Evaluating market efficiency without price data
The Swedish market for wood fuel

By

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Abstract

The objective of this paper is to shed some empirical light on the price development and price formation for wood fuel used by the Swedish district heating sector. According to Lönner et.al. (1998), there is a significant potential for increasing the use of wood fuel in Sweden, and that at a fairly moderate cost. The basic question raised in this paper is why this potential is not realized, in spite of the low cost. Here we identify three possible explanations; (1) the marginal cost for providing wood fuel is higher than expected, (2) the market for wood fuel is not functioning efficiently due to market imperfections, (3) investments in wood fuel burning technology do not take place due to risk and uncertainties concerning the future energy taxation system. In this paper we focus the second explanation, and propose a methodology for testing whether the market imperfections are present. The test we propose is a two-step procedure. In the first step the shape of the technology in the Swedish district heating sector is estimated. In the second we combine the estimated technology and the assumption of cost-minimizing firms to calculate shadow prices of wood-fuel, i.e., marginal valuation of wood fuel in this sector. If the average shadow price significantly deviates from the average observed price we may conclude that this market is inefficient. To construct confidence intervals for the shadow price we use bootstrap techniques. The resulting point estimates of the shadow price implies that this market is inefficient in the sense that the firms values additional quantities higher than the ruling price, implying that too small quantities of wood fuel is traded. However, according to the bootstrap confidence intervals this difference between the shadow price and the ruling price is not significant, implying that we cannot, on statistical grounds, reject the efficient market hypothesis.
1. Introduction

One of the most striking observations in the Swedish energy system during the last 10 years is the sharp increase of the use of wood residues as fuel in the generation of heat. In 1989 wood fuels accounted for approximately 8.3 percent of total fuel input in the Swedish district heating sector, and in 1996 the same number is 23.5 percent.¹ This development is in line with Swedish energy and environmental policy. However, this development should be accelerating since, recently, the Swedish government officially have declared that the future energy system should be based on renewable energy. This is among other things manifested in the current system of energy taxation, where fossil fuels are heavily taxed while the use of biofuels is untaxed. Since Sweden is a country with vast forest resources, more biofuels means an increase in the use of forest fuels. In addition, the conventional wisdom is that there is a huge potential for using domestic forest residues as fuel in the Swedish energy system (Lönner et.al. (1998), Parikka (1997) and Hektor et al. (1995)). The annual potential supply of unrefined wood fuel is approximated to 130 TWh, which should be compared with the consumption of 40 TWh in 1995.²

According to Paprika (1997, Table 1) available felling residues, such as tops and branches, amounts to 65 to 81 TWh. However, currently only 9 Two, or 11 to 14 percent, are utilized.³

Basically, there are three possible reasons as to why not a larger part of the potential is used. The first reason is of course that domestically produced wood fuel is expensive due to high costs for production and/or distribution, relative other fuels. The second reason is that the market for forest fuels is not well developed and/or that the market is characterized by classical imperfections such as monopsony/oligopsony. A third reason

¹ NUTEK (1997), Table 7 and 10.
² The energy amount of 130 Twh is referred to scenario 2020 and should be seen as a predicted annual energy potential during the period 1995 to 2020.
³ However, there are some divergent opinions regarding this issue. The availability of felling residues, in addition to what is actually used in the Swedish energy system in 1995, is according to the Swedish Forest Industries Federation (Skogsindustrierna) 6-11 TWh, (Naturvårdsverket) 11-16 TWh, and Skogsägarnas Riksförbund at least 30 TWh. These numbers are considerably lower than those given by Parikka and Hektoer et al, 56-72 TWh (SVEBIO (1998)).
may be that potential users of wood fuel refrain from increasing its use due to “risks” such as uncertainty about the future energy tax system, and technical uncertainty.\textsuperscript{4}

The objective of this paper is to shed some empirical light on the price development and price formation for wood fuel used by the district heating sector taking these considerations into account. More specifically we will compare average prices on wood fuel with estimates of marginal user values. If the observed price coincides with the users marginal valuation the market is in principle efficient. If there is a significant difference the market is inefficient. To accomplish our objective we will use a data set that includes detailed information on fuel input and heat generation for most of the district heating plants in Sweden between 1989 and 1996. The dataset, however, includes inputs and output in physical units only. Given this data set we are able to estimate a production function for the district heating sector. Combining this estimated production function with some behavioral assumption, such as cost minimization, will provide us with shadow prices, or marginal valuation, of the various inputs. These shadow prices will then be compared with actual (or average) prices obtained from official sources. A rough test of the functioning of the market is then to test if there is any significant difference between “actual” and estimated “shadow” prices.

The rest of the paper is structured as follows. Section 2 provides some details about the development in the wood fuel market. Section 3 provides a theoretical model of a cost-minimizing district heating plant, and the derivation of shadow prices. Section 4 describes the econometric specification. The estimation results are presented and discussed in Section 5. Section 6 offers some concluding remarks.

\textbf{2. The Swedish Wood Fuel Market}

Total energy supply in Sweden has increased from 457 TWh in 1970 to 485 TWh in 1996, or 6\%.\textsuperscript{5, 6} In 1970 3.2 percent (14.6 TWh) of total supply came from the district

\textsuperscript{4} However, according to Hillring (1999b), much indicate that plants in the Swedish district heating sector are flexible. They have invested in capital that is currently inactive, but that can be quickly activated to meet changes in energy policy.

\textsuperscript{5} NUTEK (1997), Table 2.

\textsuperscript{6} The corresponding change relative to 1999 is 36 percent, as the total supply is 615 TWh (Energimyndigheten (2000), p. 6.)
heating sector and in 1996 the figure was 10.9 percent (52.7 TWh).\textsuperscript{7} In 1970 oil accounted for 98\% (14.3 TWh) and biofuels 2\% (0.3 TWh) of total primary energy in the generation of heat. However, since then there has been a strong substitution from oil towards biofuels. In 1996 oil accounted for only 16.5 percent (8.7 TWh) of total fuel input, whereas the share for biofuels was 43.5 percent (22.9 TWh).\textsuperscript{8,9} One explanation to this outcome is the oil crises of the 1970s and the resulting increase in the oil price. However, even though this was the first upswing for biofuels, higher oil price is not the only explanation to the current dominating position for biofuels. Another major explanation can be found in the development of Swedish energy and environmental policy, which includes higher taxes on fossil fuels as well as a decision to phase out nuclear power.

The most prominent policy instruments so far are energy taxes. As a part of a general tax reform the CO\textsubscript{2} tax was introduced in 1991. The CO\textsubscript{2} tax is levied on the CO\textsubscript{2} content in fossil fuels, which means that fuels with relative high carbon content per unit of energy faces relatively high taxes compared to fuels with low carbon content.\textsuperscript{10} Although combustion of biofuels, such as wood residues, implies a release of CO\textsubscript{2} they are exempted from the CO\textsubscript{2} tax. The motivation for this exemption is an implicit assumption of a sustainable forestry, i.e., the release of CO\textsubscript{2} is balanced by growth in biomass. Taken together, higher oil prices in combination with a systematic policy development have led to a shift from oil to biofuels.

Due to the described development the Swedish wood fuel market has grown rapidly. From a few large-scale users of wood fuel there are now 150 district heating plants demanding wood fuel and some 60 producers supplying it (Hillring (1999b)). The use of wood fuel for producing heat has annually grown by approximately 26 percent from

\textsuperscript{7} NUTEK (1997), Table 10.
\textsuperscript{8} NUTEK (1997), Table 10. In 1999 the corresponding numbers X and Y, respectively.
\textsuperscript{9} Notable is that in 1996 the remaining constituents making up fuel inputs in the Swedish district heating sector was; heat pumps 12.9, coal including blast furnace gas 9.3, natural gas 7.6, waste heat 7.2, and electric boilers 3.0 percent, respectively.
\textsuperscript{10} Apart from the CO\textsubscript{2} tax, fossil fuels are subject to a general energy tax and a sulfur tax. For a more detailed description of the current Swedish energy taxation system, see for example Brännlund & Gren (1999) or Brännlund & Kriström (2001).
Furthermore, the annual growth rate was larger during the 1980’s than it was from 1990 to 1996, approximately 30 percent compared to 23 percent.

It is also clear that real prices of wood fuel have dropped as the market for wood fuel has grown (Hillring (1997, 1999b)). For instance, during 1990 to 1996, when the demand for unrefined wood fuel annually increased with about 11 percent on average, prices decreased approximately 5 percent. Furthermore, the demand for refined wood fuel changed dramatically from 1993 to 1996 with a 63 percent annual increase. However, at the same time prices dropped approximately 9 percent annually. A tentative conclusion would then be that the supply of wood fuel has increased at a faster rate than demand. This may, besides direct effects of political decisions, be due to a more rational production and distribution technology, but also due to an increase in imports of refined wood fuels, such as powder, pellets and briquettes. According to Hillring (1999a) imports were estimated to an amount of about 3 to 5 TWh in 1996, which should be compared to a total usage amounting to 12.4 TWh.

Furthermore, in Hillring (1999c) the price formation in the Swedish wood fuel market is described as follows: “The production costs dominate price levels, as the physical access to wood-fuel vastly exceeds the demand. There are many producers on the market, and there is strong competition between them, showing transparency in the production costs. On the market, buyers do not need to pay more than what is required to cover producers’ costs plus a small margin in order to allow producers to continue their operations” (p. 816).

However, whether price formation in the Swedish wood fuel market is functioning efficiently has never been formally tested. In this paper we therefore suggest a two-step procedure to test market efficiency. First, a shadow price, or a marginal user value, of

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11 NUTEK (1997), Table 7.

12 It should be emphasized that we disregard the commercial markets for wood fuels in the forest product industry, including the pulp and paper industry, the particle-board industry, as well as sawmills, and among households. However, these markets are to a large extent for internal production and use of wood fuel (hillring (1999c)).

13 According to Hillring (1999c) the commercial market for unrefined wood fuel consists of chipped or crushed logging residues, saw dust and by-products from the forest products industry. The market for refined wood fuel consists of powder, pellets and briquettes.
wood fuel is calculated. Then, a test statistic for comparing this shadow price to the actual price, given in Hillring (1997), is calculated. If the shadow price, i.e., the demand side valuation of the last unit wood fuel used, significantly differs from the actual price paid, the wood fuel market is price inefficient.

3. Theory

We use a straightforward approach based on production theory, where the 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;

\[ Q_{it} = F_{it}(x_{it}, L_{it}, K_{it}) \]

where \( Q \) is the output of heat, \( x = [x_1, x_2, ..., x_n] \) is a vector of primary energy inputs, \( L \) denotes labor input, \( K \) the capital stock, and \( F \) is a production function. Furthermore there are \( i = 1, ..., N \) plants and \( t = 1, ..., T \) 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 \( P(x) \), which is assumed to be nonempty.

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

\[
\min \sum_{i} p_{it} x_{it} + w_{it} L_{it} + r_{it} K_{it} \\
\text{s.t. } F_{it}(x_{it}, L_{it}, K_{it}) = Q_{it}
\]  

By solving (2) we obtain the conditional demand for the variable inputs as a function of fuel prices, \( p \), the wage, \( w \), the price of capital, \( r \), and the level of production, \( Q \). From the first order conditions we obtain the shadow price of each input, which in this simple case equals the market price.

The formulation in (2) is the textbook case in the sense that it is assumed that each decision unit takes all prices as given and that they do not face any other restriction.
Here, however, we will assume that each decision unit may not be able to buy as much wood fuel as it wants at the ruling price. In addition we will assume that the capacity for burning wood fuel may be restricted in the short run. More specifically we assume that a particular firm is facing a market supply function for wood fuel:

\[ p_i^w = p_i^w(x_i^w, z), \quad \frac{\partial p_i^w}{\partial x_i^w} \geq 0, \]  

(3)

where \( x_i^w = \sum x_{it} \), and \( x_{it} \) denote firm \( i \)’s input of wood fuel in period \( t \). The inverted supply function in equation (3) says that the supply price, \( p_i^w \), is an increasing function of the volume supplied.

Furthermore, we will assume that the firms face a short-run quantity restriction;

\[ x_{it} \leq \bar{x}_{it}, \]  

(4)

Given equations (1), (3), and (4), the cost minimization problem can be written as:

\[
\min_{x_i^w, x, L, K} \quad p_i^w(x_i^w, z)x_{it} + p_i x_i + w_{it}L_{it} + r_{it}K_{it} \\
\text{s.t.} \quad F_i(x_i, L_{it}, K_{it}) = \bar{Q}_{it} \\
\quad x_{it} \leq \bar{x}_{it}
\]  

(5)

The Lagrangean to (5) is then:

\[
L_{it} = p_i^w(x_i^w, z)x_{it} + p_i x_i + w_{it}L_{it} + r_{it}K_{it} + \lambda_i \left[ \bar{Q}_{it} - F_i(x_i, L_{it}, K_{it}) \right] + \mu_i \left[ \bar{x}_{it} - x_{it} \right]
\]  

(6)

The corresponding first order conditions are:

\[
p_i^w \cdot (1 + \Theta_i \gamma) + \mu_i = \lambda_i \frac{\partial F}{\partial x_{it}}, \quad i = 1, \ldots, N
\]  

(7)

\[
p_i^j = \lambda_i \frac{\partial F}{\partial x_{ij}}, \quad j \neq 1,
\]  

(8)

where \( \Theta_i = \frac{\partial x_{it}}{\partial x_{ij}} \cdot \frac{x_{it}}{x_{ij}} \) is the conjectural elasticity, and \( \gamma = \frac{\partial p_i^w}{\partial x_i^w} \cdot \frac{x_i^w}{p_i^w} \) is the supply elasticity for fuelwood. If firm \( k \) believes that its behavior won’t have any effect on
other firms, then $\Theta_k$ equals zero. This will, for example, be the case if firm $k$ is small in relation to the total market. If firm $k$ is alone on the market its clear that $\Theta_k$ equals unity. Thus, for any $\Theta_k$ greater than zero the shadow price will exceed the observed market price.

Dividing equation (7) by the first order condition for the $j^\prime$ input and multiplying with $p_j^\prime$ gives us the expression for the shadow price of wood fuel as:

$$p_i^w \cdot (1 + \Theta_{it} \gamma) + \mu_{it} = \tilde{p}_{it}, \quad (9)$$

where $\tilde{p}_{it} = \frac{\partial F}{\partial x_{it}} / \frac{\partial F}{\partial p_j^\prime} p_j^\prime$

From equation (9) we can see two basic reasons as to why the market price (observed), $p_i^w$, for forest fuels may deviate from the shadow price. The first reason is market imperfections of the kind described above, i.e. $\Theta$ is greater than zero, in combination with rising marginal costs for supplying wood fuel ($\gamma>0$). The second reason is that the capacity constraint is binding, which implies that $\mu$ is positive. Equation (9) can be rewritten as:

$$\tilde{p}_{it} - p_i^w = p_i^w \Theta_{it} \gamma + \mu_{it} \quad (10)$$

Thus, given an unbiased estimate of the shadow price, $\tilde{p}_{it}$, a natural test of market imperfections is to test whether the difference in (10) is significantly different from zero or not. If the mean over all firms for a specific year is significantly greater than zero we cannot reject the hypothesis of market imperfections, and/or involuntary capacity constraints. As a consequence the use of wood fuel is to low from an efficiency view. From (10) it should be noted that the use of wood fuel might be efficient although market imperfections are inherent. This may be the case when the supply of wood fuel is completely inelastic, i.e. if $\gamma=0$. 


4. Data and empirical model

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. In the data set, fuel input is divided into 16 different types of fuels, which from a statistical point of view necessitates some form of aggregation. Here we have quite arbitrarily aggregated fuel inputs into four groups; wood fuel \((x_1)\), fossil fuels \((x_2)\), electricity \((x_3)\), and “other fuels” \((x_4)\). Fossil fuels include oil, coal, natural gas, and propane. Given this level of aggregation we implicitly assume that there are no substitution possibilities within each group, which of course may be a strong assumption. To test how sensitive the results are to this we will try alternative aggregations. Descriptive statistics of the data set 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 can’t estimate market performance using the shadow cost or profit function approach suggested by Atkinson & Kerkvliet (1989). Neither do the data set include firm specific total cost, which rules out the subvector distance function approach suggested by Ahltin (1995). At most the data set allows us to estimate the production function, and hence the rate of technical substitution between various inputs.

To estimate the technology parameters we assume that the technology can be approximated by a production function of the Cobb-Douglas type, i.e.,

\[
\ln Q_{it} = \alpha_{0i} + \sum_{k=1}^{4} \alpha_k \ln x_{ikt} + \alpha_{L} \ln L_{it} + \alpha_{K} \ln K_{it} \\
+ \sum_{k=1}^{4} \sum_{s=2}^{4} \beta_{ks} \ln x_{iks}S_{s,ilt} + \sum_{s=2}^{4} \gamma_{s} S_{s,ilt} t + \gamma_{0} t + \varepsilon_{it},
\]

where \(S_{s,ilt}\) is a dummy variable that equals 1 if firm \(i\) in period \(t\) belongs to size class \(s\), zero otherwise.

In equation (11) the first four terms on the right hand side represents a standard Cobb-Douglas specification in terms of fuels, labor, and capital, where \(\alpha_{0i}\) allows for firm
heterogeneity. The fifth term allow differences in output elasticity depending on firm size. Here we have divided firms into four size classes, where size class 1 firms are those belonging to the first quartile, and size class 4 the fourth quartile. The sixth and seventh term in equation (11) implies that we allow the ratio of marginal products for the various fuels to vary with firm size, and that technical progress is Hicks neutral, but is allowed to vary with plant size. The last term, $\varepsilon_i$, is an error term that is purely random and uncorrelated with all other right hand side variables.

Given the data set used, two problems must be solved. The first problem is that our data set does not include labor input, which means that equation (11) cannot be estimated as it is. To solve this problem in this specific case we assume that the labor requirement is proportional to the capital stock.\textsuperscript{14} The labor requirement for plant $i$ can then be written as $L_i = a_i \cdot K_i$, where $a$ is a firm specific labor/capital ratio. The second problem is that the choice of production function implies that all inputs are necessary in production, whereas our data set records that not all firms are using all inputs. One solution to the latter 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 the approach suggested by Battese (1998). This approach is essentially a dummy variable approach, where a dummy variable for each input is included. The dummy variable representing each input is set equal to one whenever positive amounts of this input is used, and zero otherwise. In addition, we define a new variable, $x^*$, which equals the observed input quantity whenever $x$, the input quantity, is greater than zero, and zero otherwise.\textsuperscript{15} In general the number of dummy variables depends on the number of possible input combinations. In this case with four fuel inputs, and all firms using at least wood fuel, the maximum number of dummy variables are $7 (2^3 - 1)$, given that at least one input is required.

\textsuperscript{14} This implies essentially that we assume that there are no substitution possibilities between labor and capital, which is not unreasonable in this particular case.

\textsuperscript{15} See Battese (1998) and Brännlund & Kriström (2001) for the details concerning the Battese approach.
Given these assumptions we rewrite equation (11) as:

\[
\ln Q_{it} = \alpha_{0i} + \sum_{h} \phi_{hi} D_{hit} + \sum_{k=1}^{4} \alpha_k \ln x_{ikt}^* + \alpha_L (\ln a_i + \ln K_{it}) + \alpha_K \ln K_{it} + \sum_{k=1}^{4} \sum_{s=2}^{5} \beta_{ks} \ln x_{ikt}^* S_{sit} + \sum_{s=2}^{4} \gamma_s S_{sit} t + \gamma_0 t + \varepsilon_{it},
\]

\[
= \alpha_{0i} + \sum_{h} \phi_{hi} D_{hit} + \sum_{k=1}^{4} \alpha_k \ln x_{ikt}^* + \alpha_L \ln K_{it} + \sum_{k=1}^{4} \sum_{s=2}^{4} \beta_{ks} \ln x_{ikt}^* S_{sit} + \sum_{s=2}^{4} \gamma_s S_{sit} t + \gamma_0 t + \varepsilon_{it},
\]

(12)

where \( \alpha_{0i} = \alpha_{0i} + \alpha_L \ln a_i \) and \( \alpha_K = \alpha_L + \alpha_K \), which means that the labor capital ratio is included in the fixed effects.

\[D_{hi} = \begin{cases} 
1 & \text{if "input combination" } h \text{ is used} \\
0 & \text{otherwise}
\end{cases}, \quad \text{and } x_{ki}^* = \begin{cases} 
x_{ki} & \text{if } x_{ki} > 0 \\
1 & \text{if } x_{ki} = 0
\end{cases}
\]

\( h = 1, \ldots, 7 = \text{"input combinations"}, \)

\( i = 1, \ldots, N = \text{firms}, \)

\( k = \text{bio, fossil, el, rest, capital = inputs}, \)

\( s = 1, 2, 3, 4, 5 = \text{class size}, \)

\( t = 1, 2, 3, 4, 5, 6, 7, 8 = \text{time period} \)

\( \varepsilon_{it}, \text{finally, are assumed to be purely randomly distributed errors}.\)

Given the production function in equation (12) we can write the rate of technical substitution between wood fuel and any other fuel, \( k' \), for firm \( i \) in period \( t \) as, given positive quantities of wood fuel and fossil fuels:

\[
RTS_{1,t}^{ii} = \left[ \frac{\alpha_k + \sum_s \beta_{ks} S_{sit}}{\alpha_k + \sum_s \beta_{ks} S_{sit}} \right] \frac{x_{ikt}}{x_{it}}
\]

(13)

A reasonable assumption is that the firms within the heating sector acts as price takers on the market for fossil fuels, which implies that the shadow price for fossil fuels equals the market price. Thus we can write the shadow price for wood fuel as:

\[
\tilde{p}_{it} = RTS_{1,2}^{ii} \cdot p_{it}^2
\]

(14)
A weighted average of the shadow price in each time period is then:

\[ \bar{p}_{it} = \sum_{i=1}^{N} h_{it} \cdot \bar{p}_{it}, \]  

(15)

where \( h_{it} = \frac{x_{it}}{\sum_{i=1}^{N} x_{it}} \), and \( N^1 \) is the number of firms using strictly positive quantities of wood fuel and fossil fuels.

The relevant test statistic can then be written as:

\[ \hat{z}_t = \bar{p}_{it} - p_{i}^w, \]  

(16)

where \( p_{i}^w \) is the “average” market price that we can observe. A test of market efficiency is thus equivalent to a test of whether \( z_t \) is zero. From above it is clear that \( z_t \) is a non-linear function of the estimated parameters, which may create some problems in the estimation of the standard error. In the literature three basic methods for estimating the standard error are discussed; the Fieller method, the delta method, and the bootstrap method. The first two are asymptotic methods where the Normal distribution is used as an approximation, whereas the bootstrap method is based on the empirical distribution.\(^{16}\) The Normal approximation implies an assumption of symmetry. If the bootstrap method is used, however, no prior assumption concerning symmetry has to be made. Due to this we have chosen to use the empirical distribution for inference purposes.

The bootstrap method used here can shortly be described as follows. Let \( \hat{z} \) be our initial estimate of \( z \) obtained from equation (15). The empirical distribution of \( \hat{z} \) can be found by a simple two-step procedure. In the first step \( N \cdot T \) residuals, denoted \( \varepsilon^1 = (\varepsilon^1_{11}, \ldots, \varepsilon^1_{NT}) \), are randomly sampled from the empirical distribution of \( \varepsilon = (\varepsilon_{11}, \ldots, \varepsilon_{NT}) \), i.e. from the estimated residuals in equation (12). Given this residual vector and estimates of the parameters in equation (12) a new output vector

\(^{16}\) The Fieller method is due to Fieller (1932, 1954) and Zerbe (1978). The delta method is based on Taylor series approximation according to Goldberger (1964). The bootstrap method was first introduced by Efron (1979).
\( Q^1 = (Q^1_1, \ldots, Q^1_{NT}) \) can be calculated. In the second step equation (12) is re-estimated with \( Q^1 \) as the dependent variable, which parameters in turn are used to calculate a new value of \( z, \hat{z}^1 \), using equations (13) – (16). If step 1 and 2 is repeated \( B \) times we obtain the empirical distribution of \( \hat{z} \) as \( \tilde{z} = (\hat{z}^1, \ldots, \hat{z}^B) \). Given a certain confidence level, the next step is to find the critical values \( \tau_{\omega} \) and \( \tau_{1-\omega} \) in the empirical distribution, \( \tilde{z} \), such that:

\[
\Pr(\tau_{\omega/2} < \hat{z} - \hat{z} < \tau_{1-\omega/2}) = 1 - \omega,
\]

where \( \omega \) is the level of significance. Given the solution to (17) we also have, at least asymptotically, that:

\[
\Pr(\tau_{\omega/2} < \hat{z} - z < \tau_{1-\omega/2}) = 1 - \omega
\]

Solving for \( z \) gives us the desired confidence interval for \( z \) as:

\[
\hat{z} - \tau_{1-\omega/2} < z < \hat{z} - \tau_{\omega/2}.
\]

In our empirical application \( B = 1000 \), and \( \omega = 0.10 \).

5. Results

The specification in equation (12) provides several natural specification tests. Here the unrestricted model is the one that includes fixed effects, size dummies, varying technical progress, and Battese dummies. Thus, the first test is to decide whether fixed effects should be included or not. Conditional on the outcome of this test we will proceed with all other specification test. Thus the specification test applied here can be seen as a sequential test procedure. The test results are displayed in table A2 in the appendix.

The conclusion that can be drawn from the specification tests is that we can reject the hypothesis of common intercept, and output elasticities that are independent of firm size. In addition we can reject the hypothesis that the Battese dummies are jointly zero, and the hypothesis that technical progress is independent of firm size. Thus our final
model specification will be the one that includes all sets of dummy variables. However, as can be seen in table A2 the Battese dummies are barely significant at the 10% level, and certainly not at any higher level of significance. Due to that we will present the results without Battese dummies.

Table A3 and A4 in the appendix has detailed estimation results of equation (12), the unrestricted model and the restricted without Battese dummies. In summary, there is a strong correlation between fuel input and production, as expected. Most of the parameters are significantly different from zero. It should be noted that the parameter estimates presented in table A2 are unbiased only if the right hand side variables are uncorrelated with the error term. Here we have simply assumed that the list of included production factors is complete, and that the errors are pure measurement errors. If we have omitted some production factors they will show up in the error term, and the estimates will in general not be unbiased since the error term in that case likely is correlated with the included variables.

The parameter estimates presented in table A3 are used to calculate the rate of technical substitution between wood fuel and fossil fuels according to equation (13). The estimated rate of technical substitution is in turn used in equation (14), (15) and (16) to obtain the shadow price of wood fuel as well as \( z \). The point estimates of the average shadow price and \( z \) are presented in column two and three in table 1. Confidence intervals based on the standard percentile and the biased corrected percentile methods are presented in columns 3 and 4 in table 1.

The point estimates of \( z, \hat{z}, \) in table 1 are all negative, implying a shadow price that is higher than the ruling market price. This in turn would imply that the current level of wood fuel use is too low from an efficiency point of view. It should also be noted that this result is independent of the choice of model. However, the confidence intervals indicate that we can’t reject equality between shadow and observed price for some of the years. If the unrestricted model is the correct model the difference is significant for 1989, 1990, and 1996, whereas if we believe in the restricted model a significant difference is found for 1990, 1991, and 1996. It may be worth noting that the difference between the observed average price and the shadow price have decreased over time, which may indicate that inefficiencies due to market imperfections have become less
serious over time. The latter is in line with the conventional wisdom that this market has
gone from a rather primitive form in the eighties, to a rather transparent and well
functioning market the latter years (Brännlund, Hillring and Kriström, 1999).

Table 1. Estimates of market efficiency and 90% confidence intervals.

<table>
<thead>
<tr>
<th>Year</th>
<th>Unrestricted model</th>
<th>Restricted model</th>
</tr>
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<tbody>
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<td>Lower</td>
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<tr>
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<td>-0.92</td>
<td>-1.27</td>
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<tr>
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<td>-1.39</td>
<td>-1.94</td>
</tr>
<tr>
<td>91</td>
<td>-0.87</td>
<td>-1.19</td>
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<tr>
<td>92</td>
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<td>-1.10</td>
</tr>
<tr>
<td>93</td>
<td>-0.50</td>
<td>-0.68</td>
</tr>
<tr>
<td>94</td>
<td>-0.55</td>
<td>-0.76</td>
</tr>
<tr>
<td>95</td>
<td>-0.82</td>
<td>-1.11</td>
</tr>
<tr>
<td>96</td>
<td>-0.50</td>
<td>-0.64</td>
</tr>
</tbody>
</table>

From the empirical distributions of $\hat{z}$ for 1989 and 1996 in figure 1, two observations
can be made. The first observation is that the empirical distributions in figure 1 are
skewed to the left, which to some extent is in line with our prior belief of the
functioning of this particular market. A second observation is that the variance of the
distribution is smaller in 1996, which is confirmed by the confidence intervals presented
in table 1.

Figure 1. Empirical distribution of $\hat{z}$, 1989 and 1996.
6. Concluding comments

Recently it has been claimed that there is an unused potential for increasing the use of wood fuel in district heating and electricity generation. The annual potential supply of unrefined wood fuel is approximated to 130 TWh (Lönner et al. (1998)), which is almost as much as total electricity consumption in Sweden, or twice as much as total nuclear power. In other words, this potential could easily replace all nuclear power in Sweden. According to the same source a substantial share of this potential can be supplied at costs that are well below the costs for other fuels, such as oil and coal. The basic question raised in this paper is why this potential is not realized? We identify three basic reasons to this. The first reason is of course that domestically produced wood fuel is more expensive to supply than expected. The second reason is that the market for forest fuels is not functioning properly, due to classical imperfections such as monopsony/oligopsony. The third reason may be that potential users of wood fuel refrain from investments in boilers due to “risks” such as uncertainty about the future energy tax system, and technical uncertainty. If the last two explanations hold we would expect that the marginal valuation of wood fuel in the district heating sector is higher than the ruling market price. Thus our test is to evaluate the difference between estimated shadow prices and the ruling market price. To achieve our objective we estimate the technology in the district heating sector. The estimated technology is combined with the assumption that firms are cost-minimizers, which then allow us to estimate the shadow price of wood fuel.

The result from the analysis provides us with point estimates that tell us that the shadow price is higher than the ruling market price, implying inefficiency. In addition, the point estimate of the difference between the market price and the shadow price shows a clear trend, in the sense that the difference is decreasing over time. The latter may be interpreted as an improvement of market efficiency over time. A problem faced in this study is that the parameter under consideration is nonlinear in the underlying technology parameters. This implies that inference is subject to some complexity. Here we have chosen to solve this problem by using bootstrap techniques. That is, inference will be based on the empirical distributions, rather than on asymptotic ones. Using the empirical distribution is not only convenient due to nonlinearities, but also due to the
fact that we can allow for non-normal errors. Given the results from the bootstrap analysis we end up with the conclusion that there is, at least for certain years, a significant difference between the market price and the shadow price (at the 90% level). The results also show that there has been a declining trend in the difference between the observed price and the shadow price, which may indicate that inefficiencies have become less during the last years.

There are of course a number of issues that has to be considered thoroughly before any firm conclusions can be reached. The first group of issues concerns methodology and econometric framework, while the second issues concerns data. The methodology chosen here may be viewed as a “direct” approach where we estimate the technology directly via the production function. Coupled with cost minimization we can then derive the shadow price. The first major problem with this methodology is that the estimated technology parameters may be very sensitive to omitted variables. If we have omitted an input it is very likely that the parameter estimates are biased since the choice of the included inputs probably are correlated with the omitted one. A second problem is that the parameter under consideration is a nonlinear compound of the underlying estimated technology parameters. This will almost by certainty result in wide confidence intervals for the parameter under consideration since we can expect confidence interval of the underlying parameters that are quite wide, due to collinearity between the included inputs. Another issue is the choice of functional form. Here we have chosen a Cobb-Douglas production function, which we know impose very specific restrictions on technology. An alternative would be to employ a more flexible form, such as the translog production function. However, by doing this we would further increase the problem with correlated right hand side variables, which obviously will widen our confidence interval. Our conclusion would then be that methodology used here is not very well adapted to answer the question asked. A more efficient method, probably, is to use a dual approach, where some of the problems discussed are less pronounced. The dual approach implies in principle that we utilize the relation between the cost/profit function and the technology, and direct tests of price setting behavior can then be
performed.\footnote{A classical paper on the estimation of market power using duality is Appelbaum (1979). More recent applications can be found in Atkinson and Kerkvliet (1989), Bergman and Brännlund (1995), and Hjalmarsson (2000). For a survey on this issue see Bresnahan (1989).} Given the particular data set the dual approach is unfortunately not feasible. The reason is that we currently have no detailed price data, nor any specific data that enable us include the supply of wood fuel into the model.
References


Appendix

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

<table>
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<tr>
<th></th>
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<tbody>
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<td>16684</td>
<td>19567</td>
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<td>25008</td>
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<td>286</td>
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<td>154</td>
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<td>69</td>
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<td>79</td>
<td>80</td>
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*Installed effect, MWh.

Table A2. Specification tests

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<th>Test-stat</th>
<th>Crit.value(α=10%)</th>
<th>Rejection</th>
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<td>F_i(15,436)</td>
<td>3.26</td>
<td>1.49</td>
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<td>F_i(4,821)</td>
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<td>1.94</td>
<td>YES</td>
</tr>
</tbody>
</table>

F_i = test for fixed effects, H_0 = α_i = 0, i = 1, ..., K, where K is the number of plants
F_2 = test for Battese dummies, H_0 = φ_h = 0, h = 1, ..., 6, number of input combinations
F_3 = test for size effect on output elasticity, H_0 = β_k = 0, k = 2, ..., 4, s = 2, ..., 4
F_4 = test for size effect on technical progress, H_0 = γ_s = 0, s = 2, ..., 5 = size classes
Table A3. Estimation results, unrestricted model.

<table>
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<tr>
<th>Parameter</th>
<th>Estimate</th>
<th>t-statistic</th>
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</tr>
<tr>
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Table A4. Estimation results, restricted model.

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