed 2000 prices). Total energy costs are divided by total energy consumption and thereafter deflated by PPI.
epex	Real energy price exclusive taxes (€ in fixed 2000 prices). Total energy costs exclusive taxes are divided by total energy consumption and thereafter deflated by PPI.
etax	Real energy taxes (€ in fixed 2000 prices). Total energy taxes are divided by total energy consumption and thereafter deflated by PPI.
wage	Real wage (€ in fixed 2000 prices). Total compensation of employees is divided by the total number of employees and thereafter deflated by PPI.

Yet, with the available data, panel regression techniques were indeed feasible. When the data set contains not only cross-sections[4] but also repeated observations over time for each cross-section, panel regression techniques may provide better estimates compared to disjointed OLS regression of each individual cross-section. This is because panel regression takes into account also the variance across sections (and time) in making the estimates. However, panel regression is appropriate only if it makes sense to pool observations to search for some joint coefficient estimates while still allowing for certain differences between individual sectors and/or time periods. In our case, we have a panel data structure, where the cross sections (i.e. groups) are the respective industry sectors for which data were collected, and the time series are the annual observations between 1990 and 2003 for each industry sector.

[2] See, for example, Hunt and Manning (1989); Hunt and Lynk (1992); Bentzen and Engsted (1993); Barker et. al (1995); Asafu-Adjaye (2000); Stern (2000); Enevoldsen (2005, pp.187-220).
[3] The producer price index (PPI) for each sector is used as a substitute for the sector-specific GDP-deflator (the price level of all input factors) for which data were not available.
[4] Cross-sections refer to observations across different individuals, sectors, or countries at some point in time.

Since all the chosen industry sectors are characterized as energy intensive or medium energy intensive, and all of them reside in countries that count as advanced North European economies (with the exception of Slovenia), it is assumed that the data set is sufficiently homogeneous to pool the observations. In Table 3, average unit energy costs are shown for each cross-section to provide an idea about the homogeneity across sections with respect to one of the most central variables in the analysis.

Table 3. Unit energy costs by industrial (NACE) sector and country. Average energy costs(€) per 100 € value added

	Denmark	Finland	Germany	NL	Slovenia	Sweden	UK
15.1	5.0	4.9	6.9	4.9	8.6	3.9	5.8
21.2	3.2	4.2	5.8	4.5	15.0	4.7	6.8
24.1	10.6	37.3	25.3	20.7	24.0	17.5	28.6
24.4	2.3	3.5	2.7	4.2	3.5	1.6	2.5
26.1	7.0	14.4	15.7	13.6	23.4	13.0	8.2
26.5	30.0	37.0	42.0	9.5	64.5	38.6	25.0
27.1-3	11.4	47.1	32.5	24.0	72.0	28.7	47.7
27.4	4.5	28.6	26.0	33.6	188.6	27.5	19.1

Test were carried out to determine the appropriate extent of pooling and on the basis of these test it was decided to use panel regression methods that allow the individual effects to differ across sectors, but not over time.[5]

The panel regression analyses centres around two basic models:

$$y_{it} = \alpha'_i + \beta' x'_{it} + u_{it} \quad \text{(1a)}$$

$$y_{it} = \beta' x'_{it} + (\alpha + u_i + \varepsilon_{it}) \quad \text{(1b)}$$

The first model is the fixed effects panel regression model. In this model, the omitted sector specific structural variables are treated as fixed constants over time (α'_i). The second is the random effects model in which the individual effect is considered as a time invariant component in the error term, that is, a random disturbance (u_i) of the mean unobserved heterogeneity (α). Although both models incorporate individual effects stemming from omitted variables,

5 We tested for the existence of individual group effects and time effects by analysing the variance using the *pstats* procedure in RATS. The method works by decomposing the variance into three different alternatives, one with a random component plus individual effects only, a second with a random component plus time effects only, and a third with random plus joint individual and time effects. F-tests from one-factor and two-factor analyses of the variance are calculated for the three alternatives. The test results showed that individual effects alone were highly significant, that time effects alone were not significant, and that joint effects were also significant. But the test results also showed that joining the effects adds very little to model perfection as compared with the individual effects model (which has the advantage of leaving many more degrees of freedom). Therefore, the individual effects model was selected as our general approach to pooling the data.

the central difference is that the random effects model represents the individual effects by a random component in the error term and thus prohibits correlation between these individual effects and the regressor variables *x*'.

Because of the endogeneity problems that apply to the models under investigation (see above), there is most likely correlation between the residuals and regressors and hence it is not very likely that the individual effects stemming from omitted variables are uncorrelated with the independent variables. This suggests that we use the fixed effects model.[6] Hausman specification tests were carried out to verify that the fixed effects model is superior to the random effects model for the relations we want to estimate.

4. The relation between energy taxes, competitiveness and output

There are a variety of indicators for industrial competitiveness. Focusing on the impact of energy taxes, the most relevant measure of price competitiveness is *unit energy costs*, which is defined as total energy expenditure (including taxes) per unit of gross value added in market prices. While unit energy costs is a partial measure of the price competitiveness of an industry, it is also a measure of energy intensity. Hence, if unit energy costs decrease as a consequence of substitution of labour for energy, which then turns out to increase unit labour costs, the firm will, on balance, not necessarily become more price competitive, but it will surely be less energy intensive. However, if real unit energy costs decrease and other unit input costs remain stable, it is indeed an indication that price competitiveness improved. We therefore investigated the impact on two partial measures of price competitiveness: unit energy costs and labour unit costs (defined as total wages and compensation per unit of gross value added in market prices).[7]

The original single equations used for estimating unit energy costs respective are listed as equation (2) and (3) below: All variables in these and the coming equations refer to their logarithmic (ln) values to make the results interpretable in percentage elasticities. Equations 2 and 3 appear as fixed effect models, where α_i respectively D_i are the fixed effect constants for each individual sector, τ *(t)* is a general linear trend and μ_{it} (u_{it}) are the residuals. The right-hand side include a lag of the dependent variables. The remaining symbols represent estimates of the regressor coefficients that are assumed to be joint for all sectors. In the underlying work, this assumption was relaxed by carrying out individual tests at the sector level by the very same basic model, which in this more disaggregated setting allow coefficients to vary across

[6] See Hsiao (2003: 41ff) for a further discussion of the theoretical and methodological considerations in choosing between fixed and random effects models.
[7] It would be relevant to investigate the impact on total unit input costs (including costs of capital and raw materials) also, but since the data set does not contain sufficient information on these costs, it was not feasible to use it as an independent variable in a separate estimation.

industry sectors, or across countries. The sector-specific results will be reported in a later article.

Through Hausman specification tests[8] it was investigated whether random effects models were more appropriate for estimating the unit cost equations and in both cases the answer was negative, as we suspected already from the endogeneity problem.

$$\text{uec}_{it} = \alpha_i + \beta * \text{epex}_{it} + \chi * \text{etax}_{it} + \nu * \text{ulc}_{it} + o * \text{urc}_{it} + \delta * \text{gva}_{it} + \tau * \text{trend} + \phi * \text{uec}_{i,t-1} + \mu_{it} \qquad (2)$$

$$\text{ulc}_{it} = D_i + w * \text{wage}_{it} + e * \text{uec}_{it} + r * \text{urc}_{it} + y * \text{gva}_{it} + t * \text{trend} + f * \text{ulc}_{i,t-1} + u_{it} \qquad (3)$$

The assumption behind the basic models is that unit energy and unit labour costs are, of course, determined first and foremost by the real price of respectively energy and labour. Moreover, they are determined by the unit costs of other input factors. For example, increasing unit labour costs will probably encourage industrial firms to use more energy as a substitute and thus raise unit energy costs. Unit costs are also influenced by the output quantity (gva) as economies of scale reduce average production costs and since growth tend to reduce problems with over-capacity.

Our proxy measure for unit raw material costs (cf. Table 2) is subject to more uncertainties than our similar measure for unit energy and labour costs. Moreover, it is not entirely clear that increasing raw material costs would lead to factor substitution towards energy as the consumption of the two often go together. We therefore tested the possibility for excluding urc as a regressor from both the uec- and ulc-equation and found that it could be excluded from the former, but not the latter.[9] Subsequently, we estimated the uec-equation without the urc-variable.

Table 4 and 5 shows the single equation estimation of respectively (2) and (3) without the urc-regressor in equation (2). The 56 dummy coefficients accounting for the fixed effects are not reported in the tables. The model statistics show a very good fit for both the uec- and the ulc-equation (r^2=0.989 respectively 0.968) The equations were estimated with *robusterrors* option in the RATS software package in order to correct the covariance

[8] In order to harmonize the number of coefficients and covariance matrix from the two competing models, and thus simplify the calculations involved in the Hausman test, a general constant was added to the fixed effects model. The constant creates no disturbance as it washes out in the performed regression.

matrix to allow for complex residual behaviour including heteroscedaticity and serial correlation. The estimated models were also tested for heteroscedaticity by means of the White test (1980) and for serial correlation by the Breusch-Godfrey test and the tests could not confirm the null hypothesis of respectively homescedaticity and no autocorrelation among the lagged residuals. When estimating the models without the lagged dependent variables, White and Durbin–Watson tests indicated similar problems.

Table 4. Unit energy costs

Equation 2 estimated with fixed effects and robust errors

Variable	Parameter estimate	Standard error	T-stat	p-value
epex	$\beta =$ 0.527	0.0678	7.78	0.000
etax	$\chi =$ 0.030	0.0071	4.27	0.000
uwc	$v =$ 0.293	0.0581	5.05	0.000
urc	*excluded*			
gva	$\delta = -0.511$	0.0483	−10.57	0.000
trend	$\tau =$ 0.005	0.0021	2.62	0.008
uec(t–1)	$f =$ 0.241	0.0457	5.29	0.000

Table 5. Unit labour costs

Equation 3 estimated with fixed effects and robust errors

Variable	Coefficient estimate	Standard error	T-stat	p-value
wage	$w =$ 0.343	0.0360	9.55	0.000
uec	$e =$ 0.123	0.0259	4.73	0.000
urc	$r =$ 0.145	0.0277	5.25	0.000
gva	y = −0.325	0.0385	−8.45	0.000
trend	$t = -0.004$	0.0019	–2.41	0.016
ulc(t–1)	$\Phi =$ 0.330	0.0393	8.41	0.000

The problems may relate to the many dummy variables included, but it could also be due to the endogeneity of the gva-, uec-, and ulc-variables which, in any case, suggests that it is preferable to estimate the uec- and ulc-equations simultaneously along with an output-equation, that is, as a 3-equation system. Before we move on to this next step, and before we start to interpret the results, we will shortly discuss and provide a first single equation estimate of output(gva).

The central measure of economic performance is growth in terms of output. Gross value added is the normal indicator of economic growth, and we therefore investigated the impact of energy prices, energy taxes, labour costs and raw materials costs on value added. According to economic theory, in-

[9] The test was carried out with the *exclud*e command in RATS which provide F, or in this case Chi-square (because robust errors were used), for the restriction that the listed coefficients are zero.

dustrial supply is influenced by input factor prices. If the cost of production factors go up the cost of supplying the same quantity will increase and hence supply will be reduced causing *ceteris paribus* a decline in output. It is the total marginal costs of input factors that determines supply and hence it should not matter whether higher costs are caused by higher energy costs, labour costs or raw materials costs. Furthermore, if an increase in one of these costs is fully offset by decline in one or more of the other cost factors, supply should not be affected.

Output is also influenced by demand, that is, the consumer's willingness to pay for the products. Ideally, output should therefore be estimated by the means of a simultaneous supply and demand equation. However, in our case, we do not have sufficient information to estimate demand. Yet, the output measure is, to a certain extent, corrected for the demand factor as it is deflated by the producer price index (PPI). For our purposes, it should therefore be sufficient to estimate a supply-focused output-equation:

$$\text{gva}_{it} = \kappa_i + \gamma * (\text{uec}_{it} + \text{ulc}_{it} + \text{urc}_{it}) + \varsigma * \text{trend} + \psi * \text{gva}_{i,t-1} + \varepsilon_{it} \qquad (4)$$

In the output equation, unit input costs are represented by uec+ulc+urc, which should cover the full input costs since unit raw materials costs (urc) are measured here as all intermediary costs of production excluding energy costs and compensation of employees.[10]

Table 6. Gross value added

Equation 4 estimated with fixed effects and robust errors

Variable	Coefficient	Standard error	T-stat	p-value
unit input costs	$\gamma = -0.490$	0.0380	–12.89	0.000
trend	$\zeta = 0.013$	0.0017	7.98	0.000
gva(t–1)	$\psi = 0.544$	0.0438	12.42	0.000

Model 4 has a very high r^2 (=0.996), and the coefficients all have the expected sign just like the coefficients in model (2) and (3), but again there are problems with endogeneity, heteroscedaticity and autocorrelation. In the next step we therefore specified the full system of simultaneous equations – especially with a view to get a clearer picture of the reciprocal influence between output, unit energy costs and unit labour costs.

From the observation that the trend variable is more important in the output equation than in the uec- and ulc-equation (cf. the higher T-stat for trend in Table 6 vs. Table 4 and 5), we made further investigations and came to the

[10] It therefore includes intermediary costs related to administration also

conclusion that the output-model in the full equation system could be improved by working with sector-specific trends instead of a common trend. We therefore added a fixed effects dummy trend variable, but only to the output-equation within the system.[11]

$$\text{gva}_{it} = \kappa_i + \gamma * (\text{uec}_{it} + \text{ulc}_{it} + \text{urc}_{it}) + \varsigma_i * \text{trend} + \psi * \text{gva}_{i,t-1} + \varepsilon_{it} \tag{5a}$$

$$\text{uec}_{it} = \alpha_i + \beta * \text{epex}_{it} + \chi * \text{etax}_{it} + \nu * \text{ulc}_{it} + \delta * \text{gva}_{it} + \tau * \text{trend} + \phi * \text{uec}_{i,t-1} + \mu_{it} \tag{5b}$$

$$\text{ulc}_{it} = D_i + w * \text{wage}_{it} + e * \text{uec}_{it} + r * \text{urc}_{it} + y * \text{gva}_{it} + t * \text{trend} + f * \text{ulc}_{i,t-1} + u_{it} \tag{5c}$$

Equations 5a to 5b were estimated with the *nlsystem* procedure in RATS which allow us to work with complex simultaneous equations, including formula, and use an generalized method of moments (GMM) estimator. GMM estimators apply an optimal weighting matrix to the orthogonality conditions that are used for correcting the covariance matrix (Hansen, 1982). The applied GMM estimator corrects, as much as possible without changing the model, for problems with heteroscedaticity and serial correlation. Moreover, simultaneous estimation allow us to work with endogeneous variables (in this case, gva, uec and ulc) vis-á-vis instrumental variables (the regressors that appear only on the right-hand side) and thus with a theoretically more adequate model. In such a model, the problems with residual variance and residual correlation are expected to be smaller.

The cost of simultaneous equations is the loss in degrees of freedom when so many parameters have to be estimated at once. Out of the 783 observations 435 were usable (the rest were skipped due to missing data in some variable). In total, 238 parameters had to be estimated including 224 dummy variables!. That still leaves enough degrees of freedom to be confident about the estimates. R^2 for the respective equations within the system are, as expected, very similar to those of the single equations. Yet, most of the coefficient estimates are quite different as we see from Table 7.

[11] It might have been relevant to work with sectors-specific trends also for the uec- and ulc-equation, but that would require the estimation of another 112 parameters and thus deplete our degrees of freedom to an unacceptable extent. The dummy trend vector was therefore used where it mattered most – in the output-equation.

Table 7. Simultaneous estimation of gva, uec and ulc

Equations 5a-5c subject to nonlinear GMM estimation

Equation	Variable	Coefficient	Std. error	T-stat	p-value
GVA	unit input costs	γ = –0.241	0.0123	19.66	0.000
GVA	gva(t–1)	ψ = 0.200	0.0283	7.08	0.000
UEC	epex	β = 0.546	0.0494	11.04	0.000
UEC	etax	χ = 0.021	0.0079	2.66	0.008
UEC	uwc	ν = 0.066	0.0699	0.95	0.344
UEC	gva	δ = −0.534	0.0585	−9.11	0.000
UEC	trend	τ = 0.009	0.0023	3.74	0.008
UEC	uec(t–1)	Φ = 0.289	0.0317	9.12	0.000
ULC	wage	w = 0.372	0.0365	9.55	0.000
ULC	uec	e = 0.050	0.0313	1.60	0.109
ULC	urc	r = 0.164	0.0246	6.67	0.000
ULC	gva	y = −0.265	0.0401	−6.61	0.000
ULC	trend	t = –0.006	0.0017	–3.54	0.016
ULC	ulc(t–1)	f = 0.362	0.0314	11.51	0.000

5. Interpretation of results

With the final estimation of the major dependent variables from equation 5a-5c, we can go on to interpret the results.

Unit energy costs

The results show, as expected, that rising energy prices over time lead to increasing unit energy costs, although the impact is not a 1 to 1 relation. From the estimation of the simultaneous equation (5b), it appears that the long-term impact –after factor substitution, output adjustment, etc. – of a 1 per cent increase in the real energy price is a 0.77 per cent increase in unit energy costs.[12] This is very close to the estimate in the single uec-equation (cf. Table 4).

More interesting, the effect on unit energy costs of 1 a per cent energy tax increase is 26 times as little (0.546/0.021) compared to a 1 per cent increase in the market energy price. Since the level of market energy prices is, on average, 17 times higher than energy taxes for the observations in this data set, the result indicates that a change in the energy tax has a relatively lower effect on unit energy costs than the same absolute change in the market energy price. Hence, there is some indication that energy taxes does not harm competitiveness as much as ordinary price increases.[13] The total long-term

[12]This is because 0.546/(1-0.289) = 0.77 after taking into account the correction for lagged dependent variable (cf. Greene, 2000: 727).

[13] In the single equation, the result is different. Here energy taxes tend to have the same effect as market energy prices when the same absolute size is compared. Yet the simultaneous estimation is probably more credible as it takes into account the recursive impact from energy taxes via output.

effect of a 1 per cent energy tax increase is that unit energy costs go up by some 0.03 per cent.

Unit labour costs (ulc) tend to have a weak positive impact on unit energy costs, which is what we would expect from factor substitution. Yet, the estimate is only significant in the single equation. The results moreover show that higher output reduce unit energy costs, which is also expected, although it is a bit unexpected that the relation is almost as strong as the energy price effect. This might indicate that the real recursive relation between gva and uec is not fully captured even in the simultaneous equation system.

Unit labour costs

The results show the same basic pattern as above. Unit labour costs are first of all determined by the price of labour, that is, real wages. But the wage–ulc relation is more inelastic than the epex–uec relation. Unit energy costs and unit raw materials costs both have a positive influence on unit labour costs as the firms substitute towards labour – especially when the price of raw materials go up. And again, output work through economies of scale to reduce unit labour costs.

Economic output

The output equation clearly illustrates the need for simultaneous estimation. The single equation estimate indicate an extremely steep supply curve since a 1 per cent increase in unit input costs lead to a 1.07 per cent decline in output (after correcting for the lagged endogeneous variable). The estimate from the simultaneous equation 5a is theoretically more justified and also much more realistic. According to this estimate, a 1 per cent increase in unit input costs leads to a 0.3 per cent decline in output.

The effects of energy taxes on economic performance

On that basis, we conclude the following with respect to the average impact of energy taxes on competitiveness and output. Competitiveness is reduced as a consequence of higher energy prices as it leads to both higher unit energy costs and unit labour costs. However, unit energy costs only go up by 0.3 per cent and unit labour costs by 0.023 per cent if energy taxes increase by as much as 10 per cent. If, for example, energy costs amount to 10 per cent and labour costs amount to 50 per cent of all input costs, the final effect of a 10 per cent energy tax increase will be a small 0.04 per cent decline in output. Hence competitiveness and economic output is not affected very much by changes in energy taxes. This conclusion apply to changes within the scope of experienced fluctuations in the period under investigation. Moreover it does not distinguish between the tax level at which the tax increase occurs. A many-doubling of energy taxes may thus have more drastic(exponential) effects, especially if it is a many-doubling of an already high tax level.

Searching for the Porter effects

In the theoretical section, we identified two possible Porter effects, a supply-oriented that mainly operates via factor substitution and energy efficiency improvements and a demand-oriented mainly operating via green innovation that raise demand for industry products. In other words, the first Porter effect mainly works by reducing energy consumption and the second mainly works by increasing the consumers willingness to pay. The influence of market energy prices and taxes on energy consumption can be roughly approximated by the following single equation:

$$\text{encon}_{it} = D_i + a*\text{epex}_{it} + b*\text{etax}_{it} + c*\text{wage}_{it} + d*\text{gva}_{it} + g*\text{trend} + h*\text{e}ncon_{i,t-1} + u_{it} \quad (6)$$

A more correct estimate of energy consumption would be expected from simultaneous factor input equations, but since we have no reliable data on the price of raw materials and capital, we satisfy for the proxy type in equation (6) which normally works reasonably well in estimating energy consumption.

Table 8. Energy consumption

Equation 6 estimated with fixed effects and robust errors

Variable	Coefficient estimate	Standard error	T-stat	p-value
epex	$a = -0.435$	0.0641	–6.78	0.000
etax	$b = 0.011$	0.0081	1.35	0.178
wage	$c = -0.093$	0.0723	–1.29	0.198
yvol	d = 0.335	0.0443	7.56	0.000
trend	$h = 0.004$	0.0029	1.62	0.105

The results show that the long-term elasticity of energy consumption with respect to market energy prices is –0.435 which is well in accordance with recent findings in the area of industrial energy price elasticities.[14] Industrial output quantity has the expected positive impact on energy consumption although it is far from constant returns to scale. The other relations are not significant. Surprisingly energy taxes does not have a significant negative

[14] We choose to exclude the lagged dependent variable this time as it tend to over-determine the regression. The main conclusions are not affected by whether it is included or not, although the long-term coefficients tend to moderate. Yet, hetero-scedaticity and autocorrelation problems apply (the Durbin-Watson statistic is only 1.09). A truly dynamic cointegration model would probably be required to do away with this and perhaps be able to give a better account of the tax effect.

influence on energy consumption. This could be due to imperfect model specification (the lack of individual factor equations). Yet, it could also be the case, that energy taxes mainly work through the demand-related Porter effect on output and therefore implies a positive recursive influence on energy consumption via output.

To test further the idea that energy taxes has a positive direct impact on demand we re-estimated the simultaneous equation system 5a-c by adding the etax variable to the right-hand side of equation 5a. Although this implies some multicollinearity, the problem should be very small as the energy tax is only a tiny part of total input costs. The results are shown in Table 9.

Table 9. Simultaneous estimation of gva, uec and ulc

Re-estimation of 5a-5c by adding etax with coefficient named π to 5a

Equation	Variable	Coefficient	Std. error	T-stat	p-value
GVA	etax	$\pi = 0.023$	0.0055	4.24	0.000
GVA	unit input costs	$\gamma = -0.241$	0.0120	–20.05	0.000
GVA	gva(t–1)	$\psi = 0.206$	0.0277	7.44	0.000

We find that energy taxes have a very significant direct impact on output in that a 10 per cent increase in energy taxes lead, on average, to an increase in gva by some 0.23 per cent. The two other coefficients and their statistics remain relative stable after the inclusion of etax. in 5a. Although the additional results in Table 8 and 9 far from answer all open questions related to the hidden Porter effect[15], we have at least provided a strong indication that there is indeed a Porter effect that mitigates the immediate negative impact of green energy taxes on economic performance. We also reach the tentative conclusion that the operating Porter effect works through demand-related green innovation rather than supply-related factor substitution.

Conclusion

In the beginning of the article we posed the question whether Porter effects, which is normally associated with environmental regulation of a more traditional kind, also play a role with respect to economic instruments of environmental regulation such as (green) energy taxes. In general, the literature has experienced difficulties in providing clear-cut evidence in favour of the Porter hypothesis. Yet economic instruments of environmental regulation have quantitative properties that provide for better access to test for effects on competitiveness on economic performance. In this article such an attempt was made with respect to energy taxes. Energy taxes were described and

[15] A direct regression of willingness-to-pay (demand) against energy taxes and other demand-related variables would have been preferable, but is not feasible with the available WP3 data set.

carefully measured along with a number of other central economic variables in the WP3 data set containing time series of 8 relatively energy-intensive industry sectors in 7 different countries.

By the means of econometric panel regression techniques we have demonstrated the impact of market energy prices, energy taxes, labour and raw materials costs on price competitiveness and economic output. We have quantified the economic impact of energy taxes and have shown that higher energy taxes lead to a moderate increase in unit energy costs and a small increase total unit input costs which again lead to an even smaller reduction in economic output according to our simultaneous equation model. We have also demonstrated that, with a high probability, the very moderate negative economic impact is the result of Porter effects – in particular because the application of (mainly green) energy taxes stimulate efforts within the industries that in turn raise the demand for their products and thus have a direct positive impact on output that counteracts the negative supply effects of the tax increase. We also provided strong indications that energy taxes have different effects on competitiveness and output than market energy prices of similar size.

With the available data, it is, however difficult to say whether the interesting effects can be ascribed solely to the energy taxes, or if they energy taxes systematically go hand in hand with various kinds of government support (for example earmarked subsidies for energy-savings, public information and marketing campaigns and compensation of the industries with respect to other taxes or social contributions). A more rigorous testing would require some measure of government support to be included in the models. It would also require a better demand model than the proxy we have devised under the present conditions, along with more reliable data on capital and the price of raw materials. Moreover, it would require much longer time series that allow for dynamic VAR estimation methods and hence a more reliable account of the complex endogeneity among the central variables.

This article, which centres around the aggregate/average effects across all industry sectors, will be followed up by an article that apply the models on a disaggregated basis to the respective industry sectors and countries within the data set. It has the purpose of analyzing similarities and differences between the cross-sections and further test the validity of the models.

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