TOO HOT TO HANDLE?[1]

Benefits and costs of stimulating the use of biofuels in the Swedish Heating Sector

Runar Brännlund
Professor of Economics
Department of Economics
Umeå University
SE-901 87 Umeå, Sweden
Runar.Brannlund@econ.umu.se

Bengt Kriström
Professor of Resource Economics
Department of Forest Economics
SLU
SE-901 83 Umeå, Sweden
Bengt.kristrom@sekon.slu.se

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Abstract

This paper evaluates the impact of changes in current Swedish energy taxation by analyzing a panel of approximately 150 district heating plants in Sweden. We estimate plant-specific production functions and derive the economic repercussions of the tax. We also estimate the resulting changes of emissions of Sulfur, NOx, particulates and CO_2 and assess the externality costs. Our results raise the issue of whether or not the Swedish tax system needs to be complemented with additional environmental taxes, covering, say, emissions of particulates. However, because the geographical variation of damages is likely to be substantial, an overall assessment of current regulatory schemes seems preferable. The current system of using both taxes and regulations needs to be re-structured, in particular in the case of global environmental problems.

Key Words: Energy Taxation, Heating Plants, Panel Data, Externalities

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1. Introduction

Beginning in 1997, the Swedish government has devised a program that stimulates a significant increase of the use of biofuels. Biofuel is in this context usually defined as renewable biomass[2]. The program includes subsidies to households and large scale combustion plants. It comes amidst an overhaul of the whole energy taxation system that, in contrast, entails a relative cost increase of using biofuels in heating plants. In the new energy taxation system, the objective is to harmonize energy taxes between the industrial and the heating sector, which in practice implies a reduction of the general energy tax and the CO_2 tax for the heating sector. The objective of this paper is to shed empirical light on this issue, by estimating the impact on district heating plants of a comprehensive change in energy taxation. Using a detailed panel-data set that describes heating plants 1989-1996, we estimate the technology for each plant and simulate the choice of fuel-mix for several policy packages. In addition, we estimate environmental impacts, by using detailed data on plant technologies. By combining our estimates of the physical environmental impact with studies of the external costs, we are able to shed some light on social costs and benefits associated with different tax reforms.

The paper is structured as follows. Section 2 provides some details about the current energy taxation system and proposals to restructure it. Section 3 provides a theoretical model of a cost-minimizing power plant. Section 4 describes the econometric specification. The estimation results are presented in section 5. Simulations of the different policy packages are given in section 6, while section 7 displays the projected emission changes as well as the estimated externality costs. Section 8 offers some concluding remarks.

2. Energy Taxation in Sweden[3]

In order to understand the background for the simulation below, it will be useful to comment on some salient features of the current energy taxation system.

- Fuels used for energy purposes are taxed differently depending on where they are used. The general principle is that an energy tax, a carbon dioxide tax, and a sulfur tax, is

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[2] In this paper we define biofuels as fuels originating from wood products, such as residues from cuttings, wood chips, and wood pellets.

[3] A more comprehensive description of energy taxation in Sweden is given in Harrison & Kriström (1998) and SOU 1997:11

charged on fossil fuels used for heating and as vehicle fuels. In addition, an energy tax is charged on the consumption of electricity.

- Fuels used in the production of electricity and heat are taxed according to different principles. All fuels used in electricity production, including plants that produces both electricity and heat, are exempted from the energy tax and the CO_2 tax. On the other hand, fuels used for heating are taxed differently, depending on whether heat is produced by the industry, by district heating plants, or in combined power and heating plants.

- Peat and biofuels are exempted from both energy tax and CO_2 tax. Peat is subject to sulfur tax.

- Fuels are taxed differently depending on how they are used. In general, motor fuels are charged a higher energy tax than fuels used for heating purposes.

- Fuels are taxed differently within the same area of use. The energy tax is not proportional to energy content. For instance, the energy tax on coal is only 60% of the energy tax for oil. As a consequence, the total tax on coal and oil is similar, in spite of the higher carbon content in coal per unit of energy.

The work on a reformed energy taxation system is in progress, although it is known that it will most likely be based on a proposal made by the Green Tax Commission in 1997 (SOU 1997:11). The principles underlying the proposal can be outlined as in table 1.

Table 1. Starting points for a new Swedish system of energy taxation.

	Energy-tax per KWh	CO_2 tax per kg CO_2	Sulfur tax Per kg/S	“Traffic and environmentally related tax“	Total tax
Energy products	E	K	S	T	E+K+S+T

The point of departure is that all primary use of energy products – fossil fuels, biofuels and uranium, should be taxed according to the sum of the following four components:

- The carbon dioxide tax, which remains proportional to carbon content.

- The energy tax, which is restructured such that it is proportional to energy content.

- The sulfur tax, which remains proportional to sulfur content.
- A traffic and environmental tax, T, which is allowed to vary between fuels to accommodate concerns about particular environmental impacts and other external costs.

The energy-tax is isolated to become a pure fiscal tax in the new system, while the carbon dioxide, sulfur, and traffic and environmental tax are viewed as environmentally related taxes with a fiscal component. The traffic and environmentally related tax component can also be used to correct externalities originating from motor-traffic.

The new model implies that all energy products are taxed equally, independently of whether the products have been used for generation of heating or electricity. However, motor fuels are subject to a higher tax compared to fuels used for heating purposes.

3. Theory

We use a straightforward production theoretic approach where production of heat may be written as a function of the input of a number of fuels, labor, and capital, and the state of the technology. While there are combined heating plants, producing both heat and electricity, we study only the heat-producing plants.

The general form of the production function is written as;

$$Q_{it} = F_{it}(\mathbf{x}_{it}, L_{it}, K_{it}), \quad i = 1, \ldots, N, \; t = 1, \ldots, T \tag{1}$$

where Q is production of heat, $\mathbf{x} = [x_1, x_2, \ldots, x_n]$ is a vector of primary energy inputs, L denotes labor input, K the capital stock, and F is a production function. Furthermore there are $i = 1, \ldots, N$ plants and $t = 1, \ldots, T$ periods of time. It is assumed that the production function F is everywhere continuous and everywhere twice-continuously differentiable. The production function implicitly defines the feasible set $P(\mathbf{x})$ which is assumed to be nonempty.

Furthermore we assume that each firm behaves as a cost minimizer in the short run, i.e.,

$$\begin{aligned} &\min_{\mathbf{x},L} \mathbf{p}_{it}\mathbf{x}_{it} + w_{lit}L_{it} \\ &s.t.\; F_{it}(\mathbf{x}_{it}, L_{it}, K_{it}) = \overline{Q}_{it} \end{aligned} \tag{2}$$

By solving (2) we obtain the conditional demand for the variable inputs as a function of fuel prices, **p**, the wage, w_l, the fixed capital stock, K, and the level of production, Q. From the solution of (2) we also obtain the elasticity of demand with respect to each input price, which in general is a function of all input prices, the level of production, and the fixed capital stock. If we denote the demand elasticity for primary energy input j with respect to primary energy price k as $\varepsilon_{jkit}(\mathbf{p}_{it}, w_l, K, Q)$, a general expression for the change in conditional demand for input j is;

$$\Delta x_{jit} = \sum_k \varepsilon_{jkit} \cdot \Delta p_{kit}\,, \qquad j = 1,\ldots, n \quad k = 1,\ldots, n \tag{3}$$

where Δ denotes percentage change.

It should be noted that the demand elasticities, ε_{jk}, in general are functions of input prices and the fixed capital stock, and can thus not be treated as constants, at least not for large changes in w.

Our main focus here are the effects due to changes in energy taxes, which means that the price-change of primary energy inputs are expressed as;

$$\Delta w_i = \frac{(\overline{p}_i + t_i^1) - (\overline{p}_i + t_i^0)}{\overline{p}_i + t_i^0} \tag{4}$$

where $\overline{p}_i$ is the price before tax and t_i^0, t_i^1 denotes the sum of taxes for fuel i before and after the change.

The production of heat gives rise to negative externalities in the form of airborne emissions of various substances. Here we assume that the emissions, at least in the short run, are linear functions of the primary energy inputs, i.e.,

$$\mathbf{B}_{it} = \psi_{it}\mathbf{x}_{it} \tag{5}$$

where $\mathbf{B} = [B_1,\ldots, B_p]$ is a M-dimensional vector of bad outputs, $\boldsymbol{\psi}$ is a $(M\times n)$-dimensioned emission coefficient matrix, and **x** the n-dimensional input vector. From (5) it should be clear that emissions can be reduced either by lowering the elements in $\boldsymbol{\psi}$**,** or by changing the input mix. However, in the short run we will assume that $\boldsymbol{\theta}$ is fixed; emissions can only be reduced by changing the input mix.

It should be noticed that the specification presented here is rather restrictive. If we view the production of heat (good output) and emissions (bad output) as a result from a multioutput technology, then the specification above rules out the possibilities of "inaction" and "weak disposability". By "inaction" we mean that it is possible to produce nothing (goods or bads), given $\mathbf{x}>\mathbf{0}$. From equation (7) we see that this is not possible, since the "production" of bads is a linear function of **x** with fixed coefficients. Weak disposability says that if **x** can produce $\mathbf{y} = [Q, \mathbf{B}]$, then **x** can produce a proportional reduction of **y**. Again, this is not possible in the present specification of the production of bads in equation (7). A less restrictive departure would thus be to generalize the production function in (1) to a multioutput technology which allows for weak disposability and "inaction".[4] However, viewed as a short run analysis, the specification here is probably not very restrictive.

4. Data and empirical model

The main objective of the present study is to develop a model which allows simulations of various tax changes. We therefore need empirical estimates of how heating plants as buyers of primary energy inputs respond to price changes. From the theoretical section above it should be clear that this can be accomplished in two different ways.

The first way is to use the duality between costs and technology by specifying a cost function.[5] Applying Shepard's lemma gives us the conditional demand functions for the various inputs as functions of all variable input prices, the fixed capital stock, and the level of production. A necessary requirement to follow this route is data on output and input quantities as well as input prices facing each individual firm.

The second route is to estimate the production function (1) directly. Given estimates of the production function, the demand elasticities can be retrieved by assuming cost minimizing behavior. The data requirements are slightly different, since the estimation of the production function only requires data on output and input quantities. In the calculation of demand elasticities, however, price may be necessary, depending on functional form. If it is assumed that

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[4] See Färe & Primont (1995) for a general specification of a multioutput technologies when some of the outputs are "bads". Empirical applications of the multioutput approach in envirionmental economics can be found in Färe et.al. (1993), Coggins & Swinton (1996).

[5] The cost function is the solution to the cost minimization problem min wx, s.t. $f(x)=y$, where $f(x)$ is the production function. The solution to this problem, $C(w, y)$, fully characterize the technology (see Chambers (1989) or Varian (1992).

the plants chose cost minimizing bundles of inputs it would, in principle, suffice to have actual prices on one of the inputs. This follows from the first order conditions of cost minimization.

We have access to a panel data set covering nearly every heating plant in Sweden for the time period 1989-1996. The data set includes production levels of heat, the amount of fuels used in production, installed effect (capital), and the location of the plant. Descriptive statistics are given in table A1 in the appendix. Unfortunately, the data set does not include input of labor, investments, plant specific prices on output and inputs, or other plant characteristics. The lack of plant specific prices means that we must rule out the dual approach in the empirical analysis. Instead, we follow the second route by estimating the production function directly. To calculate elasticities we assume cost minimizing behavior. For simulation purposes we calculate price changes using the average sector input prices.

We assume that the technology can be approximated by a general Cobb-Douglas function, i.e.,

$$F_{it}(\mathbf{x}_{it}, K_{it}, L_{it}) = \prod\nolimits_k x^{\alpha_{kit}} K^{\beta_{it}} L^{\gamma_{it}} \tag{6}$$

The specification in (6) is of a general form since we allow all parameters to vary between firms and time periods.

Given this choice of functional form, all inputs are necessary. Since there is large variation between plants in terms of fuel-mix, so that $x_{kit} = 0$ for several plants, fuels and time periods, we need to aggregate fuels. Since our primary purpose is to study the substitution between biofuels, fossil fuels, and electricity, we have aggregated fuels into four groups; biofuel (x_{bio}), fossil fuels (x_{foss}), electricity (x_{el}), and “other fuels” (x_{rest}).[6] Fossil fuels include oil, coal, and natural gas. “Other fuels” include, for example, industrial hot water, peat and waste.

Since we have no data on labor input we assume that the labor requirement is proportional to the size of the plant, or the capital stock. The labor requirement for plant *i* can then be written as $L_i = a_i \cdot K_i$, where *L* is labor input, *K* capital, and *a* is a firm specific labor/capital ratio.

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[6] It should be noted that “biofuels” is in this paper synonymous with fuels based on wood, such as residues from forest cuttings.

Substituting the labor requirement into the production function (6) gives:

$$F_{it}(\mathbf{x}_{it}, K_{it}, L_{it}) = \prod\nolimits_k x_{kit}^{\alpha_{kit}} K_{it}^{\beta_{it}} a_i^{\gamma_{it}} K_{it}^{\gamma_{it}} = \prod\nolimits_k x_{kit}^{\alpha_{kit}} K_{it}^{\tilde{\beta}_{it}} \tilde{a}_{it} \tag{7}$$

where $\tilde{\beta} = \beta + \gamma$, and $\tilde{a} = a^{\gamma}$

The formulation in (7) can thus be estimated by using a fixed effects model where labor input is included in the fixed effect $\tilde{\alpha}_{it}$[7].

A second problem is that the choice of production function implies that all inputs are necessary in production. One solution to this problem is to use only a subset of the data to estimate the production function, namely a subset of plants that are using strictly positive amounts of all inputs. A major drawback with this approach is that not all information is used, and that the subset of plants may not be representative for the whole sector. In order to utilize the data set efficiently we will use an approach suggested by Battese (1998), based on dummy variables.

The approach can be illustrated as follows. Suppose there are only two inputs, x_1 and x_2, that are used in the production of Q. Assume further that n_1 is the number of plants that uses both inputs, and that n_2 plants uses only the first input, x_1. Given a C-D technology, the regression equations for the two types of plants can be written as:

$$\ln Q_i = \alpha_0 + \alpha_1 \ln x_{1i} + \alpha_2 \ln x_{2i} + \varepsilon_i, \quad i = 1, \ldots, n_1 \qquad n_1 = \text{NOBS}(x_1, x_2 > 0) \tag{8}$$

$$\ln Q_j = \beta_0 + \alpha_1 \ln x_{1j} + \alpha_2 \ln x_{2j} + \varepsilon_j, \quad j = n_1+1, \ldots, n_1 + n_2 = n \qquad n_2 = \text{NOBS}(x_1 > 0, x_2 = 0) \tag{9}$$

”Pooling” (8) and (9) gives:

$$\ln Q_i = \alpha_0 + (\beta_0 - \alpha_0) D_{2i} + \alpha_1 \ln x_{1i} + \alpha_2 \ln x_{2i}^* + \varepsilon_i \tag{10}$$

where $i = 1, \ldots, n$, $D_{2i} \begin{cases} 1 \text{ if } x_{2i} = 0 \\ 0 \text{ if } x_{2i} > 0 \end{cases}$, and $x_{2i}^* = \max(x_{2i}, D_{2i})$

Equation (10) can then be estimated by OLS. Battese (1998) shows that the omission of the dummy variable will produce biased estimates. In general the number of dummy variables

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[7] Note that the ”fixed effects” in this general specification varies over time since the underlying output elasticities varies over time. In the empirical application, however, we will assume that the ”fixed effects” are fixed over tine.

depends on the number of possible input combinations, which in turn depends on the number of inputs. For a four input industry the maximum number of dummy variables are 15 (2^4-1), given that at least one input is required.

In addition we allow for technical progress and that the output elasticities may vary with the size of the plant. Technical progress is assumed to be Hick's neutral, but is allowed to vary with plant size.

These assumptions provide us with an estimatable production function of the form;

$$\ln Q_{it} = \alpha_{0i} + \sum_h \theta_h D_{hit} + \sum_k \alpha_k \ln x^*_{kit} + \sum_k \sum_s \alpha_{ks} \ln x^*_{kit} S_{sit} + \sum_s \gamma_s S_{sit} t + \gamma_0 t + \varepsilon_{it} \qquad (11)$$

where α_{0i} are "fixed effects", S_s are size class dummies,

$$D_{hit} = \begin{cases} 1 \text{ if } \textit{"input combination" } h \text{ is used} \\ 0 \text{ otherwise} \end{cases}, \qquad \text{and } x^*_{ki} = \begin{cases} x_{ki} \text{ if } x_{ki} > 0 \\ 1 \text{ if } x_{ki} = 0 \end{cases}$$

h = 1, …, 15 = "input combinations"
i = 1, …, N = firms,
k = bio, fossil, el, rest, capital = inputs,
s = 1, 2, 3, 4, 5 = class size,
t = 1, 2, 3 , 4, 5, 6, 7, 8 = time period
ε_{it}, finally, are assumed to be purely randomly distributed errors.

The specification in (7) suggests that the marginal product of plant *i* depends on size-class and the time period. Assume, for example, that $0 < \gamma_0 < \gamma_2 < \gamma_3 < \gamma_4 < \gamma_5$. This means that productivity is increasing over time and with size class. In a similar manner, we can investigate differences between firms by size-class.

By assuming cost minimizing behavior the price elasticities may be expressed as:[8]

$$\begin{aligned} \varepsilon_{it}^{jj} &= \frac{\sum_k \left[(\alpha_k + \alpha_{ks} S_{sit}) - (\alpha_j + \alpha_{ks} S_{sit}) \right]}{\sum_k (\alpha_k + \alpha_{ks} S_{sit})}, \quad j = 1,\ldots,K \\ \varepsilon_{it}^{jh} &= \frac{\alpha_h}{\sum_k \alpha_k}, \quad \mathrm{j = 1,\ldots,K \quad h \neq j} \end{aligned} \qquad (12)$$

Equation (12) can then be used in equation (3) to estimate the change in fuel mix due to tax changes. Equation (4) is used to calculate the percentage changes in prices. However, since we do not have individual fuel prices we make use of use of national prices.

5. Estimation results

Table A2 in the appendix has detailed estimation results. In summary, there is a strong correlation between fuel input and production, as expected. Most of the parameters are significantly different from zero. The size-specific effects, α_{ij}, are all significantly different from zero, suggesting that the output elasticities vary with plant size. The hypothesis of equal output elasticities is also rejected by the F-test presented in table A3 ($F_{noslope}$).

The results in table A2 have been used to calculate the price elasticities displayed in table 2. The elasticities are evaluated at the average input levels in each size class for the year of 1996. The elasticities also vary with the firm specific input combination. The numbers presented in table 2, however, are calculated on the assumption that plants use all five inputs.

All own-price elasticities are negative, as expected from the theoretical considerations. It is interesting to note that the magnitude of the elasticities is almost independent of size class. It is also apparent that biofuels are substitutes for other fuels. Note that all off-diagonals are positive for this particular technology and set of estimates.

Table 2. Price elasticities for different fuels in Swedish heating plants

	Q < 50 GWh				**50 GWh < Q < 250 GWh**			
	p_{bio}	p_{foss}	p_{el}	p_{rest}	p_{bio}	p_{foss}	p_{el}	P_{rest}
Biofuels.	-0.676	0.151	0.217	0.309	-0.797	0.404	0.077	0.315
Oil	0.324	-0.849	0.217	0.309	0.203	-0.596	0.077	0.315
Electricity	0.324	0.151	-0.783	0.309	0.203	0.404	-0.923	0.315
Rest	0.324	0.151	0.217	-0.691	0.203	0.404	0.077	-0.685
	250 GWh < Q < 1250 GWh				**Q > 1250 GWh**			
Biofuels.	-0.675	0.159	0.107	0.409	-0.693	0.738	0.155	-0.200
Oil	0.325	-0.841	0.107	0.409	0.307	-0.262	0.155	-0.200
Electricity	0.325	0.159	-0.893	0.409	0.307	0.738	-0.845	-0.200
Rest	0.325	0.159	0.107	-0.591	0.307	0.738	0.155	-1.200

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[8] In the calculations of the price elasticities we assume that the capital stock (installed effect) is fixed. Thus we assume that there are no substitution possibilities between fuels and ”capital”, which we think is a reasonable assumption.

6. Simulations

This section presents a number of simulation results, that we also use to calculate emission impacts. We comment on some matters, before proceeding to the simulation results. The first issue is the treatment of ”other fuels”, when taxes change. ”Other fuels” contains, as noted, a disperse set of fuels (peat, waste, industrial hot water and others). Because there is no obvious way to handle this aggregation problem, we present two different sets of simulation results. In the first set we assume that the use of “other fuels” are fixed in the short run. A tax change will thus only give rise to substitution between biofuels, fossil fuels and electricity. Although this assumption may be unrealistic in the long run, it may be reasonable in the short run, since many plants must comply with long term contracts to incinerate waste and to buy industrial hot water. One consequence of this assumption is that the substitution effects, due to tax changes, will be smaller compared to the unrestricted case. In the second set of simulations “other fuels” are allowed to vary.

A second matter is that fossil fuels consist of oil, coal and natural gas. Thus, we need to solve an index problem, that is, creating an efficient ”price index” for fossil fuels. We have chosen to calculate the induced price change on fossil fuels according to:

$$\Delta p_{foss} = \Delta p_{oil} \cdot \frac{x_{oil}}{x_{foss}} + \Delta p_{coal} \cdot \frac{x_{coal}}{x_{foss}} + \Delta p_{n-gas} \cdot \frac{x_{n-gas}}{x_{foss}}$$

where $x_{foss} = x_{oil} + x_{coal} + x_{n\text{-}gas}$

Thus, any change of the taxes that hits oil, coal and natural gas will have an impact on the price of fossil fuel, which in turn will affect the fuel-mix.

We consider three different policy packages. In the first package we reduce the CO_2 tax and remove the general energy tax. This implies that the heating plants face the same taxes on energy as the Swedish manufacturing industry (in which various exemptions are used). In the second package, we keep the lower CO_2 tax and remove the energy tax, but give a subsidy to the use of biofuels. The third package adds to the first by introducing a subsidy that will keep current use of biofuels constant. Thus, given the lowered carbon tax, we estimate the subsidy (per GWh of input) that will guarantee constant use of biofuels in heating plants. Table 3 summarizes the various packages considered.

Table 3. Simulations.

Scenario	**Carbon Tax**	**Biofuel subsidy**
SIM1	50% reduction of CO_2 tax + removal of energy tax	0
SIM2	50% reduction of CO_2 tax + removal of energy tax	0.05 SEK/kWh
SIM3	50% reduction of CO_2 tax + removal of energy tax	Biofuel consumption is constant (0.02 - 0.03 SEK/kWh)

Baseline taxes are reproduced in table 4 (as of 1/1 1998), and table 5 summarizes the results of the simulations.

It is seen that a carbon tax corresponding to 50% of the general level (0.37 SEK/kg), and a removal of the general energy tax is equivalent to (in a partial equilibrium sense) a lowering of the price of oil, coal, and electricity of 37, 44, and 25% respectively.

According to the results of SIM1, consumption of fossil fuels and electricity increases, while the consumption of biofuels is reduced by approximately 18%, given that “other fuels” is fixed. If “other fuels” is variable the reduction in biofuels will, as expected, be somewhat smaller. SIM1 give rise to a 2.3 billion SEK, or 63%, decrease in government revenue. SIM2 complements, as explained above, SIM1, by introducing a subsidy equal to 0.05 SEK/KWh. The subsidy means that the price of using biofuels (everything else being given) decreases by 49%. According to SIM2, there is a significant increase of biofuel consumption at the expense of electricity and to some extent fossil fuels. This scheme costs about 3 billion SEK, in terms of lower tax revenues and the cost of the subsidy itself. SIM3 uses a subsidy that maintains consumption for biofuels at the initial level. We calculate this subsidy to be about 0.033 SEK/KWh (a price reduction of about 32%) if “other fuels” are fixed, and 0.023 SEK/KWh if “other fuels” are variable. SIM3 is almost neutral with respect to fossil fuel use, whereas there is a significant reduction in the use of electricity.

Table 4. Baseline fuel taxes SEK/KWh.

Fuel	**Carbon tax**	**Energy tax**	**Sulfur tax**	**Sum**
Biofuels	0	0	0	0
Oil	0.10	0.066	0.01	0.176
Coal	0.122	0.037	0.02	0.179
Natural gas	0.073	0.02	0	0.093
Electricity	0	0	0	0

Table 5. Simulation results.

	Price-changes, %					
	Δp_{bio}	Δp_{oil}	Δp_{el}	Δp_{coal}	$\Delta p_{n\text{-}gas}$	Δp_{fossil}
SIM1	0	-37	-25	-44	-26	-37
SIM2	-49	-37	-25	-44	-26	-37
SIM3	-32	-37	-25	-44	-26	-37
	Quantity changes, % (GWh)					
	Δx_{bio}	Δx_{foss}	Δx_{el}	Δx_{rest}		
	”other fuels” fixed					
SIM1	-18.6 (-2141)	7.4 (1575)	2.3 (33)	0		
SIM2	8.9 1023)	-1.6 (-333)	-12.9 (-192)	0		
SIM3	0 (0)	1.5 (316)	-7.7 (-115)	0		
	”other fuels” variable					
SIM1	-15.1 (-1741)	7.3 (1546)	5.0 (75)	-19.4 (-4444)		
SIM2	17.6 (2034)	-0.5 (-102)	-8.1 (-120)	-30.3 (-6962)		
SIM3	0.0 (0)	3.7 (788)	-1.0 (-15)	-24.4 (-5602)		
	ΔTax revenue(million SEK)					
	Biofuels	Fossil fuels	Electricity	Sum	%	
	”other fuels” fixed					
SIM1	0	-2150	-136	-2286	-63	
SIM2	-628	-2264	-136	-3028	-83	
SIM3	-379	-2225	-136	-2740	-75	
	”other fuels” variable					
SIM1	0	-2152	-136	-2287	-63	
SIM2	-679	-2250	-136	-3065	-84	
SIM3	-265	-2197	-136	-2598	-71	

7. Externality costs

There is today a significant and expanding literature on valuation of external costs of energy generation. For recent summaries of this literature, see e.g. Kommey & Krause (1997), EXTERNE (1998) and Radetzki (1997). In order to construct the mapping from energy combustion to emissions, we have scrutinized a substantial number of plants, via their environmental reports. We have also assembled a number of survey reports, summarizing the input-emission mapping for Swedish heating plants. We assume that there is a constant relationship between the fuel input and the emissions in the relevant data-range. We also assume that the regulatory constraint is not binding. Indeed, if the price vector facing the plant changed substantially, some plants may choose an infeasible point in the output-emission space, at least from a regulatory point of view. It is, at least in principle, possible to complement our econometric model with plant-specific regulations. However, due to the complexity of the regulations and other constraints, we have not been able to implement all constraints facing an individual plant, at this stage of our research.

Emission Changes

Combustion of fossil fuels, such as biofuels, leads to a large number of different emissions. We will limit our attention here to four important emissions to air; sulfur (S), nitrogen oxides (NOx), particulates (Pm) and carbon dioxide (CO_2), leaving other parameters for future research. The advantage of restricting our analysis to these four parameters is that much is known about their impact on the environment, health and the externality costs.

Table 7 and 8 display all necessary details for replicating our calculations on emission changes and the externality costs.

Table 7. Average Emissions from Swedish Heating plants (ton/GWh).

	NOx	*S*	*Pm*	*CO_2*
Biofuels	0.24097	0.0193	0.0227	0
Oil	0.39469	0.1622	0.0240	277.2
Coal	0.15030	0.0729	0.02457	331.2
Nat.gas	0	0	0	178.0

Source: Yearly environmental reports from a number of heating plants and surveys of emission technologies

Table 8. Externality costs used in calculations (USD/ton)

Parameter	*Used cost*	*Basis*
NOX	4500	Current Environmental Charge
S	3750	Current sulfur tax
PM	32500	Literature Survey
CO_2	46.3	Current CO_2 tax

We note that the externality cost for PM is especially difficult to estimate, given the large variations of this estimate in the relevant literature. The number chosen for PM is taken to be an upper bound, when most estimates are below the chosen level. This choice does not alter our conclusions.

Given the data in table 7 and 8, and the estimates of the change in the fuel mix for each scenario, the change in emissions can be calculated. The result is displayed in figure 1.

In SIM1 sulfur and CO_2 emissions increases with approximately 8%, while the increase in NOx emissions is only around 1%. Due to the substitution from biofuels to fossil fuels in SIM1 the emissions of particulates will even decrease slightly. In SIM2 sulfur and CO_2 emissions are decreasing, reflection a substitution toward biofuels. On the other hand this pattern of substitution will also increase the emissions of NOx and particulates. The third scenario, SIM3, gives rise to an increase in all emissions, since the only substitution that takes place is from electricity to fossil fuels.[9]

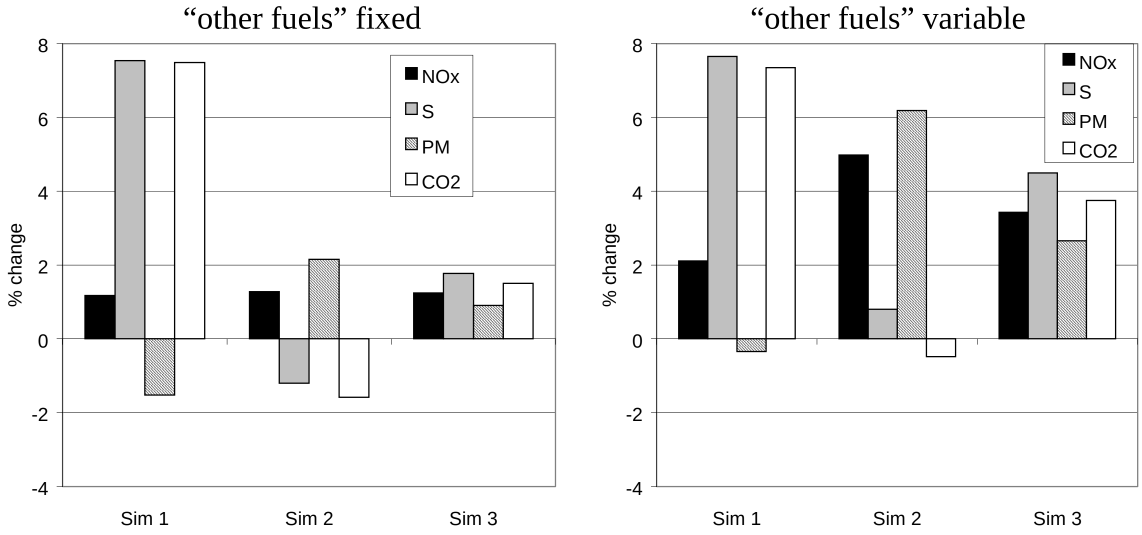

Figure 1. Calculated emission changes under scenario SIM1-SIM3.

A comparison of the two panels in figure 1 shows that the patterns are similar. The level of the change, however, is larger when we allow for substitution also for "other fuels". When we allow "other fuels" to vary we obtain a substantial substitution from this untaxed group of fuels to fossil fuels, which increases emissions. This emission reduction should, however, be

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[9] We do not consider how the electricity is generated. The net change in emissions will also depend on how electricity is generated.

interpreted with care since the reduction of “other fuels” may be associated with large emission reductions depending on the content of “other fuels”.

According to our simulations, the largest social costs of the policy packages we have simulated, displayed in figure 2, are due to an increase of CO_2-emissions. When heating plants are already paying environmental taxes for sulfur, NOx and CO_2 emissions, we cannot claim that the reform is socially costly, despite emission increases, without further qualifications. In some sense, the costs for NOx and sulfur emissions are already internalized. If the environmental tax is optimal ex ante, then any small change in emissions do not change social welfare. The externality cost for CO_2, on the other hand, can be viewed as a social gross cost if the damage of a one kg CO_2 increase is equal to the current level of the tax (0.37 SEK/kg), since the tax changes significantly.[10] Although the overall gross cost of emissions of NOx, sulfur, and particulates seems to be fairly small for the tax reforms simulated, the environmental impacts will be heterogeneous across the country. Roughly, it is the large heating plants in the larger cities that are likely to increase their emissions significantly. This raises the issue whether or not the environmental charges should be uniform across the country, as it is today; if the damage is local, there is a case in favor of using a differentiated tax. This argument loses some of its force if each plant is subject to a optimally set local regulations on emissions. Even so, our simulations suggest that those regulations may have to be re-assessed, if the government proceeds with a policy stimulating biofuels.

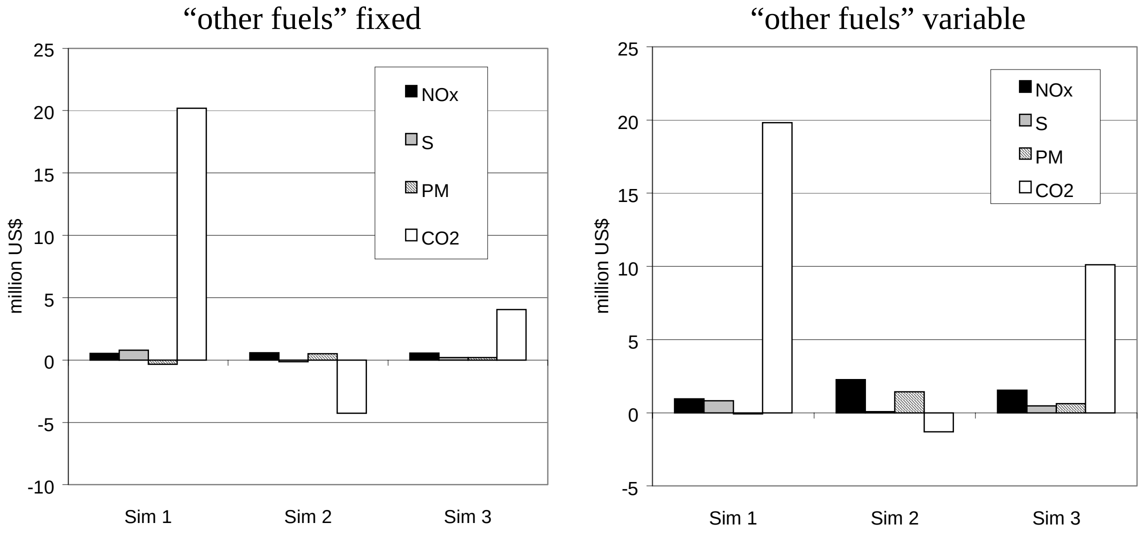

Figure 2. Estimated externality costs.

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[10] The gross cost of the CO_2 increase, in for example SIM1, is approximately 20 million US$. The net social cost is approximately 5 million US$, assuming that the marginal damage is constant at the initial tax and using the usual surplus triangle.

8. Conclusions

The purpose of this study is to analyze possible impacts on the Swedish heating sector and externality costs due to a reformation of the Swedish energy tax system. The basic scenarios analyzed are reductions of the CO_2 tax and subsidies to promote biofuels. We link three different modules: A production module gives us the change in fuel mix due to a change in taxes and subsidies; the emission module includes emission parameters for each fuel type; the externality cost module provides a monetary value of the health effects caused by various emissions.

Our empirical results shed some light on the impacts of various changes of the tax system. The policy packages we have simulated implies changes in the fuel mix, which in turn imposes a change in externality gross costs. In fact, since all policy packages includes a reduction of the CO_2 tax, externality gross costs increases to some extent, as expected. We also note that the distribution of the externality costs are likely to be uneven, in the sense that they will be concentrated to large cities. Because NOx and VOC emissions are positively correlated, and of particular interest in large cities, our results seem to suggest that current regulations need to be scrutinized, if the current policy of stimulating biofuels is continued. Our results also raise the issue of whether or not the Swedish tax system needs to be complemented with additional environmental taxes, covering, say, emissions of particulates. If we assume away the potential suboptimality of taxing only one of many sectors that contribute to “untaxed externalities”, it would seem reasonable to buttress the feasibility of introducing new environmental taxes in the system. However, because the geographical variation of damages is likely to be substantial, an overall assessment of current regulatory schemes seems preferable. The current system of using both taxes and regulations needs to be re-structured, in particular in the case of global environmental problems. It is inefficient to use both a carbon dioxide tax and a regulatory cap on carbon dioxide emissions. It makes sense, however, to tax some locally important emissions, at the same time keeping the regulatory safeguard.

Finally, we note that the model employed gives a rather simplified picture of the Swedish heating industry. It assumes that the markets for the various fuels work more or less perfectly, implying that the plants can buy whatever quantities they want at the ruling price. It is “well-known” that many heating plants have local monopolies in the market for forest fuels, which may give rise price repercussions not accounted for in this study. Furthermore it is assumed that the substitutions implied by the scenarios are technically feasible. This assumption is an oversimplification, especially under non-marginal tax reforms.

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Appendix

Table A1. Descriptive statistics for the Swedish heating sector. All numbers are in GWh.

	1989	1990	1991	1992	1993	1994	1995	1996
Q(sum)	30832	29992	34388	33502	35564	32683	37632	39472
Q(meanl)	231	239	260	257	291	257	298	299
Q(stddev)	486	521	566	566	621	561	651	719
X_{bio}(sum)	3015	3326	4248	4390	5608	6889	8295	9771
X_{bio}(mean)	22	26	32	33	45	54	65	74
X_{bio}(stddev)	51	57	70	69	82	105	123	137
X_{olja}(sum)	3967	2596	3855	3770	4355	4962	4514	6565
X_{olja}(mean)	29	20	29	29	35	39	35	49
X_{olja}(stddev)	61	35	47	53	89	129	134	135
X_{coal}(sum)	7884	6364	5236	4422	4074	3115	3146	4100
X_{coal}(mean)	59	50	39	34	33	24	24	31
X_{coal}(stddev)	191	178	188	178	174	142	154	189
X_{n-gas}(sum)	1336	1838	2346	2798	2990	2036	2886	2785
X_{n-gas}(mean)	10	14	17	21	24	16	22	21
X_{n-gas}(stddev)	65	107	122	139	152	120	140	128
X_{foss}(sum)	13187	10798	11437	10990	11420	10113	10546	13450
X_{foss}(mean)	99	86	86	84	93	79	83	101
X_{foss}(stddev)	247	240	263	264	288	268	277	326
X_{el}(sum)	4907	5720	5121	4079	3482	1962	2724	1369
X_{el}(mean)	36	45	38	31	28	15	21	10
X_{el}(stddev)	109	134	126	79	63	33	58	42
X_{rest}(sum)	16404	16570	19529	19024	20148	17980	20924	19846
X_{rest}(mean)	123	132	147	146	165	141	166	150
X_{rest}(stddev)	323	333	370	370	395	336	404	386
K(sum)*	18978	18637	19486	19521	19545	17970	20242	19792
K(mean)*	142	149	147	150	160	141	160	149
K(stddev)*	292	308	306	315	321	288	327	330
NOBS	133	125	132	130	122	127	126	132

* Installed effect, MWh.

TableA2. Estimation results.

Parameter	Estimate	t-statistic	Parameter	Estimate	t-statistic
α_1	0.23	3.72	α_{14}	-0.220	-3.46
α_2	0.15	4.10	α_{24}	-0.140	-3.79
α_3	0.30	5.39	α_{34}	-0.300	-5.27
α_4	0.25	6.67	α_{44}	-0.230	-6.05
α_5	0.27	4.05	α_{54}	0.540	8.67
α_{12}	-0.16	-2.56	α_{15}	-0.210	-3.32
α_{22}	-0.12	-3.14	α_{25}	-0.110	-1.92
α_{32}	-0.26	-4.52	α_{35}	-0.290	-5.02
α_{42}	-0.18	-5.00	α_{45}	-0.260	-3.51
α_{52}	0.40	6.79	α_{55}	0.410	4.36
α_{13}	-0.21	-3.43	γ_0	-0.004	-0.41
α_{23}	-0.12	-3.15	γ_2	0.032	3.03
α_{33}	-0.30	-5.25	γ_3	0.032	3.11
α_{43}	-0.23	-6.02	γ_4	0.027	2.48
α_{53}	0.50	8.28	γ_5	0.028	2.21

NOBS=1027 R^2=0.99 SSR=4.43

Table A.4. Model specification tests.

Test	Test-stat	Critical value
Fnoslope(20,815)	7.73	1.88
Fnodummies(198,815)	15.54	1.00
Fnofixed(170,815)	16.12	1.00
Fnobatt(12,815)	2.24	2.18
FnoTC(4,815)	2.80	3.32

Fnoslope = α_{is} = 0,i = 1,…,5,s=2,…,5
Fnodummies = α_{is} = 0, i = 1,…,5, s = 2,…,5 and α_{0k} = 0,k = 1,…,K, where Kis the number of plants
Fnofixed = α_{0k} = 0, k = 1,…, K, where Kis the number of plants
Fnobatt = θ_h = 0, h = 1,…, 15, number of input combinations
FnoTC = γ_s = 0, s = 2,…, 5 = sizeclasses