Dynamics of Technical Efficiency and Productivity Change under Central Planning: The Romanian Cement Industry 1966-1989*

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Abstract: This paper investigates the time-path of efficiency and productivity change in the case of the Romanian cement industry 1966-1989. The analysis is based on different specifications of stochastic frontier models. The efficiency scores and the time paths of efficiency and technical change are found to vary substantially among models. The most important feature of the Romanian cement industry before the revolution in 1989 is a slow rate of productivity progress, and a corresponding catch up in the level of productive efficiency.

Keywords: Productivity change, productive efficiency, stochastic frontiers, time-varying efficiency, panel data, cement industry, Romania

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1. INTRODUCTION

Because of lack of reliable data very little is known about actual technical change and productivity growth in the former communist countries, and there are very few published industry studies based on micro data from the pre-revolutionary period in Eastern Europe. On the empirical side, the contribution of this paper is an analysis of the Romanian cement industry 1966-1989. Thus, this study will provide some insight into productivity change and productive efficiency of one of the key industries in former Eastern Europe and especially in Romania during the Ceausescu period. Romanian cement production per capita during the 1970s and 1980s was for example about twice the Swedish per capita level. Large investments in capital-intensive manufacturing and infrastructure (including the extensive renewal of the capital, Bucuresti) and some export are the main reason for this difference.

Analysis of productive efficiency of various sectors in the economy has been a major research area during the last decade. While most studies have been based on cross-section data, there is an emerging set of empirical applications based on balanced or unbalanced panel data. Because such data will provide a much more detailed evaluation of the relative performance of micro units, linking efficiency to productivity and technical change, they are of great value.

One important aspect of efficiency is its stability over time. Is high efficiency a temporary phenomena or a permanent one? Or is there a certain time-path of efficiency? Only a few attempts to answer these questions have been made so far; see Kumbhakar et al. (1997). The second purpose of this paper is to contribute with a study of the time path of efficiency in the case of the Romanian cement industry 1966-1989, for which we have collected a set of unbalanced panel data. Such a study should reveal the time path of efficiency for the micro units answering questions about the degree of stability in efficiency scores, and whether inefficiency has been a transitory or permanent state in this industry. Moreover, the rate of technical or productivity change will be revealed and related to the development of technical efficiency.

The analysis will be based on stochastic frontier models, and we will compare different specifications of efficiency and technical change, which have been suggested in literature[1.] Concerning the specification of efficiency and technical change in panel data modelling, two main branches have developed. The first assumes technical efficiency to be time-invariant; see

1 A previous version, Cotfas et.al (1998) also contains a comparison with DEA models.

Pitt and Lee (1981), Schmidt and Sickles (1984), and Battese and Coelli (1988), among others. The second allows technical efficiency to be time varying; see Cornwell, Schmidt and Sickles (1990), Kumbhakar (1990), Battese and Coelli (1992), Lee and Schmidt (1993). Each of these two branches can be further sub classified depending on whether or not any distributional assumptions or functional forms are imposed on the inefficiency terms; for a comprehensive survey of the frontier literature, see Kumbhakar and Lovell (2000).

In this study we will focus on the specification and estimation of various models incorporating time-varying technical efficiency and technical change for the Romanian cement industry. In the literature on stochastic frontier functions, several models are proposed to allow technical efficiency to be time varying. Here we will apply four different models, three with time-varying technical efficiency explicitly parameterised and one with technical change only. Differences in empirical results between the different specifications will be investigated, in terms of input elasticities, returns to scale, technical progress, total factor productivity growth, TFP, and technical efficiency measures.

A priori, there is no reason to expect efficiency to be constant over time. However, the theoretical foundation is still weak, and the specification of time-varying efficiency in the models applied is rather much ad hoc, i.e. it is not based on any theoretical models, which generate inefficiency. There is one theoretical model which provides some conclusions for the development of inefficiency in an industry, namely the vintage or putty-clay model; see Hjalmarsson (1973), Forsund and Hjalmarsson (1974), Hjalmarsson (1974), and Forsund and Hjalmarsson (1987). In a vintage model with economies of scale ex ante or embodied, but no disembodied technical progress, a certain micro unit becomes gradually less efficient as new technology is picked from the ex ante production function. Second, in a putty-clay model without technical progress or scale economies in the ex ante production function, one should expect a gradual compression of the efficiency structure, since when all units are renewed they will pick technology from the same constant ex ante production function. In this case, the efficiency of a certain unit will remain constant until there is a jump in the efficiency score from worst practice to best practice, when the unit changes its vintage from the oldest to the newest. One condition to keep efficiency constant over time in a putty-clay model is when the rate of disembodied technical progress compensates for embodied technical progress and scale economies in the ex ante function.

Outside the stylised models, the presence of disembodied technical progress may give some inefficient units a chance to catch up with the frontier units as these are gradually improving. Elimination of organisational slack may compress the efficiency distribution, while generation of slack works the opposite way. Thus a priori, only under strong assumptions could we expect efficiency to be time invariant. Another important observation is the close dynamic relationship between efficiency development and technical change in a putty-clay model. The rate of technical change at the frontier may be an important determinant behind the time pattern of technical efficiency.

Because of the technology one should expect the cement industry to approximate a putty-clay industry quite well. The basic technology is embodied in the cement kiln, the design of which is decided at the investment date. Technical progress worldwide is characterised by capital-embodied energy-saving progress, while labour-saving progress seems to be of a more disembodied or gradual nature; see Forsund and Hjalmarsson (1983) and (1987).

In the next section the stochastic frontier production function models are presented. Section 3 describes data and Section 4 contains the empirical results, along with a comparison of the performance of the different model specifications. Section 5 summarises and draws conclusions.

2. THE MODELS

As a benchmark, we will first introduce one model aiming at the measurement of technical change, and with only a plant specific effect and no inefficiency term. Then we will specify three different models for the measurement of efficiency where efficiency is time varying.

An important issue here is the measurement of productivity change. In general, total factor productivity, TFP, change consists of a technical change (TC) component and a scale component. However, in the case of inefficiency, technical efficiency (TE) change provides a third component to TFP change. Formally

(1) $$\Delta TFP = TC + \Delta TE + (E-1)\sum \frac{E_j}{E}\Delta X_j$$

where E_j is the partial elasticity of input X_j with respect to output and E is the elasticity of scale. As will be discussed below, a principal econometric problem in stochastic production frontier modelling is to disentangle technical change at the frontier from efficiency change below the frontier; see Kumbhakar and Lovell (2000). This is a problem in two of our models, namely the Lee and Schmidt (1993) model and the Cornwell, Schmidt and Sickles (1990) model, denoted by LS and CSS respectively.

The standard time trend (STT) model

As the benchmark model for technical change at the frontier we apply the standard time trend (STT) model. To avoid strong a priori restrictions on the technology, a flexible functional form, translog, is chosen. Thus, we assume that the production technology of the Romanian cement plants is represented by

(2) $$\ln Y_{it} = \alpha_0 + \sum_j \alpha_j \ln X_{jit} + \alpha_t t + 1/2 \left\{ \sum_j \sum_k \alpha_{jk} \ln X_{jit} \ln X_{kit} + \alpha_{tt} t^2 \right\} + \sum_j \alpha_{jt} \ln X_{jit} t + \varepsilon_{it}$$

where $\ln Y_{it}$ is the logarithm of output of firm i (i = 1, 2,..., N) at time t (t = 1, 2,..., T_i), $\ln X_{it}$ is the corresponding matrix of k inputs, (also varying both over firms and over time) and α is a vector of unknown parameters to be estimated, t is the time trend representing the rate of technical change or shift in the production function over time, and ε_{it} is the error term to be specified. Technical change (TC) is specified as

(2) $$\tau_{it} = \partial \ln Y_{it} / \partial t = \alpha_t + \alpha_{tt} t + \sum_j \alpha_{jt} \ln X_{jit}$$

In Eq. (2) technical change consists of two parts, the pure technical change component $\alpha_t + \alpha_{tt} t$, which is invariant across plants, and the non-neutral component $\sum_j \alpha_{jt} \ln X_{jit}$, which varies across plants and over time.

In the STT model the error term, ε_{it} is specified as

(3) $$\varepsilon_{it} = \mu_i + \upsilon_{it}$$

The v_{it} are statistical noise and are assumed to be independently and identically distributed with zero mean and constant variance, and μ_i is a plant-specific effect. Following panel data literature one can assume μ_i as either fixed (FE-model) or random variable (RE-model). Since the STT model is linear in parameters, the standard panel data techniques can be used to estimate the model.

The model in (1) and (3) can be written as

(4) $y_{it} = \alpha_i + x_{it}^{'}\alpha + v_{it}$

where

(5a) $\alpha_i = \alpha_0 + \mu_i$

or when inefficiency is introduced below

(5b) $\alpha_{it} = \alpha_i - u_{it}$

is the intercept for firm i at time t[2]. The expression in (5a) is the intercept for firm i. It is time invariant. In order to make the inefficiency term time varying, it is made a function of time as follows in the following three time-varying efficiency models.

The Lee and Schmidt (LS) model

In the Lee and Schmidt (1993) model, α_{it} in Eq. (5b) is specified as

(6) $\alpha_{it} = \lambda_t \mu_i$

where λ_t and μ_i are unknown parameters to be estimated. The μ_i are considered as unobservable plant-specific effects in the STT and LS models and in the CSS model below. In the latter two models in a second step of the estimation procedure, those effects are transformed to deviations from maximum intercept and considered as fixed inefficiency effects. Thus, no functional form is assumed here, but the *temporal pattern of efficiency* (not the magnitude) is assumed to be *the same for all plants*.[3] This assumption might be useful and reasonable when the number of periods (T) is small. For identification purposes, λ is normalized by allowing $\lambda_1 = 1$. The model is non-linear and allows for the inclusion of variables that are time- or plant-invariant in the

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2 This means that the efficiency scores calculated from this model are deterministic in the sense that they contain both the plant-specific intercept and the residual. Although efficiency scores vary over time it is not a true time-varying efficiency model.

3 Lee and Schmidt found their model to perform better in cases with relatively large number of firms but small number of periods. Since firm and time specific intercepts (α_{it}) is obtained from the interaction of two firm and time effects vectors, relative to CSS fewer degrees of freedom are used. In order to allow for non-constant time effects across firms, a further non-linearity must be introduced (like interaction of α_{it} with some of the explanatory variables) in the model specification. This would have made the analysis more complicated and beyond the scope of this study.

specification.

The v_{it} are assumed to be i.i.d. with mean zero and constant variance σ_v^2. Depending on the assumptions made regarding correlation between the effects and the explanatory variables, the parameters $\alpha, \lambda_t, \sigma_v^2$ and μ_i are then to be estimated in either a fixed-effects model or a random-effects model, where instead of μ_i its variance σ_μ^2 is estimated. In a fixed-effects model the number of parameters, μ_i, depends on the sample size (cross-section). Following Schmidt and Sickles (1984), the frontier intercept at time t, α_t, and the plant-specific level of technical inefficiency for plant i at time t, u_{it}, are estimated, respectively, as

(7) $$\hat{\alpha}_t = \max_i(\hat{\alpha}_{it}) \quad \text{for each } t = 1,2,\ldots,T_i$$

and

(8) $$\hat{u}_{it} = \hat{\alpha}_t - \hat{\alpha}_{it}$$

Estimators of plant-level technical efficiency in each year are then derived from

(9) $$TE_{it} = \exp(-\hat{u}_{it})$$

As regards technical change, the principal econometric problem is to disentangle technical change from efficiency change if time appears both as a proxy for technical change in the deterministic kernel of the stochastic frontier and as an indicator of technical efficiency change in the error component (6). Without specifying technical change in the deterministic kernel, the rate of technical change in the LS model is measured as the difference between the coefficients of two time dummies associated with two consecutive time periods[4].

The Cornwell, Schmidt and Sickles (CSS) model

Cornwell, Schmidt and Sickles (1990) allow the plant-specific effects to vary over time by replacing the α_{it} by a parametric function of time. Technical efficiency (including the intercept, α_0) is modelled as

(10) $$\alpha_{it} = \theta_{i1} + \theta_{i2}t + \theta_{i3}t^2$$

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4 An attempt to introduce technical change in the deterministic kernel of the LS model resulted in unreasonably low efficiency scores

where θ_{i1}, θ_{i2} and θ_{i3} are unknown parameters. Thus, *efficiency* α_{it} is a quadratic function of time, and it *varies across plants*. No assumption other than this specification is involved here. The temporal pattern of efficiency is quite flexible, although in a different way than in the LS model. Following Schmidt and Sickles (1984), the frontier intercept, α_t, the level of technical inefficiency, u_{it}, and the estimator for technical efficiency for plant i at time t, TE_{it}, are obtained as in Eqs (7) to (9).

Like the LS model, we are not able to disentangle technical change, TC, from change in technical efficiency, TE. The rate of technical change, (or rather productivity change) is obtained as $(\partial \ln Y / \partial t)$. TC involves only the θ_2 and θ_3 components interacting with a trend and trend squared, while TE involves the θ_1 term not interacting with a trend as well. It is true that the plant-specific intercept θ_1 can be considered as a persistent part of efficiency not changing over time, while the other two $(\theta_2$ and $\theta_3)$ components can be considered as the residual part and functions of trend.

The estimation methods used are least square in the STT and CSS models and non-linear least square in the LS case. The only transformation that is required in addition to the usual data transformations necessary for a translog specification, is interaction between time trend and time trend squared with plant dummy variables in the CSS model. In the LS model, the vectors of time and plant dummies are interacted directly in the iterative estimation procedure. All three models are estimated as fixed-effect models.

The Battese and Coelli (BC) model

Finally, in the Battese and Coelli (1992) model, efficiency is specified as

(11) $$u_{it} = \{\exp[-\eta(t - T_i)]\} u_i$$

where η is a single unknown parameter and u_i is assumed to be i.i.d. distributed as half normal, $N(0, \sigma_v^2)$ or truncated normal, $N(\mu, \sigma_v^2)$. The random error term, v_{it}, is assumed to be i.i.d. $N(0, \sigma_v^2)$. Technical efficiency is allowed to change over time. However, the *temporal pattern* is assumed to be the *same for all plants*. This assumption is quite restrictive, but not unreasonable for a putty-clay industry like cement. The model is estimated by the maximum likelihood method. The time-dependence of technical efficiency and the assumption of truncated normality of u_i can be tested from the parameters μ and η. The level of technical efficiency of plant i in period t is obtained as

$$(12) \quad TE_{it} = \exp(-u_{it})$$

which is $E[\exp(-u_{it})|\varepsilon_{it}]$, the conditional expectation of $\exp(-u_{it})$ given ε_{it}; see Battese and Coelli (1992). In the BC-models the frontier is constructed in such a way that no plant is producing on the frontier: A single observation is used as the reference technology, and the reference observation does not need to be fully efficient, i.e., located on the frontier.

Unlike the LS and CSS models, the BC model accommodates technical change as represented by a simple time trend in the production function, and is separated from technical efficiency change.[5] To allow for non-neutrality of technical change in the LS and CSS models make the models complicated and over-parameterised. One possible way, instead of interaction of vector of time dummies in the LS model and plant-specific time trend in the CSS model, may be to introduce non-neutrality of TC using interaction of a simple time trend with the input-variables. In the CSS model the rate of TC are enough flexible by being both plant and time-specific, while the LS model yields unreasonable results. Therefore, all models except LS, incorporate non-neutral components; see the parameter estimates in Table A1 in the Appendix. The joint test for non-neutrality of technical change is accepted.

3. DATA

The data used in this study cover the entire Romanian cement industry 1966-1989. The number of plants increases from 7 in 1966 to 10 in 1989. The final data consist of an unbalanced panel of 222 plants observed over the period 1966 to 1989. The plants were all owned by the Romanian state.

The cement industry produces a homogeneous output. The production process, which goes from the extraction of the raw material to the distribution of the final product, includes the following steps: (i) the transportation of the limestone from the quarry to the stone mills, (ii) the

5 Only in the BC model, technical change (TC) and technical efficiency (TE) change can be decomposed. Since not all models employed in this paper allow for such decomposition, we avoided this step. Our objective has been limited to comparison of the various model specifications outlined with respect to TC and TE. In addition, TFP-measures are calculated for all models. Since the elasticity of scale is larger than one in all models, TC and TFP differ.

crushing and grinding of the limestone, wet or dry, into a slurry or a fine powder, respectively, which is fed into the kiln, (iii) heating, burning and calcining of the slurry or powder into what is called clinker, and finally (iv) cooling of the clinker and grinding it together with gypsum or pozzolan to produce different types of cement.

The kiln is essentially a huge cylindrical steel rotary tube lined with firebrick. Its capacity determines the capacity of the plant. In the 1960s, the wet process was the most common process in the Romanian cement industry. This process has, in general, higher energy input coefficients than the dry process, and was in Romania (as in most countries) gradually replaced by the dry process. In some cases, however, the character of the limestone makes it impossible to use the dry process.

The data include the actual production figures and installed capacity of the cement plants, as well as the variable inputs labour and energy. Since there is no data for the replacement value of the capital stock, we have to use installed capacity as our capital measure. All the data have been obtained directly from site visits to the plants. Summary statistics of the data are presented in Table 1.

INSERT TABLE 1

Output (Y) is defined as the observed production of cement per year. It is measured in tonnes. The capacity (C) of a plant is measured in tonnes per year and is defined as the technical maximum capacity available for production. Capacity utilisation (CU) is defined as the ratio of observed output to the capacity of the plants.

The cement industry is a very energy-intensive industrial process. The energy variable (E) is measured in mega calories and is an aggregate of the plant level consumption of fuels. The types of fuel used in the production process are coal, natural gas and oil. The various types of energy are transformed to common unit of measurement.

Production of cement is not a very labour-intensive production process. The labour variable (L) includes both blue and white-collar workers. It is expressed in working hours per year. We do not have information on the two types of labour and their variations across plant/time. Thus, no adjustment for quality of labour has been possible to perform. The raw material, limestone measured in thousands of tonnes, is proportional to output and is, therefore, not included in the analysis.

4. EMPIRICAL RESULTS

The four models presented in Section 2 above, single time-trend (STT), Lee and Schmidt (LS), Cornwell, Schmidt and Sickles (CSS), and Battese and Coelli (BC), are used to estimate technical or productivity change (TC), and technical efficiency (TE). The empirical results are based on the sample of the 11 Romanian cement plants observed during 1966-1989. The main objective is to investigate the development of efficiency over time and the rate of technical change, TFP change and returns to scale. A translog production function is used to represent the production technology in all specifications. The STT, CSS and LS models are estimated using linear/nonlinear OLS, while the BC model is estimated using maximum likelihood and a half-normal distribution. The fixed-effect assumption applies to STT, LS and CSS models, while a random-effects assumption applies to the BC model. The estimates of the parameters of these models are presented in Appendix in Table A1.

The R^2 values are very high in all three OLS-estimated models, exceeding 0.99. The MSE in the CSS model is about 50% lower than in the other models. In models with flexible functional forms incorporating second orders and interaction terms, it is not possible to expect each one of the coefficients to be significantly different from zero. However, in our model specifications (Table A.1) most of the coefficients are statistically different from zero at the 5% levels of significance, although they vary across models by size and in some case, even by sign. It should be noted that not all plant dummies and their interaction with trend and trend squares in CSS are statistically significant. As a matter of fact, only four of the time-interaction dummies are significant at a 5% level. We preferred to keep the insignificant parameters to preserve the flexibility of the model and its comparison with other competitive models. We will comment on a few parameter estimates in the discussion of empirical results below.

Input elasticities and returns to scale

Since the coefficients of the translog production functions do not have any direct interpretation, we calculate the elasticities of output with respect to each of the inputs, E_j, where

(13) $$E_j = \partial \ln Y / \partial \ln X_j = \alpha_j + \sum_k \alpha_{jk} \ln X_{kit} + \alpha_{jt} t, \qquad j = L, E, K$$

These input elasticities vary over both time and plants. Returns to scale, RTS, i.e., the elasticity of scale, is calculated from the sum of the input elasticities as

(14) $$RTS = \sum_j E_j$$

where E_j is defined as in (13). In Table 2 the overall mean of the input elasticities and returns to scale are reported. The elasticities are evaluated at the mean of the data for the entire period. Since E_j is a linear function of X_k and t, the elasticities evaluated at the mean are the same as the mean elasticities. The non-linearity in LS and CSS arise in the intercept part. There is no interaction between this part and the slope X-variables. Thus, elasticities calculated at the mean value of X-variables and mean elasticities should be equal. Other than this, the main reasons for calculating elasticities by observation was to see whether the mean elasticities vary over time.

INSERT TABLE 2

The magnitude of the *overall mean* elasticities of output with respect to labour (E_L), energy (E_E), and capital (E_K), are rather model dependent.[6] On the other hand, the *time development* of these elasticities (not shown here) is similar among models, with labour and capital elasticity decreasing and energy elasticity increasing in all models. The STT model yields negative capital elasticities all years and so does the LS model after 1980. One reason for the negative (or small positive) and declining capital elasticity may be the low rate of capacity utilisation towards the end of the period. Mean capacity utilisation declined from about 90% in the mid 1970s to about 60% in 1989. Surplus capacity should result in a low or even negative capital elasticity. While there is a decreasing *trend* in labour and capital, there is an increasing trend in the energy elasticity. This development reflects the change in the relative importance of labour and energy, and especially the serious energy shortage in the Romanian economy during the Ceaucescu period.

A priori, one would expect increasing returns to scale in this industry, and in all models the mean value of the elasticity of scale (RTS) is above 1, suggesting that the Romanian cement industry has been using a technology with fairly large increasing returns to scale, although RTS shows a decreasing trend over time in all models; see Figure 1.

INSERT FIGURE 1

The main impression from Figure 1 is a rather uniform development of returns to scale across

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6 Here comparison of elasticities is made across models for the same input, rather than between different inputs for the same model. The differences according to the former measure are found to be relatively small.

models although there are some *level differences* (and also substantial variations among individual plants), the average Romanian cement plant is of sub optimal size, and almost all Romanian plants seem to be below the minimum efficient size or technically optimal scale level. A Chow test also indicated a non-constant returns to scale technology, as it is evident from Figure 1 (see also standard errors of returns to scale).

Productivity change

The overall rate of technical or productivity change is obtained as the logarithmic derivative of the production function with respect to time, τ_{it}, specified in Eq. (2) for the STT and BC models. τ_{it} varies over both time and plants. In the CSS model one can obtain productivity change, defined as $(\partial \ln Y / \partial t)$, without decomposition into pure and non-neutral technical change. In the LS model, technical change is measured as the difference between the coefficients of two time dummies associated with two consecutive time periods. The overall mean estimates of productivity change are reported in Table 2 (TC column) and its time development plotted in Figure 2[7].

INSERT FIGURE 2

The overall mean values varies between -0.1% and 1.1% productivity change per year, the BC yielding the lowest and the CSS model the highest value. (The mean of τ_{it} by plants varies in the interval -1.3% to 3.8%.) In the benchmark model, STT, technical change starts at about 1% change per year and ends at 0 the last year. The BC model yields slightly negative values or zero change all years except one with rather little variation between years, while the CSS model yields positive values all years in the range 0.7% to 1.5% change per year. The main reason for the very slow rate of technical progress is probably the low rate of capacity expansion and lack of modernisation of plants during this period. Technical change is to a large extent embodied in the technology in this industry.

Decomposition into pure and non-neutral components reveals for STT and BC models a high pure component neutralised by a correspondingly low non-neutral component. Both components are fairly constant over time. In the STT model the squared technical change

7 The rate of technical change was calculated at each data point. It is both plant and time specific. The values reported in Table 2 are thus the mean of changes.

component is very small and non-significant. The same holds for capital-using technical progress; see Table A1.[8]

TFP change

Because of the rather large elasticity of scale in all models, the scale component in total factor productivity, TFP, change is of substantial importance. The rates of total factor productivity growth are calculated for all models using the formulas given in Eq. (1). The overall mean values vary between 1.1% and 1.9% TFP change per year, the BC model yielding the lowest and the LS model the highest value.

The annual means of the rates of TFP growth are shown in Figure 3. As indicated by the standard deviations in Table 2, the TFP values vary much more than the TC values. However, there is substantial covariation in the TFP change rates among all the models, although the level differences are quite large in some years. All models yield slightly decreasing trends in TFP growth.

INSERT FIGURE 3

Technical efficiency

Overall mean efficiency scores are presented in the last column of Table 2, while the development over time of the mean values is plotted in Figure 4. Looking first at the overall mean values of efficiency scores for the entire period, we find the range rather small for the three models with time-varying efficiency. LS and BC models generate the highest means, 0.75 in both cases, while CSS generates the lowest, 0.66. Although hardly surprising, the overall efficiency in the STT model is very low, only 0.42. The STT model is not fully comparable with the other models, since its efficiency scores contain both noise and inefficiency as discussed in Section 2.

Concerning the temporal pattern of efficiency, in all three time-varying models the efficiency level is rather low at the beginning of the period, but then the time development differ among the models.

INSERT FIGURE 4

The LS and BC models are very close to each other and show an increasing trend in

8 Due to space limitations we have not reported all results here. Results not reported can be obtained from any of

efficiency consistent with a slow rate of technical change. Mean efficiency increases from about 0.65 in 1966 to about 0.80 in 1989. Thus, the very flexible LS model has a rather smooth development of efficiency with small deviations (except 1985) from the less flexible BC model. In contrast to the LS and BC models, the CSS model yields higher efficiency scores during the first eight years but then generates lower and decreasing efficiency scores between 1972 and 1989. (The STT model has a somewhat similar, but rather irregular, time pattern with a peak score of 0.49 in 1979 and a through in 1984 of 0.34.)

A priori, in an industry where technical progress is very slow and to a large extent embodied in the capital stock, one would expect an increasing trend in the mean efficiency level, because of most units catching up with a slowly moving best-practice frontier. If this process has been going on for a long time one would expect fairly high levels of efficiency. On the other hand, in the case of a rapidly declining capacity utilisation, which was the case in the Romanian cement industry, already from 1972 and especially from 1978 onwards, the opposite could be the case, even if technical progress has been very slow; see Figure 3 where CU denotes the ratio between actual output and full capacity output.

Thus, we are left with two time-varying efficiency models, LS and BC, generating results consistent with a slow rate of technical change and one time-varying efficiency model, CSS, generating results consistent with a decline in capacity utilisation. As discussed above, only a few of the time-interaction dummies are significant in the CSS model, while all time-related parameters are significant in the LS model and also (except one) in the BC model. Moreover, η in Eq. (11) is also significant; see Table A1. Therefore, we regard the LS and BC models as the preferred ones.

5. SUMMARY AND CONCLUSIONS

In this study we have focused on productivity change and the temporal pattern of efficiency in Romanian cement industry during 1966-1989 on the basis of stochastic frontier estimation. The estimation is based on a small sample of unbalanced panel data on cement plants. Empirical results show that:

(i) In all models increasing returns to scale are observed all years but with

some variation in returns to scale among models. Most years the LS model yields the

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the authors upon request.

highest scale elasticity value and all years the CSS model the smallest one. This means that the average Romanian cement plant is of sub optimal size, and almost all Romanian plants seem to be below the minimum efficient size.

(ii) In contrast to the substantial variation in returns to scale across models, there is rather little variation in the very slow - and in the BC model even negative - rate of technical change between different models, with the exception of the LS model. While technical change decreases gradually in the STT model, there is no trend in the other models. As expected, the LS model yields large variation between years. The main reason for the very slow rate of technical progress is probably the lack of modernisation of plants during this period.

(iii) There is substantial covariation in the TFP change rates among all the models, including the LS model, although the level differences are quite large in some years. All models yield slightly decreasing trends in TFP growth. Because of the large scale elasticity, TFP growth is positive with annual mean values in the interval 1.1% to 1.9%.

(iv) Because of the slow rate of technical progress at the frontier, we expect an increasing trend in the mean efficiency level, because of most units catching up with a slowly moving best-practice frontier. This is also the case in our preferred models, LS and BC, where mean efficiency increases from about 0.65 in 1966 to about 0.80 in 1989.

The most important feature of the Romanian cement industry before the revolution in 1989 is a slow rate of technical progress at the frontier and a corresponding catch-up in productive efficiency. The slow rate of productivity change at the frontier and the rapidly declining capacity utilisation, which was the case in the Romanian cement industry, already from 1972 and especially from 1978 onwards, may be explained by Romania´s effort to eliminate its hard currency debt (which was entirely eliminated by mid-1989). From the beginning of the 1980s Ceausescu was determined to make Romania self-sufficient in everything, also in spare parts, which made adequate maintenance impossible; see Patterson (1994). Export receipts from the internationally oriented part of the economy (including the cement industry) were almost entirely used for the repayment of debt, while the industrial capital stock was run down; see Smith (1992) and Patterson (1994).

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Table 1: Summary statistics of the Romanian Cement plants, 1966-1989. (N=222).

Variable	Mean	Std Dev	Min	Max
Output (Y)	1160.3	653.3	16	2666
Capacity (C)	1540.3	911.9	32	3333
Labour (L)	989204	560126.8	67280	2150160
Energy (E)	1149652	639804.7	14700	2151100
Number of kilns	5.6	2.7	1	9

Table 2: Overall means of input elasticities, elasticity of scale, and productivity change across model. Standard deviations within parenthesis.

Model	Labour	Energy	Capital	Scale el	TC	TFP	Efficiency
STT	0.62 (0.52)	0.92 (0.36)	-0.15 (0.22)	1.39 (0.40)	0.005 (0.007)	0.014 (0.20)	0.42 (0.24)
LS	0.64 (0.44)	0.74 (0.59)	0.06 (0.46)	1.44 (0.32)	0.003 (0.021)	0.019 (0.181)	0.75 (0.20)
CSS	0.36 (0.33)	0.74 (0.17)	0.09 (0.10)	1.19 (0.24)	0.011 (0.022)	0.012 (0.094)	0.66 (0.22)
BC	0.61 (0.39)	0.76 (0.42)	-0.01 (0.30)	1.36 (0.29)	-0.001 (0.008)	0.011 (0.170)	0.75 (0.17)

**Table A 1: Parameters of the translog stochastic frontier models.
Standard errors within parenthesis.**

Parameter	STT	LS	CSS	BC
α_0	-52.73 (7.04)	-45.52 (5.95)	-	-38.88 (6.38)
α_L	6.69 (1.46	7.55 (1.25)	3.49 (1.47)	4.66 (1.38)
α_E	-1.16 (0.90)	-4.30 (0.77)	0.79 (0.84)	-1.40 (0.85)
α_K	2.32 (0.64)	4.04 (0.50)	0.16 (0.67)	2.69 (0.52)
α_{LL}	-0.035 (0.091)	-0.220 (0.084)	0.017 (0.084)	0.015 (0.091)
α_{EE}	0.204 (0.063)	0.220 (0.060)	0.153 (0.054)	0.238 (0.061)
α_{KK}	0.048 (0.028)	0.152 (0.022)	0.062 (0.024)	0.084 (0.026)
α_{LE}	-0.214 (0.136)	0.128 (0.133)	-0.251 (0.114)	-0.192 (0.134)
α_{LK}	-0.191 (0.072)	-0.276 (0.076)	-0.020 (0.073)	-0.148 (0.069)
α_{EK}	-0.069 (0.067)	-0.259 (0.049)	-0.079 (0.060)	-0.182 (0.057)
α_{KT}	0.005 (0.003)		0.004 (0.007)	0.003 (0.003)
α_{LT}	-0.023 (0.005)		0.012 (0.009)	-0.026 (0.005)
α_{ET}	0.012 (0.003)		-0.004 (0.010)	-0.013 (0.003)
α_T	0.108 (0.031)			0.134 (0.032)
α_{TT}	-0.000 (0.000)			0.0002 (0.0002)
η				0.021 (0.007)
σ^2				0.042 (0.007)

Table A1. Continous. Plant specific effects

	STT	LS	*CSS*		
Plant	μ_i	μ_i	θ_{i1}	θ_{i2}	θ_{i3}
1	-	0.22 (0.08)	-31.08 (7.87)	-0.095 (0.117)	-0.0016 (0.0007)
2	-0.39 (0.04)	-0.33 (0.08)	-31.43 (7.85)	-0.158 (0.112)	0.0023 (0.0006)
3	0.43 (0.13)	0.15 (0.09)	-30.90 (7.74)	-0.110 (0.105)	-0.0018 (0.0017)
4	-0.04 (0.03)	0.19 (0.08)	-30.85 (7.83)	-0.128 (0.112)	-0.0008 (0.0008)
5	0.86 (0.37)	0.56 (0.17)	-30.88 (7.56)	-0.133 (0.088)	0.0011 (0.0003)
6	-0.16 (0.06)	0.17 (0.09)	-32.22 (7.88)	0.025 0.131)	-0.0040 (0.0016)
7	-0.53 (0.03)	-0.51 (0.07)	-31.52 (7.86)	-0.124 (0.114)	-0.0000 (0.0004)
8	-0.27 (0.05)	0.04 (0.08)	-30.41 (7.96)	-0.181 (0.127)	0.0013 (0.0015)
9	-0.56 (0.03)	-0.58 (0.08)	-31.46 (7.86)	-0.144 (0.114)	0.0005 (0.0005)
10	-0.05 (0.04)	0.10 (0.06)	-30.84 (7.87	-0.134 (0.114)	-0.0009 (0.0005)
11	-0.55 (0.03)	-0.52 (0.08)	-31.36 (7.85)	-0.132 (0.122)	-0.0006 (0.0004)

Time dummies

	LS			LS	
Time index	λ_t	Std err	Time index	λ_t	Std err
2	0.966	0.112	14	0.857	0.107
3	0.952	0.111	15	0.728	0.103
4	1.013	0.115	16	0.834	0.107
5	0.931	0.110	17	0.710	0.101
6	0.920	0.109	18	0.644	0.099
7	0.820	0.105	19	0.363	0.097
8	0.886	0.107	20	0.698	0.103
9	0.900	0.107	21	0.564	0.097
10	0.922	0.108	22	0.598	0.099
11	0.944	0.110	23	0.635	0.101
12	0.873	0.106	24	0.656	0.102
13	0.839	0.105			

Figure 1. The development of mean elasticity of scale.

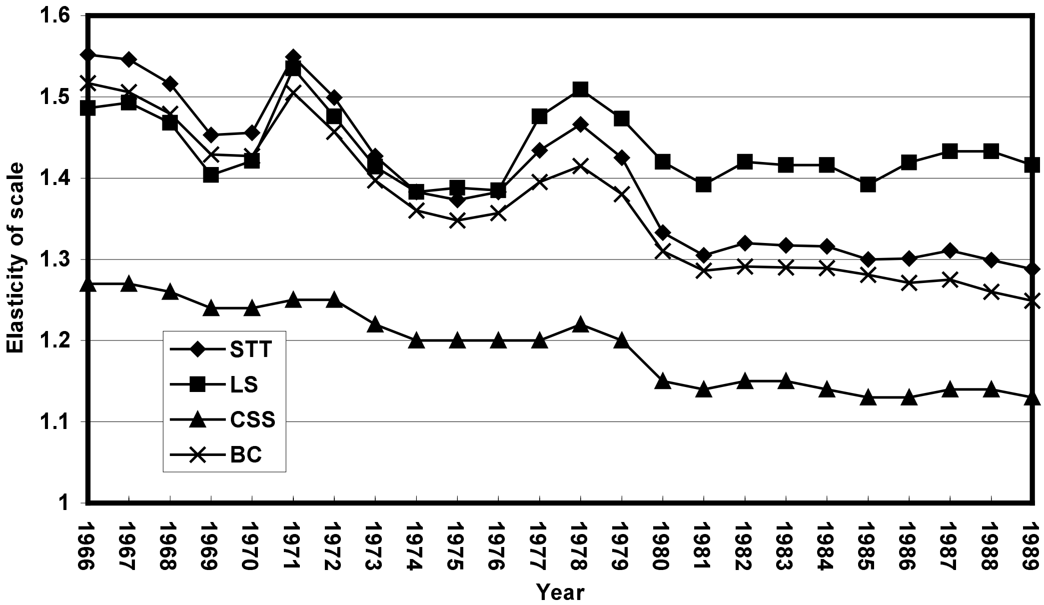

Figure 2. Rate of productivity change. Annual means.

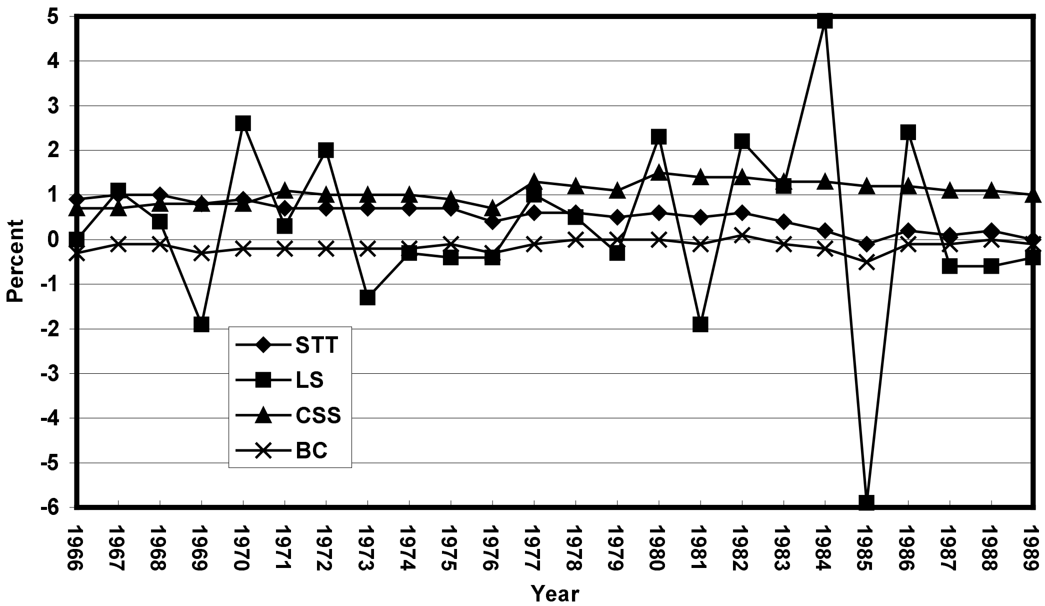

Figure 3. Total factor productivity change. Annual means.

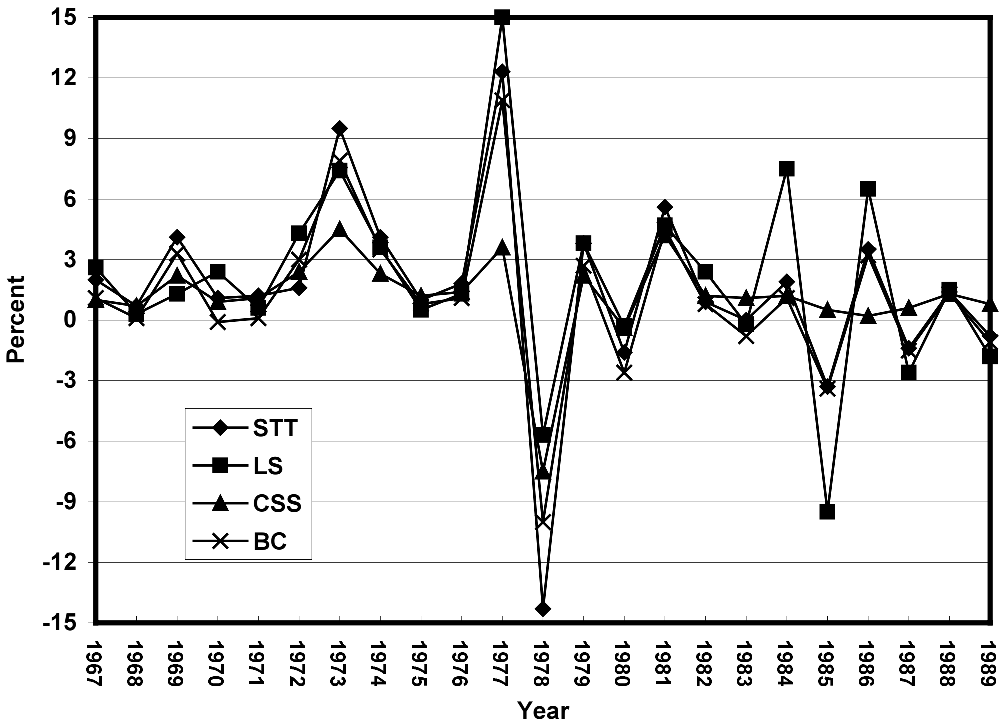

Figure 4. Annual means of productive efficiency and capacity utilisation.