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Abstract

The paper considers the estimation of a translog cost function employing panel data for a sample of 43 Swiss hydropower companies, over the period of 1995-2002. The results of this analysis indicate the existence of economies of scale and density for most output levels. The basic novelty in this paper is the estimation of a cost function for a sample of hydropower companies. In the economic literature no study on the cost structure of the hydropower plants using an econometric approach has been published so far.

1 Introduction

In order to gradually open the electricity market, the Swiss government proposed the so-called Swiss Electricity Market Law (EML) in 1999. However, in a referendum in September 2002 the Swiss population rejected this law. At the moment the Swiss Parliament is preparing a new proposal to reform the electricity sector. The general idea is to introduce competition in the generation and sale activities and to use new instruments in the regulation of the transmission and distribution activities. The main goals of this reform are to increase the efficiency of the sector and to be compatible with the European Electricity Directive (96/92/EC). This harmonization process with the European countries seems to be very important because of the geographical location of Switzerland. In fact, Switzerland has always been a relevant partner in the European exchange of electric power.

The Swiss electricity sector is mainly based on hydropower generation (~56%) and on nuclear power generation (~40%).[1] The run-of-river hydro power plants and the nuclear power plants are utilized principally to meet the demand for electricity at a national level during the medium and low load periods, whereas the storage and the pump storage power plants are employed to satisfy the electricity demand during the high load periods and to export electricity (mainly to Italy).

Although at the moment it is uncertain when the new electricity market law will come into force, (some fear) it is suspected that power prices in the next years will decrease, and that this decrease could have a negative impact on the competitiveness of the Swiss hydropower producers. For this reason, since several years the hydropower companies are considering the introduction of structural reorganizations of the companies in order to improve profitability and productivity. One point of interest for this discussion would be the information on the optimal size of a hydropower company. In particular, some companies see the possibility of reducing the unit costs by operating several hydropower plants. Today, a number of companies are operating only one hydropower plant, whereas others run several plants. The differences between the cost per unit of output among companies may be due to the quantity of electricity generated as well as to the number of plants they operate.

[1] The hydropower companies are aapproximately 80, whereas the nuclear power companies are 5 in number. The production of electric power using thermal power plants or using wind or photovoltaic energy is currently limited (~4%).

The purpose of this study is to make a contribution to this discussion through the econometric estimation of a translog variable cost function for a sample of Swiss hydropower companies. This study is useful for verifying the presence of economies of scale and to analyze the impact of the number of plants on the production costs. Despite the fact that this subject is topical for the hydropower sector operating in the Alpine countries like Switzerland, France and Italy, in the international literature there are, to our knowledge, no published studies on economies of scale of the hydropower companies. Several studies (Christensen and Greene (1978) among these) have been published on the estimation of cost functions for other generation technologies such as thermal plants (coal, nuclear and gas power plants).[2]

This paper is structured as follows: section 2 discusses the variable cost model; section 3 presents the data, while section 4 illustrates the parameter estimates of the cost function and the results in terms of economies of scale. Finally, we will complete the paper with the main conclusions and policy implications.

2 Specification of the variable cost function for the hydropower plants

The main costs of operating a hydropower company comprise the costs of building and maintaining the dam, the steel lined pressure shaft, the power house and the turbines. Moreover, these costs may depend upon the size of the reservoir, the type of the hydropower plant (storage or run-of-river) as well as on the number of plants operated by a single company. In fact, the Swiss hydropower companies partly operate several plants located in the same region. Therefore, an analysis of the cost structure of these companies should take account of the fact that the same quantities of electricity can be produced using several and/or different types of plants (storage, pump-storage and run-of-river). In the cost model specification it is therefore important to introduce some variables related to both the type of the power plants employed in the production and the organization of the companies.

We consider one single output in the cost model for the hydropower plants. Inputs consist primarily of labor, material and capital. The main reason for choosing the estimation of a variable instead of a total cost function is that the investments into the plants were made some decades ago (at least in most of the cases) and therefore the capital costs and depreciation can be considered fixed at least in the short and medium term.

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[2] For a review of cost functions in the electric utility industry see Ramos-Real (2005).

Assuming that output and input prices are exogenous, and that (for a given technology) firms adjust input levels so as to minimize costs, the firm's total cost of operating a hydropower company can be represented by the cost function

$$VC = V(Q, N, P_L, C, D_{R1}, D_{R2}, D_S, D_{PS}, T) \qquad (1)$$

where VC represents variable cost, Q is the output represented by the total number of GWh produced and N is the number of plants. P_L is the price of labour and C stands for the capital stock described as the book value of the companies. Unfortunately, we could not consider the price of material in the model specification (1) due to lack of data.[3]

Finally, we introduced 4 dummy variables ($D_{R1}, D_{R2}, D_S, D_{PS}$) in the model to check for differences in cost among different types of hydropower plants used by the companies: run-of-river with an exploitable drop below 25 m, run-of-river with an exploitable drop above 25 m, storage and pump-storage plants. T, the time trend, is included as a way of capturing the effects of neutral technical change.

The properties of cost function (1) are that it is concave and linearly homogeneous in input prices, non-decreasing in input prices and output, and, regarding capital stock, non-increasing[4].

To estimate the cost function (1), a translog functional form is employed. This flexible functional form is a local, second-order approximation to an arbitrary cost function. It places no a priori restrictions on the elasticities of substitution and allows the economies of scale estimate to vary with the output level.[5] The translog approximation to (1) is

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[3] The effect of this input price on cost is thus considered in the constant.

[4] See Cornes (1992), p. 106.

[5] A translog function requires the approximation of the underlying cost function to be made at a local point, which in our case is taken at the median point of all variables. Thus, all independent variables are normalized at their median point.

$$\ln(VC) = \alpha_0 + \alpha_Q \ln Q + \alpha_N \ln N + \alpha_{PL} \ln P_L + \alpha_C \ln C + \frac{1}{2}\alpha_{QQ}(\ln Q)^2 + \frac{1}{2}\alpha_{NN}(\ln N)^2 + \frac{1}{2}\alpha_{PLPL}(\ln P_L)^2$$
$$+ \frac{1}{2}\alpha_{CC}(\ln C)^2 + \alpha_{QN}(\ln Q)(\ln N) + \alpha_{QPL}(\ln Q)(\ln P_L) + \alpha_{QC}(\ln Q)(\ln C) + \alpha_{NPL}(\ln N)(\ln P_L) \qquad (2)$$
$$+ \alpha_{NC}(\ln N)(\ln C) + \alpha_{PLC}(\ln P_L)(\ln C) + \alpha_{R1} D_{R1}, + \alpha_S D_S + \alpha_{PS} D_{PS} + \alpha_T D_T$$

In order to improve the efficiency of the estimation of least squares parameter estimates for the cost function, a cost system is being estimated[6]. This system consists of the translog cost function (2) and the factor share equation for labour. By applying Shephard's lemma, the resulting share equation takes the familiar form:

$$S_L = \alpha_L + \alpha_{LL} \ln P_L + \alpha_{QPL} \ln Q + \alpha_{NPL} \ln N + \alpha_{PLC} \ln C \qquad (3)$$

The translog cost function permits scale economies to vary with the level of output, factor prices and the variables characteristic of output.

3 Data

The model is estimated with panel data from a sample of Swiss hydropower companies. Our study is principally based on a database created by using different sources: the Swiss Federal Statistical Office's value added statistics (”Wertschöpfungsstatistik”), the financial statistics (“Finanzstatistik”) of the Swiss Federal Office of Energy, and a database created by the Centre for Energy Policy and Economics by collecting annual financial and economic reports of the companies. Additional technical information was taken from a database on this sector built up by the Federal Office for Water and Geology.

After this information was collected and the data sets were merged, the final data set consisted of a sample of 60 hydropower companies. However, some of these had to be excluded from the econometric analysis due to missing data. Model (2) has been estimated using an unbalanced panel data set, which includes 43 companies observed over a period varying from 2 to 7 years.

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[6] See, for a similar approach in modelling the cost structure in the electricity sector Filippini (1998, 1996).

The variable cost per year is equated to the sum of labour, operations (including material) and energy costs. Average annual wage rates are estimated by dividing the labour expenditure by the number of employees. Unfortunately, no information is available to define a price for the use of materials. The capital stock is defined as the book value as reported in the annual financial reports of the companies.[7] All input prices, total costs and variable costs were deflated to 2000 constant Swiss francs using the Consumer Price Index. Descriptive statistics of the variables included in the model are presented in Table 1.

Table 1: Descriptive statistics of variables included in the model

Variable	*Description*	*1. Quartile*	*Median*	*3. Quartile*
Q	GWh	223.4	424.3	855.5
N	number	1	3	4
PL	SwF per months	97200	106500	117600
C	Book value in SwF	59’700’000	146’500’000	361’500’000

The composition of the hydropower plants included in the sample is the following: 37% are pump-storage plants, 23% storage plants, 21% run-of-river with an exploitable drop below 25 m and 19% run-of-river plants with an exploitable drop above 25 m.

4 Empirical results

The multivariate system of equations (2) and (3) has been iteratively estimated using the Zellner (1962) procedure for seemingly unrelated regressions.[8]

The estimated coefficients of the translog cost model (2) are presented in Table 2. The results are satisfying in so far as all first order coefficients and most of the second order coefficients are significant and carry the expected signs. As can be seen, the corrected R^2 for the model is also satisfying with a value of 0.86.

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[7] No data were available which would allow the calculation of the capital stock using the perpetual inventory method.

[8] For a discussion of this procedure see Greene (2003). The model has been estimated using the computer program LIMDEP 7.0.

A well-defined variable cost function should be increasing with respect to output and input prices, concave with respect to input prices and non-increasing with respect to capital stock.

Table 2: Variable cost parameter estimates (standard errors in parentheses)

Parameters	*Values*
Constant	15.742*** (0.092)
αY	0.516*** (0.052)
αPL	0.436*** (0.007)
αN	0.441*** (0.061)
αC	0.090** (0.034)
αYY	-0.005 (0.056)
$\alpha PLPL$	0.102** (0.047)
αNN	0.571*** (0.148)
αCC	-0.034 (0.021)
αYPL	0.016 (0.010)
αYN	0.025 (0.010)
αYC	0.068 *** (0.024)
αPLN	0.079*** (0.013)
αPLC	-0.017** (0.007)
αCN	-0.288*** (0.042)
$\alpha DR2$	-0.021 (0.084)
αDS	-0.043 (0.078)
αDSP	0.213** (0.082)
αT	-0.018** (0.009)
R^2	0.859

*, **, *** significantly different from zero at the 90, 95 and 99 % confidence level.

Since total cost and the regressors are in logarithms and have been normalized, the coefficients are interpretable as cost elasticities. The output elasticity is positive and implies that an increase in the production will raise the variable costs. A 1%

increase in the quantity of electricity produced will increase the variable cost by approximately 0.5%.

The labor cost share is positive, implying that the cost function is increasing in this input factor.

The elasticity of the variable costs with respect to the number of plants is positive and implies that an increase in the number of plants will raise the variable costs. A 1% increase will raise the variable costs of a hydropower company by about 0.4%. This result indicates the presence of economies of operational functions derived from managing multiple plants of similar technology. Moreover, this result confirms the outcome obtained by Hiebert (2002) who estimated a cost function using a sample of coal and natural gas fired plants.

The coefficient of capital stock is positive and significantly different from zero. This result indicates, contrary to what is normally expected in cost theory, that a marginal increase in the capital stock results in small raises in variable costs. However, this result has to be interpreted carefully because of the kind of proxy variable used in the model for the capital stock.[9]

The coefficients of the dummy variables on the different types of hydropower plants show that the storage pump hydropower plants have higher variable costs than storage and run-of-river hydropower plants, respectively.[10] This result is not surprising, because storage pump plants consume a large amount of electricity to pump the water into the reservoir.

Finally, turning to the question of technological progress, 2 indicates that there is evidence of a small negative time shift of the variable cost function. Thus, the negative coefficient of T indicates that the Swiss hydropower companies underwent progressive technical change during the period considered in the analysis.

Following Caves et. al (1984) and Filippini (1996) we define economies of scale (ES) as the proportional increase in total costs brought about by a proportional increase in output, holding all input prices and the number of plants fixed.[11] This is equivalent to

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[9] See for a discussion on this issue Filippini (1996).

[10] The variable $DR1_{n}$ does not appear in the table because it is taken as reference, in order to avoid the dummy variable trap.

[11] The inverse of cost elasticity of output is referred to by Chambers (1988), as the "economies of size" rather than economies of scale, which are defined in regard to production function. Scale and size economies are equivalent if and only if the production function is homothetic (see Chambers, 1988, page 72). Here, we do not impose this assumption. However, as for the purpose of this paper we are more interested in the cost effects of output, we define the returns to scale in terms of cost elasticity.

the inverse of the elasticities of variable cost with respect to output,

$$ES = \frac{1 - \dfrac{\partial \ln VC}{\partial \ln C}}{\dfrac{\partial \ln VC}{\partial \ln Q}} \qquad (4)$$

We will talk of economies of scale if ES is greater than 1, and accordingly, identify diseconomies of scale if ES is below 1. In the case of ES = 1 no economies or diseconomies of scale exist. Economies of scale exist if the average costs of a hydropower company decrease as the quantity of electricity produced with a fixed number of plants increases.

The estimation results from Table 2 can be utilized to calculate, using equation (4), the values of the economies of scale in the Swiss hydropower sector. Table 3 presents in more detail the results for small, medium-sized and large companies, respectively. We note that all values of the indicator for economies of scale are greater than 1, which means that the majority of the hydropower companies operate at an inappropriately low scale. However, the size of these hydropower companies is limited for environmental conditions. Therefore, the only way to try to exploit the economies of scale is to merge with other companies.

Table 3: Economies of scale[12]

Size of the hydropower company	small	medium	large
Economies of scale	1.76	1.78	1.76

[12] Equations (4) and (5) have been evaluated at the input prices , value of the capita stock of the median company.

5 Conclusions

The purpose of this study was to analyse the cost structure of the Swiss hydropower companies in order to assess economies of scale. In particular, managers are interested in cost information in order to determine the impact of the size and the number of plants on costs. A translog variable cost function was estimated using unbalanced panel data for a sample of 43 companies over the period 1995-2002.

The results indicate the existence of economies of scale for most output levels. The empirical evidence suggests that operating several hydropower plants is the most efficient form of production organisation in this industry.

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