Electricity Demand and Factor Substitution in the Swedish Mining Industry – An Econometric Approach

Eva Henriksson and Linda Wårell

Dept. of Business and Social Sciences, Economics, Luleå University of Technology, SE-971 87 Luleå, Sweden, eva.henriksson@ltu.se; linda.warell@ltu.se

ABSTRACT

We were interested in establishing electricity demand elasticities and factor substitution possibilities in the mining industry. This is an industry with relatively high electricity use and it is therefore relevant to show how responsive the industry is to changes in the electricity price (such as the introduction of a tax), and the substitution possibilities to use other input factors in the production. We chose to study mining for ores and minerals (excluding energy minerals), which includes e.g. iron ore, copper, zinc and lead industries. A unique data set from Swedish Statistics containing plant level data on outputs and inputs, as well as investments in R&D, from 1990 to 2005 was used to estimate a factor demand model. Of special interest was to study if R&D has affected electricity consumption, i.e., if there has been a link between investing in R&D and lower electricity use. The results showed that short-run factor substitution exists between the input factors. Regarding electricity elasticities, the results indicate that the industry’s electricity use has been responsive to changes in the price of electricity. Investments in R&D have decreased the use of labour, electricity and oil, but only the elasticity for labour is significant. This result might indicate that the focus of the R&D investments in the mining industry have so far been directed towards increased productivity in labour use, rather than on energy efficiencies.

Additional Key Words: Electricity elasticity, Factor demand, Minerals, Iron ore, Copper.

INTRODUCTION

The mining industry is considered energy intensive, and electricity is an important input factor in the extraction of many minerals. Given the political aim in Sweden of reducing electricity use in heavy industries, a tax of 0.005 SEK per kWh on industrial process-related electricity was introduced in July 2004. However, the opportunity of exemption from paying the tax was given to firms that joined a so-called energy efficiency program. The energy efficiency program thus reduced the price for electricity for participating firms, which in itself could lead to increased electricity consumption. The program required the implementation of energy management systems to identify energy efficiency solutions for the participating firms, with the assumption that this should lead to lower electricity use. However, the net effect of the program is not known. It is therefore important to understand electricity demand behaviour in the heavy industries. For example, what are the substitution possibilities between important input factors and electricity, and does investment in new knowledge influence electricity demand?

We analysed the electricity demand in the mining industry in Sweden, an industry where electricity consumption levels are high. We were interested in establishing electricity demand elasticities and short-run factor substitution elasticities between
inputs. Of special interest was whether firm-specific R&D affected electricity consumption, i.e., if there has been a link between investing in R&D and lower electricity use. This information will be vital in understanding if the cost reduction from joining an energy efficiency program can be transferred into R&D, and thus potentially lead to lower electricity use.

This study employed a general Leontief cost function approach, and both short- and long-run substitution elasticities were estimated. Previous studies that have performed similar analyses include: Henriksson and Wårell (2007), Brännlund and Lundgren (2007) and Ilmakunnas and Törnä (1989). Henriksson and Wårell (2007) performed a similar study to the one discussed above, for the pulp and paper industry in Sweden. They found that electricity demand elasticities are rather price-inelastic, but that investments in R&D have lead to a decreased electricity use. Brännlund and Lundgren (2007) studied the effects of the European CO2 Emission Permit Trading System on the Swedish base industry by estimating a factor demand model. One finding in their paper was that the input demands, e.g. electricity, are relatively price inelastic. Ilmakunnas and Törnä (1989) applied a generalized Leontief cost function to analyse the possibility of structural change in factor substitution between energy and non-energy factors in the Finnish manufacturing industries. They found that the energy crises in the 1970s did alter factor substitution relations.

The heavy industries in Sweden include the pulp and paper, chemistry, rubber and plastic, mining and the steel industry. Most of these industries are considered energy-intensive and as a consequence, are allowed to participate in the Swedish program for energy efficiency (PFE). Our addition to previous studies on electricity demand in heavy industries was to focus on the mining industry, which requires high electricity usage for the extraction of minerals. Furthermore, we were interested in the effects of investment in knowledge on electricity demand in the context of energy efficiency programs. The data set used was an unbalanced panel data set covering all firms within the mining industry over the time period 1990-2005, collected from Statistics Sweden.

The remainder of this paper is structured as follows: section 2 provides a general background to energy efficiency programs; section 3 presents the general Leontief cost function and the assumptions necessary for this model; section 4 describes the data and model specifications; section 5 presents and analyses the results, and finally; in section 6, some concluding remarks are made.

**VOLUNTARY ENERGY EFFICIENCY PROGRAMS**

The use of voluntary agreements as a policy instrument for increasing energy-efficiency and thereby reducing greenhouse gas emissions, in industries has been a popular practice in many industrialized countries since the early 1990s. The British Climate Change Program and the Long-term Agreements in the Netherlands are examples of such policy instruments. Voluntary agreements have also been used in Denmark to improve energy efficiency and reduce CO2 emissions within their energy-intensive industry. In Sweden, the program for improving energy efficiency (PFE) came into force in January 2005.

On July 1 2004, due to the adoption of the EU’s Energy Tax Directive, a tax of 0.005 SEK\(^3\) per kWh on industrial process-related electricity was introduced.\(^4\) The Directive

---

2 Industry branch code classification according to Statistics Sweden, SNI 131, 132 is used. In the remainder of this article when we refer to the ‘mining industry’ we only include the firms in these branch codes.

3 EUR 1 corresponds roughly to SEK 9.
however, gave the energy-intensive firms that are subject to the tax the opportunity of reduced taxation on their electricity consumption if they take action to improve their energy efficiency. As an instrument to promote this, the program for improving energy efficiency was introduced. The aim of the program was to increase the efficiency of energy use among firms that consume large amounts of electricity. Participation was voluntary and only energy-intensive firms were allowed to join the program, which runs for five years. However, participation exempts firms from paying the electricity tax. The Swedish Energy Agency is the supervising authority and ultimately decides if a firm may participate in PFE (SEA, 2005).

Under the program, the firm has to introduce and obtain certification for a standardized energy management system, and carry out an energy audit and analysis covering both short- and long-term. It must also include measures to improve electricity efficiency. The purpose of the energy audit and analysis is to enable the firm to oversee its energy consumption and identify measures to improve the efficiency of its electricity consumption. During the last three years, the firm has to implement the measures and continue to apply the energy management system, as well as procedures for purchasing and project planning. In a final report, the firm must analyse its actual electricity consumption during the period and the actual effects of the measures. If the firm has achieved an improvement in electricity efficiency which, broadly speaking, is equivalent to the improvement that would have been achieved if the tax had been imposed, than the firm will have fulfilled its obligations under the programme (SEA, 2005).

Most PFE participants are in the pulp and paper industry, which accounts for almost 75% of the consumed electricity of all of the participating firms. However, the firms in the mining industry are the second largest consumers of electricity (SEA, 2007). The two largest mining firms in Sweden both report that the energy costs is the second largest cost share in the production process. Energy efficiency measures are therefore important in order to decrease electricity costs and thus maintain a competitive production. There are also indications that the mining industry has been rather slow to adapt to energy efficiency measures compared to other industries. The mining industry is not an industry where a large share of total investments so far has been directed towards environmental protection investments (Hammam and Löfgren, 2006). One explanation for this can be that the mining industry over a long time-period experienced declining prices, and small corporate profit margins, which led to decreased funding for mining R&D (Hitzman, 2002).

THE GENERALIZED LEONTIEF MODEL
A model based on standard micro-economic foundations would suggest that given an output decision, each plant will choose a mix of inputs to minimize costs. According to duality theory, a dual cost function that contains all information needed to describe the underlying production technology exists (Varian, 1992). Following the Marshallian tradition, the assumption regarding the existence of a variable cost function VC in which the capital stock is quasi-fixed at a level not represented by full-equilibrium values, are made. First, we focus on short-run factor demand behaviour; the short-run cost function can be written as:

---

4 Manufacturing firms in the metallurgy, electrolysis and chemical reduction sectors are exempted from the tax.
where \( P_L, P_E \) and \( P_O \) are the input prices of respective factor inputs: labor, electricity and oil. Since we assume competitive factor markets, the input prices are assumed to be exogenously determined. \( Z \) denotes the level of the quasi-fixed capital stock; in this specification, \( Z \) is thus accounted for but changes in it are not explained, while \( KS \) represent the knowledge stock. Finally, \( Q \) and \( t \) denote mineral output and exogenous technical change, respectively.

The knowledge stock \( KS \) is included since we hypothesised that it is important for firms to invest in research and development (R&D) in order to become more efficient. We assume that R&D adds to a R&D-based knowledge stock, which we define as:

\[
KS_{nt} = (1 - \varphi)KS_{n(t-1)} + RD_{n(t-1)}
\]  

where \( KS_{n,t} \) is the R&D-based knowledge stock in firm \( n \) and the time period \( t \), \( KS_{n,t-1} \) is the cumulative knowledge stock of firm \( n \) from previous time periods, \( RD_n \) are the annual R&D expenditures, \( x \) the number of years it takes before R&D expenditures add to the knowledge stock and \( \varphi \) the annual depreciation rate of the knowledge stock. In the production function, we have also included \( t \), a time trend that represents technological developments that are exogenous to the firm.

In order to perform the analysis, we needed to choose a functional form, preferably with few restrictions on the technology and suitable for econometric modelling. The most popular and frequently used flexible form is the Translog function (TF), first put forward by Christiansen et al. (1971). The generalized Leontief (GL) is another often used flexible form which originates in the work of Diewert (1971). A benefit of the GL specification compared to the TL specification is that the GL form makes it possible to explicitly test if there exists any ex post factor substitution due to price changes. The GL specification, under certain parameter restrictions, reduces to the traditional Leontief cost function with a fixed coefficient technology (Chung, 1994). The GL specification employed in this paper builds on Morrison (1988) and allows for one quasi-fixed variable, capital (\( Z \)); the short-run VC function can be expressed as:

\[
VC = Q \left[ \sum_{i=1}^{3} \sum_{j=1}^{3} \alpha_{ij}P_i^{1/2}P_j^{1/2} + \sum_{m=1}^{2} \sum_{n=1}^{2} \delta_{mn}P_i^{1/2} + \sum_{m=1}^{2} \sum_{n=1}^{2} \gamma_{mn}B_i^{1/2}B_n^{1/2} \right] + Q^{1/2} \left[ \sum_{i=1}^{3} \delta_i^+ P_i Z^{1/2} + \sum_{m=1}^{2} \sum_{n=1}^{2} \gamma_{m} B_i^{1/2}Z^{1/2} \right] + \sum_{i=1}^{3} P_i' Z Z
\]

where \( i, j = L, E, O \) and \( m, n = t, KS \). This function is homogenous of degree one, and continuous. This means that if output is fixed and all prices \( P_i \) increases by \( \lambda \), VC must also increase by \( \lambda \). Flexible forms, as outlined in [3], does not guarantee global concavity in \( P \), but the curvature at each sample point can be examined via the estimated coefficient. Furthermore, \( \alpha_{ij} \) are parameters such that the symmetry condition \( \alpha_{ij} = \alpha_{ji} \) holds.

The individual factor demand equations can be derived by applying Shepard’s Lemma. In other words, partially differentiating [3] with respect to input prices, \( P_i \). In order to reduce the problem of heteroskedasticity, the functions are divided by output \( Q \).

\[\text{For more information about the knowledge stock variable, see Henriksson and Wårell (2007).}\]
which is shown by Parks (1971). This procedure results in the following input-output equations:

$$\frac{E_i}{Q} \frac{\partial V C}{\partial P_j} Q^{-1} = \sum \alpha_y \left( \frac{P_j}{P_i} \right)^{1/2} + \sum \delta_{m m} B_i^{1/2} + \sum \gamma_{m n} B_n^{1/2} B_i^{1/2} +$$

$$Q^{-1/2} \left[ \delta_{i Z} Z^{1/2} + \sum \gamma_{m n} Z^{1/2} \right] + Q^{-1/2} \gamma_{Z Z} Z$$

Equations [4] characterize the short-run demand of an \( i \)th factor and represent the behavior of a mining plant. Together, they form the basis of the econometric analysis in this paper. By estimating the coefficients, it is also possible to test the hypothesis that there is no ex post factor substitution. The coefficients in [4] will be compared to the estimates of a restricted version of the specification, where \( \alpha_y = 0 \) for all \( i, j, i \neq j \).

Following the definition in equation [5], the estimated parameters in [4] can also be used to calculate both the short-run cross-price elasticities of factor demand as well as the short-run own-price elasticities, \( \eta_{y}^{SR} \) (Morrison, 1988).

$$\eta_{y}^{SR} = \frac{\partial \ln E_i}{\partial P_j} = \frac{\partial E_i}{\partial P_j} \frac{P_j}{E_i} \left| _{k = K} = \frac{1}{2} \alpha_y \left( \frac{P_j}{P_i} \right)^{1/2} \frac{Q}{E_i} \right.$$  

These elasticities will differ at every data point and normally they are calculated at the means of the sample (Green, 1993). Furthermore, they only account for the substitution between the factors under the constraint that the aggregate quantity of factor demand remains constant and they are only valid for the levels of capital at which they are evaluated. In this specification, they do not reveal any information about the substitution between capital and other factor inputs. The input-output equations [4] can also be used to investigate how firm-specific as well exogenous technological development influence factor demand. The knowledge stock elasticities can be written as:

$$\eta_{k S} = \frac{\partial E_i}{\partial K S} \frac{K S}{E_i} = \left[ 0.5Q \delta_{k S} K S^{-1/2} + \gamma_{k S S} K S^{1/2} + 0.5Q^{1/2} \gamma_{k S S} K S^{1/2} \right] \frac{K S}{E_i}$$

From these elasticities, it is possible to reveal some information about how much a 1% change in the knowledge stock will affect the demand for labour, electricity and oil. The exogenous technological development is measured by the time trend and the related time trend elasticities can be found similarly to equation [6].

So far, we have only considered short-run behaviour. However, the short-run model allows us to induce long-run behaviour as well since the short-run cost function can be used to calculate the shadow cost of capital, \( R_Z^6 \), which is the derivative of variable costs with respect to capital, and can be written as follows;

$$R_Z = -\frac{\partial V C}{\partial Z} = -0.5Q^{1/2} Z^{-1/2} \left[ \sum \delta_{i Z} P_i + \sum P_i \sum \gamma_{m n} S_m^{1/2} \right] - 3 \sum P_i \gamma_{Z Z}$$

---

6 Total cost (TC) is equal to the sum of the VC and the fixed costs \( P_Z Z \), which gives us the following total cost function: \( TC = VC(P_L, P_E, P_D, Z, Q, K S, T) + P_Z Z \). Due to the fact that the total cost in the long-run equilibrium must be minimized the following first order condition is obtained; \( P_Z = -\frac{\partial V C}{\partial Z} \) and in full equilibrium the rental cost of capital \( P_Z \) must equal the shadow cost of capital \( R_Z \) (Morrison, 1988).
Thus, the shadow cost of capital reveals the potential reduction in variable costs due to an additional unit of capital. Using equation [7] and imposing the equality, \( P_Z = R_Z \), it is possible to solve for the full adjustment level of capital, \( Z^* \), which results in:

\[
Z^* = -0.5Q^{1/2}\left( \sum_{l=1}^{3} \delta_{IZ} + \sum_{m=1}^{3} P_l \sum_{m=1}^{2} y_{mZ} S_m^{1/2} \right) \left( P_Z + \sum_{l=1}^{3} P_l y_{IZ} \right)^{1/2} \]

[8]

The demand for desired capital [8], as well as the input/output equations in [4], is homogenous of degree zero in prices as required by economic theory. Equation [8] can then be used to derive the long-run elasticities. Long-run demand can be estimated by evaluating the factor demand equations [4] at \( Z^* \) at each observation point. The short-run adjustments can then be added to the related long-run changes in order to derive the long-run elasticities:

\[
\eta_{ij}^{LR} = -\frac{P_i}{E_j} \left( \frac{\partial E_j}{\partial P_i} \right)_{Z^*} \left( \frac{\partial E_j}{\partial Z} \right) \left[ Z - Z^* \right] \]

[9]

where \( Z = Z^* \) (Morrison, 1988). The own price elasticities are calculated in a similar manner.

**DATA ISSUES AND MODEL ESTIMATION**

We used an unbalanced Statistics Sweden (SCB) panel data set covering the Swedish mining industry over the period 1990-2005. The data includes output and input quantity and value of labour, electricity, all types of fuel used, R&D and capital. Input prices are calculated from data on quantity and value for electricity, oil and labour, which means that these prices are plant-specific. Electricity and oil are measured in TSEK per MWh and labour in TSEK per employee. Since R&D is an important factor in this paper, only firms with reported R&D expenses are included. This result in 128 observations distributed amongst 9 plants. The R&D expenses are firm-specific, but are assumed to be the same for all plants of the respective firms.

The capital stock variable was constructed using the perpetual inventory method, \( Z_t = I_t + (1 - \delta)Z_{t-1} \), where \( Z_t \) is the capital stock at time \( t \), \( I_t \) is investment on plant level and \( \delta \) is the capital depreciation rate. The capital stock for the initial year, i.e., the year 1990 or in those cases where the plant came into operation at a later stage, the start-up year, was constructed by using an industry-specific aggregate capital stock, weighted by plant specific production volume. The depreciation rate is assumed to be constant over time as well as across plants. Following Lundmark and Söderholm (2004), \( \delta \) is assumed to be 7%. The price of capital is calculated using \( P_Z = P_{it}(r + \delta) \), where \( P_{it} \) is a price index for investment goods at time \( t \), \( r \) is the interest rate and \( \delta \) is the depreciation rate. The average yields on two-year government bonds, deflated by the PPI, have been used as the interest rate. \( P_K \) is assumed to be the same for all plants. The data were collected from Riksbanken and Statistics Sweden, respectively.

In order to estimate the equations in [4], a disturbance term (\( \varepsilon_{in} \)) was added to each of the three input-output equations. This disturbance term has three components: \( \varepsilon_{in} = \alpha_{in} + \mu_{it} + \varphi_{in} \), where \( \alpha_{in} \) represents a size-specific error component, \( \mu_{it} \) shows an intra-equation inter-temporal effect due to a first-order autoregressive process (but without any autocorrelation across equations), and \( \varphi_{in} \) represents an error term that possibly can be contemporaneously correlated across the equation. The size-specific error terms can be interpreted as unobserved differences in the ways plants organized their
production due to their size of the plant. By assuming that these differences are fixed over time for a plant, we can eliminate the size-specific error term by introducing dummy variables for different sizes. As in Brännlund and Lundgren (2007), the plants were divided into small, medium and large based on the number of employees. This implies that a separate intercept term for each size-group is introduced, a solution which is referred to as the fixed-effects model. The potential bias that can occur if the unobserved size effects correlate with the regressors can be therefore be avoided (Friedlander et al., 1993). Furthermore, since it is expected that the \( q_{im} \) terms are contemporaneous and correlated across equations, it can be assumed that the resulting error vector is multivariate normally distributed with mean vector zero and constant (non-singular) covariance matrix \( \Omega_{in} \).

**EMPIRICAL RESULTS AND DISCUSSION**

The input-output equations [4] were estimated using the full information Maximum Likelihood method and the TSP software program. The parameter estimates were then used to calculate the elasticities according to equations [5] to [9]. The parameter estimates can be obtained from the authors upon request. Before proceeding, it is important to comment on the behaviour of the underlying model [4]. This can be checked by looking at the monotonicity and concavity conditions. Regarding monotonicity, only 35 out of 384 estimates showed the wrong sign and for concavity only 4 out of 128 estimates indicated the unexpected sign. Overall, the estimated GL factor demand equations are relatively consistent with its theoretical foundations.

One advantage of the GL specification is the ability to explicitly test if there exists any substitution between the input factors labour, electricity and oil. This can be performed by comparing the unrestricted version of the model with the restricted version of the model where \( \alpha_y = 0 \) for all \( i, j, i \neq j \) in a likelihood ratio (LR) test. Table 1 presents the test-statistics for the LR-test, which indicates that the null hypothesis of no substitution possibilities can be rejected on 5% but not on 1% significance level. Given that substitution possibilities exist, it is useful to investigate the magnitudes of the estimated cross-price effects.

<table>
<thead>
<tr>
<th>Null hypothesis</th>
<th>Degrees of freedom</th>
<th>Test statistics</th>
<th>Critical value ( \chi^2(0.05) )</th>
<th>Critical value ( \chi^2(0.01) )</th>
</tr>
</thead>
<tbody>
<tr>
<td>( \alpha_{LE} = \alpha_{LO} = \alpha_{OE} = 0 )</td>
<td>3</td>
<td>8.62</td>
<td>7.81</td>
<td>11.34</td>
</tr>
</tbody>
</table>

The estimated short- and long-run partial factor demand elasticities are presented in Table 2. Economic theory stipulates that the own-price elasticities should be negative, and this is the case for all three variables. The results are statistically significant and indicate that the industry has been most sensitive to changes in the oil price. Regarding the electricity elasticity we can see that the industry is relatively sensitive to price changes, at least considering the short-run estimates. The sign of the cross-price elasticities indicate whether the input factors are substitutes or complements in the mining production. Cross-price elasticities for electricity and labour indicate that they are substitutes, i.e., if the price of labour increases, demand for electricity increases. Regarding electricity and oil, these results also indicate that they are substitutes in the production. Furthermore, it seems to be easier to vary oil use, rather than electricity use. The long-run elasticities are expected to be higher than the short-run elasticites. In other words, the substitution possibilities are usually larger in the long-run since capital is allowed to reach its full
adjustment level. Overall this is the case. However, there are small differences between the short- and long-run estimates.

### Table 2: Own- and cross-price elasticities based on median values

<table>
<thead>
<tr>
<th>Elasticities</th>
<th>SR Estimates</th>
<th>P-value</th>
<th>LR</th>
<th>P-value</th>
</tr>
</thead>
<tbody>
<tr>
<td>( \eta_{LF} )</td>
<td><strong>0.176</strong></td>
<td>0.013</td>
<td><strong>0.182</strong></td>
<td>0.000</td>
</tr>
<tr>
<td>( \eta_{LO} )</td>
<td>-0.009</td>
<td>0.847</td>
<td><strong>-0.012</strong></td>
<td>0.043</td>
</tr>
<tr>
<td>( \eta_{FL} )</td>
<td><strong>1.209</strong></td>
<td>0.015</td>
<td><strong>1.257</strong></td>
<td>0.000</td>
</tr>
<tr>
<td>( \eta_{FL} )</td>
<td><em>0.564</em></td>
<td>0.088</td>
<td><strong>0.574</strong></td>
<td>0.000</td>
</tr>
<tr>
<td>( \eta_{LO} )</td>
<td>-1.269</td>
<td>0.852</td>
<td><em>-1.548</em></td>
<td>0.051</td>
</tr>
<tr>
<td>( \eta_{EF} )</td>
<td><em>12.844</em></td>
<td>0.093</td>
<td><strong>13.044</strong></td>
<td>0.000</td>
</tr>
<tr>
<td>( \eta_{LE} )</td>
<td><em>-0.165</em></td>
<td>0.065</td>
<td><strong>-0.174</strong></td>
<td>0.000</td>
</tr>
<tr>
<td>( \eta_{EF} )</td>
<td><strong>-1.760</strong></td>
<td>0.006</td>
<td><strong>-1.803</strong></td>
<td>0.000</td>
</tr>
<tr>
<td>( \eta_{LO} )</td>
<td><em>-11.539</em></td>
<td>0.083</td>
<td><strong>-11.577</strong></td>
<td>0.000</td>
</tr>
<tr>
<td>( \eta_{LF} )</td>
<td>-</td>
<td>-0.002</td>
<td>0.783</td>
<td></td>
</tr>
<tr>
<td>( \eta_{EF} )</td>
<td>-</td>
<td>-0.013</td>
<td>0.614</td>
<td></td>
</tr>
<tr>
<td>( \eta_{OK} )</td>
<td>-</td>
<td>0.036</td>
<td>0.784</td>
<td></td>
</tr>
<tr>
<td>( \eta_{SK} )</td>
<td>-</td>
<td><strong>1.084</strong></td>
<td>0.000</td>
<td></td>
</tr>
<tr>
<td>( \eta_{KK} )</td>
<td>-</td>
<td><strong>1.070</strong></td>
<td>0.000</td>
<td></td>
</tr>
<tr>
<td>( \eta_{KD} )</td>
<td>-</td>
<td><strong>0.228</strong></td>
<td>0.000</td>
<td></td>
</tr>
<tr>
<td>( \eta_{KE} )</td>
<td>-</td>
<td><strong>0.296</strong></td>
<td>0.000</td>
<td></td>
</tr>
</tbody>
</table>

***, **, * indicate statistical significance at 1, 5 and 10% level, respectively, using a two-tailed test.

Regarding the results for capital, we are pleased to see that the own-price elasticity for capital is negative. Both labour and oil are regarded as substitutes to capital, while electricity and capital are complements. This implies that when the price of labour increases, the firms substitute capital for labour in the production process. Furthermore, when the price of electricity increases, the firms tend to use less capital. This can be explained by the fact that most capital requires electricity in order to extract minerals. Given that we are interested in how the investment in knowledge has affected the factor demand equation, and substitution, Table 3 presents these elasticities.

### Table 3: Time trend and knowledge stock elasticities based on median values

<table>
<thead>
<tr>
<th>Elasticities</th>
<th>( \eta_{LT} )</th>
<th>( \eta_{ET} )</th>
<th>( \eta_{OT} )</th>
<th>( \eta_{LKS} )</th>
<th>( \eta_{EKS} )</th>
<th>( \eta_{OKS} )</th>
</tr>
</thead>
<tbody>
<tr>
<td>SR</td>
<td>0.701</td>
<td>0.576</td>
<td>1.137</td>
<td>-0.394</td>
<td>-0.260</td>
<td>-0.679</td>
</tr>
<tr>
<td>P-value</td>
<td>***0.001</td>
<td>0.334</td>
<td>0.812</td>
<td><strong>0.000</strong></td>
<td>0.168</td>
<td>0.643</td>
</tr>
</tbody>
</table>

According to Table 3, the estimates of the elasticities of the time trend with respect to labour, electricity and oil are all positive, which indicates that over time, exogenous technical development has increased the use of these factors. This result is difficult to explain, but only the estimate for labour is significantly different from zero. The estimates of the elasticities for the knowledge stock are, on the contrary, negative for all three factors, which indicates that investments in R&D is associated with decreased use of labour, electricity and oil. As for the time trend, only the elasticities for the knowledge stock regarding labour are significant. This result indicates that the focus of the R&D investments in the mining industry have been directed towards increased productivity in labour use, rather than focus on energy efficiencies. We thus conclude that there exists potential for energy efficiency improvements.

**CONCLUSIONS**

The purpose of this paper was to analyse the electricity demand in the mining industry in Sweden, and to establish electricity elasticities and factor substitution between inputs in an industry with high electricity use. Of special interest was to study if R&D has affected
the electricity consumption, i.e., if there has been a link between investing in R&D and lower electricity use. The results from the GL cost function model showed that factor substitution exists between the input factors (labour, electricity and oil) in the mining industry. Regarding electricity elasticities these are negative and significant, which indicates that the industry’s electricity use has been relatively responsive to changes in the electricity price. The results also indicate that demand for oil is relatively sensitive to changes in the price of electricity. Regarding the results for capital, both labour and oil are regarded as substitutes to capital, while electricity and capital are complements. This finding is expected given that labour is usually required to manage capital, while most capital requires electricity in order to extract minerals.

The estimates of the elasticities for the knowledge stock indicate that investments in R&D have decreased the use of labour, electricity and oil. However, only the elasticity for the knowledge stock regarding labour is significant. This result might indicate that the focus of the R&D investments in the mining industry have been directed towards increased productivity in labour use, rather than on energy efficiencies. During most parts of the time-period under investigation, 1990-2002, the industry struggled with decreasing mineral prices and thus small profit margins. This is likely an explanation for the finding that R&D investments have not been focused on energy efficiency solutions that requires larger investments. However, we believe that this result might change if the time-period is extended to incorporate the recent boom in the minerals industries, given that profit margins during these years increased substantially. Furthermore, the PFE was not introduced until 2005 and therefore the effects of this program are not captured in this paper. However, there should be relatively large potential for energy efficiency solutions within this industry and therefore it would be of interest in the future to extend the time-period.

ACKNOWLEDGEMENTS
We are thankful for useful comments on earlier drafts of this paper from Patrik Söderholm, and for generous financial support from the Swedish Energy Agency (AES Program).

REFERENCES


