Cost Inefficiency in the English and Welsh Water Industry: An Heteroskedastic Stochastic Cost Frontier Approach.

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Abstract

In this study we analyze the evolution of operating cost inefficiency for the English and Welsh water industry over the period 1995-2001 by estimating an heteroskedastic stochastic variable cost frontier. The main aim of this paper is to provide an overall picture of the industry cost inefficiency, as we consider both the water and sewerage companies and the smaller water only companies. The main results of this paper are that industry operating cost inefficiency has decreased over the sample period and that inefficiency differentials among firms have steadily narrowed. This pattern of inefficiency might have been generated by the incentives provided by comparative and capital market competition which became fully operative after the 1994 price review.

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1 Introduction

The English and Welsh water industry was privatized in 1989 and a new permanent regulatory framework was established. The main task of the new economic regulator (Office of Water Services) was to protect customer interests, to promote efficiency and to guarantee that water companies' functions were adequately financed. The regulatory regime set after privatization based on a price cap methodology evolved over time. In 1995 the price cap formula was modified in order to introduce yardstick competition in the industry: the new regulatory scheme was expected to raise incentives and to reduce costs through an indirect competition effect. Moreover, at the end of 1994 institutional limits to capital market competition were abolished: mergers and take-overs were in general allowed for all water utilities, provided they did not prejudice the regulator's ability to apply comparative competition.

Most academic studies on the English and Welsh water industry focus on the analysis of the industry cost structure in order to evaluate the existence of scale and scope economies. While some authors provide information on total factor productivity measures, none analyses the evolution of industry cost efficiency over time.

The main aim of this paper is to give an overall picture of industry operating cost inefficiency over the period 1995-2001. In order to achieve this goal we consider both the ten water and sewerage companies and the smaller water only companies; in particular we focus only on the water supply service. Average cost inefficiency is estimated by means of a stochastic cost frontier approach modified in order to account for possible heteroskedasticity problems arising from large size differentials which characterize water utilities in England and Wales; furthermore, we allow the inefficiency component of the variable cost function to depend on exogenous variables which are expected to influence cost efficiency.

Empirical results suggest that water utilities have reduced cost inefficiency over the sample period and that efficiency gaps among firms has steadily narrowed. We argue that these findings might have been generated by the incentives provided by comparative and capital market competition which became fully operative after the 1994 price review.

The remainder of the paper is organized as follows. Section 2 describes the reorganization process and the evolution of the regulatory framework which took place in the water industry in England and Wales after privatization. In Section 3 the dataset employed in the empirical analysis is described and summary statistics are discussed. Section 4 analyzes the modeling strategy and section 5 comments the empirical findings. Finally, section 6 concludes the paper.

2 Regulation of the water and sewerage industry in England and Wales: relevant issues

Before 1973 the water and sewerage industry in England and Wales had a highly fragmented structure, mainly organized on local basis. The 1973 Water Act reorganized the industry and established ten state-owned regional water and sewerage authorities (RWAs) responsible for water supply, sewerage and environmental services. Moreover, 29 privately owned water only companies (WOCs) supplied water within the boundaries of the RWAs.

During the 80's the quality of the service deteriorated and, in general, the whole industry suffered from heavy underinvestment (Hunt and Lynk (1995)) because of harder budget constraints imposed by conservative governments.

In 1989 the RWAs were privatized and became publicly quoted water and sewerage companies (WASCs)[1]; at the same time the existing constraints on the WOCs' financing and dividend policy were removed, transforming them

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[1] Environmental regulation and river maintenance activity were transferred to a government agency.

into normal public limited liability companies. Privatization was expected to improve the overall efficiency, to raise funds on the capital markets and to stimulate enhancing quality investments[2]. Moreover, the 1986 Littlechild's White Paper on the water industry privatization suggested the possibility to facilitate three possible forms of competition in the industry: comparative or yardstick competition, capital market competition and, to a lesser extent, product market competition. Nonetheless, given that the water and sewerage industry has the characteristics of a "natural monopoly par excellence" (Littlechild (1986)), privatization necessarily entailed the establishment of a permanent regulatory framework.

The natural monopoly status of the water and sewerage industry comes mainly from the establishment of the network of pipes and sewers whose costs are huge and constitute a large fraction of total costs, so that it is often not economical to duplicate the network in order to allow some product market competition between companies. Moreover, the value of the service (i.e. water or sewerage) is extremely low compared to the costs of the infrastructure and it is rather expensive transferring water over long distances: thus, the usual ways of introducing competition into network utilities (Newbery (1999)), like the creation of a national grid and the liberalization of entry, or the introduction of forms of common carriage[3], are usually not believed to be either feasible or particularly efficiency enhancing (Armstrong et al. (1994) and Cowan (1997))[4].

Since 1989 the English and Welsh water and sewerage industry has been regulated by the Office of Water Services (Ofwat). Alongside with the basic tasks of promoting efficiency, protecting customers and guaranteeing an adequate supply of water and sewerage services on a non-discriminatory basis, the main duty of Ofwat was to "secure that companies are able to finance the proper carrying out of their functions (in particular by securing reasonable returns on their capital)" (1989 Water Act); furthermore it should have promoted competition.

The chosen regulatory regime is based on an hybrid version of the well-known $RPI - X$ price cap formula (revised every five years), i.e. $RPI+K$, where RPI is the retail price index, and K is composed by an efficiency factor X, representing the amount by which each company has to reduce tariffs in real terms, and a component Q, which reflects the expenditure necessary to meet the higher quality levels set by the EC directive on water quality.

This formula contains elements typical of a rate of return regulation scheme,

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[2] Economic rationales in favor of privatization are well known (see e.g. Vickers and Yarrow (1988)). Actually, some authors suggest that competition may play a more important role in stimulating efficiency than ownhership per se. See, among others, Sappington and Stiglitz (1987), De Fraja (1993) and Newbery (1999).

[3] In a common carriage system an incumbent company shares its network with a third party to allow it to compete within the incumbent's area in the provision of water and/or sewerage services.

[4] Other possible forms of product market competition envisaged by the 1989 Water Act are Inset appointments and cross border supply. The first consists in the possibility granted to a water company to supply large users within another company area. Cross border competition allows customers living close to the border of two nearby companies to switch supplier bearing connection costs. Both forms of product market competition have had only very limited applications (OFWAT (2000a) and Sawkins (2001)).

which allows better incentives for the companies to undertake the needed investment programs[5]. Moreover, by allowing the determination of X to depend on the relative efficiency of each firm with respect to the most efficient one, this regulation formula enables the introduction of yardstick competition[6]. Although some forms of comparative competition had been called for by the 1989 Water Act, the lack of a comprehensive information infrastructure has delayed its implementation till the first 1994 price review.

The theoretical underpinnings of yardstick competition can be traced back to the works of Holmstrom (1982), Lazear and Rosen (1981) and Nalebuff and Stiglitz (1983); Shleifer in his 1985 seminal paper was the first to examine a model of yardstick competition in a regulatory framework.

Yardstick competition is a regulatory regime which allows to reduce asymmetric information between regulator and firms about the exact extension of the feasible cost reductions: in this way it combines the power of the incentive scheme to reduce costs of a pure price cap regulation method[7], with the ability to induce allocative efficiency typical of a rate of return regulation scheme[8] (Armstrong et al. (1994) and Beesley and Littlechild (1989)).

The basic idea underlying yardstick competition is to link the price every firm is allowed to charge to some function of the costs of other firms in the industry. Through an indirect competition effect firms have large incentives to improve cost efficiency, since they are residual claimant of the difference between their costs and the industry yardstick. Moreover the incentives to cut costs do not vanish before the regulatory review, because the price every firm is allowed to charge at the beginning of the regulatory period is not based on firm's own costs. Finally, since all firms share the same incentives, it is reasonable to expect that, at least in the medium run, all of them will try to improve their cost efficiency: by the implementation of yardstick competition average industry costs should decline over time and each firm's costs should converge to the industry minimum.

The proper working of yardstick competition depends on different issues: the ability of the regulator to control for different firms' operating conditions while evaluating cost differences among firms[9], the assumption that firms do

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[5] For a theoretical discussion see, among others, Laffont and Tirole (1993) and Armstrong et al. (1994).

[6] In order to prevent firms from reducing costs (thus improving their efficiency) through quality reductions, OFWAT allows firms which perform better in terms of a set of quality indicators (such as speed of repairs, number of breaks, ecc.) to have more generous caps.

[7] A pure price cap is a high-powered incentive scheme because the firm is residual claimant of any cost saving in excess of X; on the other hand, the asymmetric information about the maximum feasible cost reduction allows the firm to enjoy a rent, thus determining a divergence between prices and costs (poor allocative efficiency). Moreover the incentives to cut costs vanish before the end of the regulatory period because cost savings will be passed on to consumers (ratchet effect) at the following regulatory review.

[8] Under rate of return regulation prices are set by the regulator in order to let the firm cover all its costs: in particular the firm is allowed to earn a reasonable rate of return on the capital employed. Since prices are (at least in principle) re-set every time costs change, the earnings of the company are made largely independent on its cost performance, thus giving the firm poor incentives to cut costs. On the other hand, since prices closely track costs, this regime induces allocative efficiency.

[9] Firms' efficiency analysis is also sensible to the empirical methodology employed. On this

not collude[10] and the existence of a sufficient number of firms which allows the regulator to make valid comparisons. The last issue may interfere with the working of capital market competition if the number of firms in the industry is relatively low, like in the English and Welsh water industry: in this case the regulator may not allow some mergers or take-overs if they prejudice her ability to compare firms' efficiency.

As mentioned above, since the 1986 Littlechild's White Paper on water industry privatization, capital market competition was believed to be a way of introducing competitive pressure on regulated firms by means of the take-over threat. The 1989 Water Act accepted this idea and set up some principles for mergers and take-overs activities: basically they should not preclude Ofwat's ability to make comparisons among firms (Sawkins (2001))[11].

The first wave of take-over and merger activity in the English and Welsh water industry was carried out after privatization and, subsequently, after the 1994 expiry of the golden share on the WASCs. In 1995 Ofwat made it clear its unwillingness to accept further reductions in the number of independent comparators. Nowadays the number of water companies has fallen to 22 (10 WASCs and 12 WOCs) and it seems that capital market competition will be operating mainly through operations which do not involve "water-water" mergers within the industry[12] (Sawkins (2001) and Competition Commission (2002)).

Summarizing, the regulatory framework set after privatization has been subject to significant changes: the introduction of yardstick competition, the opening of capital market competition to WASCs and the tightening of price caps set in 1994 and 1999[13].

As far as previous empirical literature on the English and Welsh water industry is concerned, we do not report a detailed survey[14], but we just mention those few papers reporting empirical evidence on firms' inefficiency and total factor productivity after industry privatization.

Ashton (2000a) estimates an average value of inefficiency for the ten privatized WASCs over the period 1987-1997. Using a translog operating cost function estimated with a random effects (GLS) procedure, he finds moderate levels of both inefficiency and inefficiency dispersion within the industry. In a companion paper (Ashton (2000b)) he estimates a translog cost function employing a SURE procedure over the same sample period and finds a decline in total factor productivity (TFP). In particular, he found that TFP growth

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point see, among others, Bauer et al. (1998) and, for the English and Welsh water industry, Cubbin and Tzanidakis (1998).

[10] Of course, this possibility is less likely as the number of regulated firms increases. This appears to be the case of the English and Welsh water industry. See among others Tangeras (2002) and Auriol (2000).

[11] The 1989 Water Act introduced also golden shares for the ten WASCs which were going to expire in 1994.

[12] For details on firms demography of the sample used in this empirical work see section 3.

[13] There is a wide consensus on the idea that the initial caps set at privatization were too lax (see, among others, Saal and Parker (2001a)). In particular, it was only with the 1999 price review that OFWAT imposed a real tariffs reduction (which implies a negative K over the regulatory period 1999-2004).

[14] See Saal and Parker (2001b) and Ashton (2003).

declined from –0.029 % in the period 1989-91 to –0.063% in the period 1995-97. Saal and Parker (2001b) consider the ten WASCs observed over the period 1985-1999 and estimate a two output translog total cost function in order to assess the impact of both privatization and the 1994-5 regulatory tightening on the growth rate of total costs. Using a non-linear SURE methodology, they do not find any privatization effect on costs but they do find a significant reduction in the growth rate of total costs after the 1994-95 regulatory review. In another paper, Saal and Parker (2001a) adopt an index numbers approach and find, for the same sample, that privatization led to a significant increase in labour productivity and that most of this increment took place after the 1994-95 regulatory review. On the other hand, data do not show significant improvements of TFP growth after privatization and a TFP reduction after the 1994-95 price review[15].

There is also a body of literature consisting on studies sponsored and published by Ofwat which usually reports comparative statistics on several aspects of water companies performance (like unit costs, disconnections, leakage and relative efficiency). The last 2001-02 report on unit costs and relative efficiency observes, among other things, a reduction in unit operating costs and a decline of firms' cost inefficiency between 1992-93 and 2001-02[16].

3 Data

The dataset used in this study consists of an unbalanced panel of 177 firm observations on both Water and Sewerage companies and Water Only companies observed over the period 1995-2001. The main source of data comes from the "June Returns for the Water and Sewerage industries in England and Wales" published by Ofwat[17] and updated at April of each year[18]. In the empirical application we focus only on the water service and we do not consider the sewerage one.

The demography of firms included in the panel is driven by the process of mergers and acquisitions occurred within the sample period. When mergers took place between firms of similar size we have considered the merged entity as a new firm entering the panel[19]; on the other side, if mergers involved companies with considerable size differential we let the bigger survive[20]. For 1995 the panel

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[15] They also find a decline in the economic profitability of WASCs after the 1994-95 regulatory review which they explain with the tighter price caps put into place by OFWAT.

[16] Those results were obtained using a sort of corrected ordinary least squares method. For further details see OFWAT (2002).

[17] Other sources of data employed in this study are the WASCs and WOCs accounts and publications on the water industry published by the Centre for the Study of Regulated Industries.

[18] Each year of observation starts at 1st April and ends the following 31st March.

[19] This is the case of the following mergers: Chester Waterwoks with Wrexham Water; Midsouthern Water and South East Water; Northumbrian Water with Essex and Suffolk Water.

[20] This occurred for the following acquisitions: Hartlepool Water by Anglian Water, York Waterworks by Yorkshire Water and North Surrey Water by Threvalleys. In these cases the

includes 28 firms (10 WASCs and 18 WOCs) which reduce to 21 (10 WASCs and 11 WOCs) in the last year of observation[21]. The unbalancedness of the panel is described in Table 1.

In Table 2 we provide some descriptive statistics on the variables used in the empirical application. When needed, the data have been deflated with the RPI index. Operating expenditure (*opex*) is defined as operating costs less current cost depreciation and infrastructure renewal charge; unit labour cost (w) is obtained as the ratio between total labour costs and the number of full-time equivalent employees; y represents output and is proxied by the amount of water delivered; *len* is the length of mains; *aph* stands for average pumping head; *riv* represents the proportion of river sources on total sources; *nh* is the share of water delivered to non-households customers on total water delivered; *den* is the population density; *wat* is our proxy for firm's size and is defined as distribution input, i.e. the amount of water introduced into the distribution mains (it differs from our measure of output for the existence of leakage); k is the stock of capital proxied by the modern equivalent asset estimation of the replacement costs of net tangible assets as provided by the "June Returns". Saal and Parker (2001b) argue that a water industry specific Capital Cost Index (CCI) could be more appropriate than RPI (as done by Ofwat) for adjusting current costs replacement values; unfortunately values of the CCI for the last years of our panel are not available.

The summary statistics show some trends that have occurred in the industry. The average amount of both water delivered and introduced in the network has steadily increased over the sample period, thus reflecting an increase in water demand; moreover, the large values of standard deviations associated to y and *wat* suggest the presence of wide size differentials. These differentials may induce heteroskedasticity problems as the sources of noise, as well as inefficiency, might vary with size: in our empirical application we tackle theses issues by parametrizing both variance components of noise and inefficiency as a function of firm size (see below). We can further note that, over the sample period, the average value of net tangible assets has increased, thus denoting a moderate investment activity in the industry. Finally Table 2 shows large variations in the hedonic variables at firms' levels, which reflect the presence of different operating conditions.

In the following section we discuss the empirical Model used for describing firms' cost structure and modeling possible inefficiency.

4 Model specification and estimation procedures

In order to analyze the evolution of inefficiency in the English and Welsh water industry we adopt a stochastic cost frontier (SCF) approach. This approach

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size of acquiring firms was about 80 times larger than that of acquired firms.

[21] Welsh Water has been discarded in 2001 since it was transformed into a mutual company and water and sewerage services were completely out-sourced to another WASC. This creates problems for recovering data on labour costs.

allows to distinguish between cost reductions induced by technical change from those deriving from efficiency improvements. Originally proposed by Aigner, Lovell and Schmidt (1977) and Meeusen and Van den Broeck (1977), this methodology assumes that deviations from the best practice frontier might be due to both inefficiency and other random factors[22]. During the last decade some authors have suggested different methods for testing whether some portions of inefficiency departure from the frontier can be systematically explained. This issue was initially tackled with a two-step approach, by which inefficiency and exogenous effects were identified sequentially[23]. Kumbhakar et al. (1991), Huang and Liu (1994) and Battese and Coelli (1995) proposed a one-step approach by which potential inefficiency determinants are estimated simultaneously with the other parameters of the model through the parametrization of the mean of the pre-truncated distribution as a function of exogenous variables. Reifschneider and Stevenson (1991), Caudill and Ford (1993), Caudill et al. (1995), and Hadri (1999) suggest another one-step approach based on the parametrization of the variance of the pre-truncated distribution: this modeling strategy allows also to control for heteroskedasticity problems. Finally Wang (2002) combines the above approaches.

In this paper we adopt a cost function approach since we assume that firms are price takers on inputs markets and that output is exogenously determined. This appears to be the case of a regulated industry where firms are relatively small players on inputs markets and are required to satisfy market demand at prices set by the regulator. In particular, we consider a variable cost function as we assume capital stock as a quasi-fixed input, since its modification in the short run may be either not feasible or too expensive. Other studies on the English and Welsh water industry adopt a total cost approach: in particular, Saal and Parker (2001b) justify this choice by observing that the industry has been subject to intense investment programs over their sample period (1985-1999).

Nevertheless, by observing that most infrastructures needed in the water industry are built in order to meet higher levels of demand expected in the long run (20-30 years), it may be assumed that water utilities (though investing) are not in long run equilibrium with respect to capital, especially when the time span covered by the panel is short, as in our case.

Regarding the functional form, we consider a translogarithmic variable cost function to model the technology of the English and Welsh water industry:

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[22] For an introduction to efficiency and productivity analysis see, among others, Coelli et al. (1998). See Kumbhakar and Lovell (2000) for an exhaustive analysis on stochastic frontiers.

[23] For the drawbacks of this procedure see Kumbhakar and Lovell (2000).

$$\begin{aligned}
opex_{it} &= \beta_t + \beta_{sew} dsew_{it} + \sum_j \beta_j p_{jit} + \beta_y y_{it} + \beta_k k_{it} + \qquad (1)\\
&+ \sum_m \beta_m z_{mit} + 1/2 \sum_j \sum_s \beta_{js} p_{jit} p_{sit} + 1/2 \beta_{yy} (y_{it})^2 \\
&+ 1/2 \beta_{kk} (k_{it})^2 + 1/2 \sum_m \sum_r \beta_{mr} z_{mit} z_{rit} + \sum_j \beta_{jy} p_{jit} y_{it} + \\
&+ \sum_j \beta_{jk} p_{jit} k_{it} + \sum_j \sum_m \beta_{jm} p_{jit} z_{mit} + + \sum_m \beta_{my} z_{mit} y_{it} + \\
&+ \sum_m \beta_{mk} z_{mit} k_{it} + \beta_{ky} k_{it} y_{it} + (v_{it} + u_{it}) \\
j, s &= w, o \text{ and } m, r = len, aph, riv
\end{aligned}$$

where $opex_{it}$ denotes (the logarithm of) operating expenditure for firm i at time t. The vector of variable factor prices, P, is defined as $[P_w;\ P_o]$, where the subscript w and o stands for labour and other variables inputs. The price of other variable inputs is proxied by the RPI inedx. y denotes the volume of water distributed and k is the capital stock. The vector Z represents technical variables and is defined as $[Z_{len}, Z_{aph}, Z_{riv}]$. The dummy variable $dsew$ takes value one when firm i provides sewerage services alongside water supply.

The translog is a flexible functional form which approximates any twice-differentiable function without imposing any a priori restrictions on the production technology (Chambers (1988)).

We modified a standard variable cost function by including a set of technical variables $[Z]$ and a "sewerage dummy". These variables have been included because they may influence the technology under which water utilities operate and may account for exogenous differences in operating environment experienced by each firm (Bhattacharyya et al. (1995), Garcia and Thomas (2001), Stewart (1993) among the others). In particular, the sewerage dummy should pick up technology differences existing between the ten WASCs and the WOCs; a higher average pumping head implies the extensive use of pumping especially from groundwater sources, while a higher proportion of river sources is likely to induce, with respect to other sources, the necessity of more advanced chemical treatments to purify water. The inclusion of a network variable like *len* allows to distinguish between economies of output density and economies of scale (see below). Moreover, time dummies are included in the model to account for, among other things, cyclical factors and technological progress.

To correspond to a well behave production structure, the translog cost function must satisfy a set of regularity conditions: it must be non-decreasing in factor prices and output, linearly homogeneous in factor prices, concave and symmetric.

Homogeneity can be imposed by normalizing the dependent variable and factor prices with the price of one of the inputs: we normalized for the price of other variable inputs[24], thus reducing the components of the P vector to one. Symmetry of the cost function is imposed by assuming that $\beta_{js} = \beta_{sj}$ and $\beta_{mr} = \beta_{rm}$ before estimation. Concavity of the cost function is verified if the Hessian is a negative semi-definite matrix, while monotonicity in factor prices requires that costs rise as factor prices increase; finally monotonicity in output requires positive marginal costs.

As we said above, the inclusion in the cost function of the network length allows for the distinction of economies of output density and economies of scale. Short run economies of output density (EOD$_{SR}$) are defined as the proportional increase in variable costs brought about by a proportional increase in output, keeping all other variables fixed (capital, network length, input prices and technical variables):

$$EOD_{SR} = \frac{1}{\partial \ln VC / \partial \ln y} \tag{2}$$

In the long run the capital stock can be adjusted and long run economies of output density (EOD$_{LR}$) can be computed as:

$$EOD_{LR} = \frac{1 - \partial \ln VC / \partial \ln k}{\partial \ln VC / \partial \ln y} \tag{3}$$

Values of EOD greater (lower) than 1 imply increasing (decreasing) economies of output density.

Short run economies of scale (SE$_{SR}$) are defined as the proportional increase in variable costs brought about by a proportional increase in output and network length holding other variables fixed:

$$ES_{SR} = 1/(\frac{\partial \ln VC}{\partial \ln y} + \frac{\partial \ln VC}{\partial \ln len}) \tag{4}$$

The same measure for the long run (SE$_{LR}$) is defined as:

$$ES_{LR} = (1 - \frac{\partial \ln VC}{\partial \ln k})/(\frac{\partial \ln VC}{\partial \ln y} + \frac{\partial \ln VC}{\partial \ln len}) \tag{5}$$

Values of ES greater (lower) than 1 imply economies (diseconomies) of scale. The existence of economies of scale implies that average costs fall when both the volume of water delivered and network size increase: this measure is relevant when assessing possible cost savings deriving from the merger of two nearby utilities.

Turning to the composite error term $(v_{it} + u_{it})$, we make the following assumptions :

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[24] This normalization procedure is equivalent to impose the following restrictions: $\sum_j \beta_j = 1$; $\sum_j \beta_{js} = 0$; $\sum_j \beta_{jy} = 0$; $\sum_j \beta_{jk} = 0$; $\sum_j \beta_{jm} = 0$. See Jorgenson (1986).

$$\begin{aligned} v_{it} &\sim N(0, \sigma^2_{vit}) && (6) \\ u_{it} &\sim N^+(0, \sigma^2_{uit}) && (7) \\ \sigma^2_{vit} &= \exp(\gamma_0 + \gamma_{wat} wat_{it}) && (8) \\ \sigma^2_{uit} &= \exp(\delta_0 + \delta_t t + \delta_{aph} aph_{it} + \delta_{riv} riv_{it} + && (9) \\ & \quad + \delta_{nh} nh_{it} + \delta_{den} den_{it} + \delta_{wat} wat_{it}) \end{aligned}$$

The two sided-noise component v_{it} accounts for measurement errors and for other random factors, while u_{it} is the one-sided error component associated with cost inefficiency.

As we noted while describing data, our sample is characterized by large firms' size variation: this is likely to generate heteroskedasticity problems. Unmodeled heteroskedasticity in the symmetric noise error component leads to biased estimates of cost efficiency and unmodeled heteroskedasticity in the one-sided cost inefficiency error component leads to biased estimates of the parameters of the cost frontier and biased estimates of cost efficiency. In order to control for heteroskedasticity we have parametrized variances of both error components (σ^2_{vit} and σ^2_{uit}) as exponential functions of size as proxied by the variable *wat*. Moreover, the variance of the inefficiency term has been modeled as an exponential function of several hedonic variables: as pointed out by Kumbhakar and Lovell (2000) this can be seen as an approach to study exogenous effects on inefficiency.

Average pumping head (*aph*) and River (*riv*) are alternatively included as variables which might explain firms' relative efficiency or as technology shifters (i.e. as regressors in the frontier function)[25]. Higher values of *aph* reflect higher pumping costs which should determine higher cost inefficiency and high values of the variable *riv* are expected to raise cost inefficiency since water abstracted from rivers entails larger treatment costs. *nh* is a proxy for the importance of large (industrial) users: a higher proportion of large users is expected to reduce cost inefficiency because it is cheaper to distribute the same amount of water to a few large users than to an high number of small customers. Variable *den* represents population density which may have ambiguous effects on cost inefficiency: on the one hand, it may be more expensive to serve dispersed customers; on the other hand, a higher density might create congestion problems. Finally we included a time trend to account for time varying efficiency effects.

Cost inefficiency for firm i at time t can be defined as:

$$CI_{it} = \exp(u_{it}) \tag{10}$$

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[25] On this issue, different approaches have been followed in the literature on water industry cost structure. For example, Bhattacharyya et al. (1995a) include, among others, a dummy variable for tipology of sources in the frontier and network lenght and a proxy for the presence of industrial users in the inefficiency term. The same author, in another paper, includes the sources dummy in the inefficiency term.

which takes values greater than one unless a firm is fully efficient. In our empirical application we obtain estimates of CI_{it} based on the expected values of u_{it} conditioned on the observables but unconditional on the composite error term[26]. Given that the inefficiency component is distributed as an half normal with variance σ^2_{uit}, the unconditional expected value of u_{it} is:

$$E(u_{it}\ ) = \sigma^2_{uit}\frac{\phi(0)}{\Phi(0)} \tag{11}$$

where $\phi(0)$ and $\Phi(0)$ are the density and the cumulative density functions of the standard normal variable, both evaluated at the mean value of the pretruncated distribution of the inefficiency component of the error term.

In order to check the robustness of our results, our empirical strategy is to estimate three different models, where the hedonic variables *aph* and *riv* alternatively enter as additional variables in the cost frontier or as variables explaining inefficiency.

We label Model 1 a specification of equation (1) where the vector $Z = [Z_{len}]$ and the inefficiency term is parametrized as in equation (6). In Model 2 vector $Z = [Z_{len}, Z_{aph}]$ and the variable *aph* is dropped from the inefficiency term. Finally, for Model 3, vector $Z = [Z_{len}, Z_{aph}, Z_{riv}]$ and both *aph* and *riv* are not included in the inefficiency component.

All Models are estimated by Maximum Likelihood Method in order to simultaneously obtain estimates of the coefficients of the stochastic cost frontier and of variables included in equation (8) and (9). Estimates are performed using the Stata 8 software.

5 Empirical results

In this section we discuss econometric estimates of the three empirical Models outlined above. Table 3 reports ML estimates for the parameters of the heterosckedstic stochastic cost frontier. Since all right-hand side variables of equation (1) have been normalized by their sample medians, first order coefficients can be directly interpreted as cost elasticities computed at median values.

In all Models output and wage elasticities are positive, as expected for a well-behaved cost function. Estimates of the cost elasticity with respect to capital are positive but not significant. This suggests that water utilities are characterized by over-capitalization at the sample median and thus are not located on their optimal long run equilibrium path (Caves et al. (1981), Cowing and Holtmann (1983)): in this case a total cost function would have been misspecified. Similar results have been found by Ashton (2003) for 20 WOCs observed between 1991-

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[26] Being u_{it} unobservable, its best predictor is the conditional expectation of u_{it} given the observable value of $(v_{it}+u_{it})$ as suggested by Jondrow et al. (1982). As noted by Wang (2002), calculations of (cost) inefficiency conditional on the composite error term are intractable in a model where heteroskedasticity is allowed in both components of the error term.

96[27]. Possible explanations for this finding rest on the following arguments: as we noted in the previous section, in the water industry most infrastructures are built in order to meet higher levels of demand expected in the long run, so that firms may operate well below full capacity; moreover, the regulatory regime introduced after privatization, which is characterized by some elements of rate of return regulation, might have induced over-capitalization through the Averch-Johnson effect (Saal and Parker (2001b)).

Cost elasticities with respect to *aph* and *riv* (included in the cost frontier for Models 2 and 3) show that those variables significantly raise variable costs: this result confirms the usual practice of including technical variables in the cost function alongside output and input prices.

Time varying intercepts are not significant, except for the 2000 and 2001 dummies which are negative and significant, thus showing a downwards shift of the cost frontier[28]. This shift might have been induced by different exogenous factors like technical change, cyclical factors and the incentives provided by the tighter price caps set with the 1999 regulatory review. Finally, the negative and significant coefficient on the intercept dummy *dsew* reflects cost advantages for the ten WASCs which may result from the joint production of both water and sewerage services[29].

As we noted in the previous section, the inclusion in the variable cost function of network length allows for the distinction of economies of output density and economies of scale; moreover, since we control for the capital stock, we can compute those two measures both for the short and the long run (see equations (2-5)). Table 4 gives an immediate picture of estimated economies of output density and scale economies evaluated at different sample points. For all estimated Models short run output densities are found to be significantly increasing: this implies that average costs fall when the volume of water delivered in a service territory of given size increases. Furthermore, in the short run, observed firms exhibit increasing scale economies at low scale levels, with values ranging from 1.45 to 1.73 across Models, while returns turn to be constant as firms' size grows. These findings seem to suggest that only mergers between small utilities may allow cost savings in the short run[30].

Most estimated economies of output densities in the long run are greater than one (though in some cases not significantly) and, on average, decrease with size; estimates of long run scale economies suggest that water utilities in our sample are characterized by average variable costs which are approximately U-shaped with respect to size. However, any possible policy implications of these findings should be inferred with extreme caution, as our Models do not meet the conditions which guarantee that long run elasticity measures, computed

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[27] See also Bhattacharyya et al. (1994), Bhattacharyya et al. (1995a), Bhattacharyya et al. (1995b) and Garcia and Thomas (2001).

[28] We do not report estimates results for time varying intercepts for reasons of space.

[29] For the English and Welsh water and sewerage industry empirical evidence on the existence of scope economies between water and sewerage services is mixed. See Hunt and Lynk (1995) and Saal and Parker (2001b).

[30] Similar results are found, among others, by Garcia and Thomas (2001) for a panel of French water utilities.

as in equations (3) and (5), match those derived from a total cost function[31]. As pointed out by Braeutigam and Daughety (1983), this happens to be the case only if the technology is homothetic or if fixed factors are at their cost minimizing levels[32].

In order to check if the translogarithmic functional form described in equation (1) gives an adequate representation of the cost structure of our sample of firms, we run generalized likelihood ratio tests on the restrictions implied by homotheticity ($\beta_{wy} = \beta_{wlen} = \beta_{wk} = 0$) and by a Cobb-Douglas specification ($\beta_{js} = \beta_{yy} = \beta_{kk} = \beta_{mr} = \beta_{jy} = \beta_{jk} = \beta_{jm} = \beta_{my} = \beta_{mk} = \beta_{ky} = 0$). LR tests results reported in Table 5 allows to reject both restrictions in all estimated Models. Moreover, an LR test is also performed to test the null hypothesis that all years effects are jointly equal to zero: estimations of restricted Models failed to converge for Models 1 and 2, while for Model 3 the hypothesis of no year effects is strongly rejected. Nevertheless, as we noted by discussing parameters punctual estimates, there seem to be significant year effects for the last two years of the sample period.

The lower part of Table 5 reports LR tests for restrictions imposed on the structure adopted for each component of the error term (equations (8) and (9)). The hypothesis of homosckedasticity in the two-sided noise component v_{it} ($\gamma_{wat} = 0$) is rejected for both Models 1 and 2 and this result is confirmed by the significance of the coefficients of the parameter γ_{wat}, observable in Table 3. This findings support our parametrization of the variance of the noise component as the sources of noise seem to vary with firms' size. For Model 3 results are not definitive, since γ_{wat} is not statistically different from zero, and the LR test could not be computed as the homosckedastic restricted Model failed to converge.

Turning to the one-side error component u_{it}, the LR tests suggest that the inefficiency component is heteroskedastic, as the hypothesis that all parameters (excluding constant) in equation (9) are jointly zero can be rejected for Model 1 and 2. Moreover, this result implies that deviations from the best practice frontier are not entirely due to noise so that stochastic inefficiency exists and is a function of the variables included in equation (9).

In the lower part of Table 3 we report estimated coefficients associated with variables included in the inefficiency model. The size variable (*wat*) is significant only for Model 3 and its negative sign implies that inefficiency decreases with size. "Efficiency drivers" related to the composition of the customers base are represented by *nh* and *den*. Population density has a positive impact on cost efficiency in all Models, since its coefficient is negatively signed: higher levels

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[31] For a correct computation of long run elasticities see Schankerman and Nadiri (1986) and Salvanes and Tjotta (1994).

[32] Table 5 reports results of LR tests on the hypothesis of homotheticity.

of population density are thus associated with higher levels of cost efficiency[33]. On the other hand, the proxy for the importance of large (industrial) users (*nh*) is significant only for Model 1 and has a negative sign, as expected.

Variables *aph* and *riv* account for exogenous factors connected with geographical characteristics of the service area. Higher levels of average pumping head raise cost inefficiency when included as an explanatory variable for inefficiency (Model 1) and a higher proportion of river sources is found to increase cost inefficiency (Model 1 and 2).

In order to analyze the time pattern of inefficiency we have included a trend variable in the inefficiency component. Estimate results show the existence of a decreasing path of inefficiency over the sample period, as the coefficient related to *trend* is significantly negative in all Models. This inefficiency pattern is clearly identified by the analysis of average inefficiency scores computed according to equation (10)[34].

Giving a picture of the evolution of efficiency for the whole English and Welsh water industry after the first 1994 price review is indeed the major contribution of this study. In fact, previous literature focused either on the ten water and sewerage companies or on the water only companies; moreover, there is not any previous evidence on the behavior of average industry inefficiency over time and on inefficiency dispersion across firms. In fact, a few studies (Ashton (2000b) and Saal and Parker (2001a and 2001b)) provide evidence on total factor productivity change, but they do not distinguish the contribution of efficiency change and of technical change. Finally, this is the first paper which employs an heteroskedastic stochastic frontier methodology to estimate cost inefficiency for the English and Welsh water industry.

Table 6 reports estimated average cost inefficiency for each year: aggregate results show a monotonic decline of inefficiency over the sample period in all Models; in particular, inefficiency scores range from 1.15 to 1.095, from 1.094 to 1.046 and from 1.16 to 1.077 for Model 1, 2 and 3 respectively, which imply a cost inefficiency reduction of about 5% between 1995 and 2001. In order to check the statistical significance of this result we run a non parametric Kruskal-Wallis test which rejected the null hypothesis that median scores for each year are jointly equal.

Moreover, the analysis of standard deviations reported in Table 6 gives interesting insights on the evolution of inefficiency dispersion across firms: they decrease over time and, on average, range from 0.08 in 1995 to 0.03 in 2001. This finding suggests that inefficiency differentials among water utilities have reduced over the sample period in all Models and this is confirmed by observing the pattern of mean relative cost inefficiency showed in Table 7. In order to ob-

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[33] Similar results have been obtained by Fabbri and Fraquelli (2000) for a sample of Italian water utilities and by Evrard et al. (1994) for a sample of Belgian water utilities. Ashton (2003) includes a density variable in the cost function but it resulted to be not significant.

[34] The amount by which the inefficiency score exceeds one reflects the extent of possible cost savings.

tain this relative measure, we have divided each firm's inefficiency level by the minimum score observed in each year, thus obtaining an inefficiency measure which shows the distance between each firm and the less inefficient one. The steady decline of mean relative cost inefficiency over time suggests the existence of catch-up effects among firms: water utilities characterized by higher levels of inefficiency in 1995 have obtained larger efficiency gains with respect to other firms. A Kruskal-Wallis test confirms this findings.

Overall results seem to show that not only has industry average inefficiency level reduced over the sample period, but also that inefficiency differentials among firms have shrunk. These empirical findings may be linked to changes in the competitive environment occurred within the sample period, as different factors might have caused a tightening in competitive pressure faced by water utilities.

As we noted in Section 2, with the 1994 price review, yardstick competition was introduced for the first time in the industry. This change in the regulatory framework was expected to induce efficiency gains and to generate sharper incentives for the most inefficient firms such that each firm's costs should have converged to the industry minimum. Moreover, capital market competition became fully operative after 1994 when golden shares on WASCs were removed and take-over threats were extended to the whole industry thus providing further incentives to reduce possible slacks. Finally, our sample period includes the 1994 and 1999 price reviews which set tighter price caps in order to induce additional cost savings incentives.

In general terms, a possible explanation of our empirical findings rests on the efficiency enhancing effect brought about by "regulated" competition.

Our results strenghten the evidence provided by Ofwat (2000b) which reports comparative statistics on several performance indicators over the period 1990-2000 and shows that they improved over time; moreover, variances of those measures reduced over the same period. Sawkins (2001) consider these results as empirical evidence which supports the efficacy of comparative competition.

Additional evidence on the effects of changes in the regulatory environment on firms' efficiency could be provided by directly comparing our inefficiency measures with those obtained from a control sample: unfortunately we were not able to extend our sample to previous years since data on several variables used in our empirical specification were not available; at the same time it is very difficult to find an adequate comparator sample of water utilities operating in a similar institutional setting.

6 Conclusions

The last decade has been characterized by significant changes in the regulatory environment faced by water utilities in the English and Welsh water industry. The 1994 introduction of yardstick competition and the complete opening up of the industry to capital market competition was expected to provide proper incentives for firms to cut costs and to reduce X-inefficiency. Surprisingly, empirical evidence on this issue is scant.

In this study we analyze the evolution of cost inefficiency for the English and Welsh water industry over the period 1995-2001. The most important findings of this paper can be summarized as follows: average cost inefficiency has steadely decreased over time and inefficiency differentials among regulated water companies have constantly reduced. The average level of cost inefficiency reached by the English and Welsh water utilities can be considered relatively low[35], hence, we may argue that further reductions in operating costs may have to be generated mainly by technical progress and other factors which can induce shifts in the frontier.

The major novelties of this study, with respect to previous literature on the English and Welsh water industry, rest on the sample used and on the empirical approach. In fact, we consider the whole water industry and we apply an heteroskedastic stochastic cost frontier approach which allows to control for both heteroskedasticity and for possible effects of exogenous variables on firms' inefficiency; moreover we provide empirical evidence on the evolution of average cost inefficiency over time as well as on efficiency gaps among water utilities.

This paper might be extended in different directions: it would be interesting to check the robustness of our results with respect to different distributional assumptions on the inefficiency component and to alternative approaches to evaluate cost inefficiency; moreover, after extending the sample period, it would be worth to estimate a total cost function in order to analyze total cost inefficiency and compare it with our results on operative cost efficiency.

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Tab. 1: Panel Structure

Years of obs.	No.of firms	Obs.
7	18	126
6	1	6
5	7	35
2	5	10
Total Observations		177

Tab. 2: Descriptive Statistics

Year	opex(1)	w(2)	y(3)	len(4)	k(5)
1995	38.88 (45.30)	14.94 (1.53)	487.05 (575.38)	11404.29 (12735.39)	1451.19 (1816.05)
1996	36.48 (42.39)	14.98 (1.44)	475.91 (565.98)	11458.46 (12799.98)	1469.17 (1837.21)
1997	37.82 (41.42)	14.55 (1.34)	499.57 (553.99)	12497.5 (13097.45)	1594.41 (1892.31)
1998	36.76 (40.32)	14.53 (1.76)	487.15 (538.82)	12557 (13179.97)	1592.09 (1893.11)
1999	37.76 (41.77)	15.12 (2.34)	492.42 (554.881)	12638.88 (13313.81)	1575.87 (1845.15)
2000	40.07 (39.60)	14.80 (1.98)	580.36 (596.11)	14988 (14077.39)	1857.59 (1936.67)
2001	38.09 (39.37)	15.07 (1.8)	579.66 (613.7)	14564.15 (14430.11)	1795.68 (1961.89)
Total	37.84 (40.96)	14.85 (1.75)	510.52 (561.51)	12744.47 (13156.53)	1605.47 (1851.8)

Tab. 2 (continued): Descriptive Statistics

Year	aph (6)	riv (7)	nh (8)	den (9)	wat (10)
1995	118.47 (33.9)	0.4 (0.3)	0.28 (0.06)	0.47 (0.27)	608.08 (763.08)
1996	123.03 (36.04)	0.39 (0.30)	0.29 (0.06)	0.48 (0.26)	584.46 (729.51)
1997	127.58 (39.94)	0.38 (0.30)	0.29 (0.05)	0.48 (0.27)	603.29 (699.97)
1998	123.42 (35.37)	0.37 (0.30)	0.30 (0.06)	0.48 (0.27)	579.08 (662.57)
1999	126.39 (36.25)	0.37 (0.30)	0.29 (0.06)	0.48 (0.27)	579.14 (668.14)
2000	130.28 (34.53)	0.33 (0.26)	0.29 (0.05)	0.44 (0.24)	682.05 (716.76)
2001	127.06 (34.99)	0.34 (0.25)	0.29 (0.05)	0.46 (0.25)	683.83 (755.83)
Total	124.91 (35.54)	0.37 (0.28)	0.29 (0.05)	0.47 (0.26)	613.31 (702.31)

Notes: standard deviation in brackets

1) operative expenditure (millions of GB £)

2) labour costs (thousands of GB £)

3) water delivered, Megalitres/day.

4) length of mains, KM.

5) Capital stock, millions of GB £.

6) average pumping head

7) number of river sources/total sources

8) water delivered to non households/water delivered

90) population density

10) distribution input, Megalitres/day

Tab. 3: ML estimates for the parameters of the SCF

		Model 1	Model 2	Model 3
β_0	constant	-0.09 (0.017)	-0.04 (0.02)	-0.047 (0.02)
β_{dsew}	dum sewerage	-0.237 (0.025)	-0.166 (0.026)	-0.221 (0.016)
β_w	wage	0.27 (0.083)	0.191 (0.096)	0.353 (0.052)
β_k	capital	0.003 (0.08)	0.088 (0.105)	0.096 (0.08)
β_y	output	0.747 (0.066)	0.652 (0.044)	0.665 (0.026)
β_{len}	lenght	0.308 (0.098)	0.243 (0.112)	0.209 (0.092)
β_{aph}	*aph*	-	0.236 (0.032)	0.169 (0.026)
β_{riv}	river	-	-	0.039 (0.009)
β_{ww}	(wage)(wage)	1.668 (0.551)	0.76 (0.593)	1.484 (0.57)
β_{wk}	(wage)(capital)	-0.23 (0.38)	-0.353 (0.441)	0.791 (0.326)
β_{wy}	(wage)(output)	0.227 (0.313)	0.081 (0.353)	-0.542 (0.237)
β_{wlen}	(wage)(lenght)	-0.173 (0.385)	0.012 (0.515)	-0.521 (0.336)
β_{waph}	(wage)(*aph*)	-	-0.327 (0.215)	-0.296 (0.137)
β_{wriv}	(wage)(river)	-	-	-0.055 (0.046)
β_{kk}	(capital)(capital)	-1.539 (0.462)	-0.459 (0.539)	-1.647 (0.386)
β_{ky}	(capital)(output)	0.79 (0.241)	0.344 (0.211)	-0.053 (0.163)
β_{klen}	(capital)(lenght)	0.841 (0.398)	0.075 (0.52)	1.536 (0.41)
β_{kaph}	(capital)(*aph*)	-	0.125 (0.174)	-0.059 (0.156)
β_{kriv}	(capital)(river)	-	-	0.212 (0.008)
β_{yy}	(output)(output)	0.108 (0.196)	0.147 (0.223)	1.322 (0.182)
β_{ylen}	(output)(lenght)	-0.857 (0.376)	-0.314 (0.291)	-1.196 (0.203)
β_{yaph}	(output)(*aph*)	-	-0.328 (0.117)	-0.078 (0.151)
β_{yriv}	(output)(river)	-	-	0.019 (0.019)
β_{lenlen}	(lenght)(lenght)	-0.004 (0.494)	0.221 (0.618)	-0.116 (0.515)
β_{lenaph}	(lenght)(*aph*)	-	0.091 (0.215)	-0.003 (0.211)
β_{lenriv}	(lenght)(river)	-	-	-0.195 (0.013)
β_{aphaph}	(*aph*)(*aph*)	-	0.275 (0.059)	0.249 (0.034)
β_{aphriv}	(*aph*)(river)	-	-	-0.071 (0.018)
β_{rivriv}	(river)(river)	-	-	-0.016 (0.003)
γ_0	constant	-10.654 (0.926)	-6.927 (0.493)	-25.894 (11.758)
γ_{wat}	distinput	-3.188 (0.417)	-1.519 (0.344)	-0.213 (8.652)
δ_0	constant	-3.23 (0.332)	-4.471 (0.769)	-3.34 (0.245)
δ_t	trend	-0.148 (0.076)	-0.197 (0.12)	-0.212 (0.058)
δ_{aph}	*aph*	2.101 (0.526)	-	-
δ_{nh}	*nh*	-1.49 (0.84)	0.328 (1.502)	1.063 (0.723)
δ_{wat}	distr.input	-0.069 (0.208)	0.681 (0.467)	-0.212 (0.087)
δ_{den}	density	-0.869 (0.25)	-1.802 (0.382)	-1.113 (0.214)
δ_{riv}	river	0.091 (0.06)	1.571 (0.654)	-

Tab. 4: Economies of Scale and Output Density

	Model1	Model2	Model 3
		25 percentile	
EOD$_{sr}$-1	0.878(3.27)	1.031(3.61)	0.295(4.15)
SE$_{sr}$-1	0.605(2.95)	0.454(2.53)	0.728(2.93)
EOD$_{lr}$-1	0.263(1.09)	0.512(2.06)	-0.130(-1.77)
SE$_{lr}$-1	0.79(2.59)	0.082(3.07)	0.160(3.77)
		50 percentile	
EOD$_{sr}$-1	0.338(2.84)	0.532(5.11)	0.502(8.49)
SE$_{sr}$-1	-0.053(-0.61)	0.116(0.80)	0.143(1.26)
EOD$_{lr}$-1	0.332(2.43)	0.397(2.43)	0.357(2.65)
SE$_{lr}$-1	-0.056(-5.23)	0.017(0.94)	0.032(2.46)
		75 percentile	
EOD$_{sr}$-1	0.328(4.33)	0.323(4.41)	0.415(5.13)
SE$_{sr}$-1	0.026(0.71)	0.011(0.15)	0.088(1.24)
EOD$_{lr}$-1	0.094(1.28)	0.221(2.74)	0.187(2.59)
SE$_{lr}$-1	-0.154(-13.18)	-0.066(-3.78)	-1.854(-17.07)

Tab. 5: LR tests for the parameters of the SCF

Null hypothesis	Model 1	Model 2	Model 3
Homotheticity	13.84 (3)	15.72 (4)	35.15 (5)
Cobb-Douglas	74.14 (10)	f.c.	175.17 (21)
No year effects	f.c.	f.c.	75.86 (6)
Homoskedasticity in v_{it}	27.69 (1)	49.78 (1)	f.c.
Homoskedasticity in u_{it}	32.33 (6)	36.84 (5)	f.c.

Notes: f.c. = failed to converge

Tab. 6: Mean Cost Inefficiency by Year

	Model 1	Model 2	Model 3
1995	1.150 (0.068)	1.094 (0.099)	1.160 (0.072)
1996	1.140 (0.064)	1.084 (0.089)	1.139 (0.055)
1997	1.131 (0.059)	1.077 (0.083)	1.123 (0.046)
1998	1.116 (0.053)	1.066 (0.072)	1.111 (0.041)
1999	1.111 (0.051)	1.059 (0.064)	1.098 (0.036)
2000	1.109 (0.044)	1.057 (0.063)	1.089 (0.033)
2001	1.095 (0.036)	1.046 (0.042)	1.077 (0.029)

Tab. 7: Mean Relative Cost Inefficiency by Year

	Model 1	Model 2	Model 3
1995	1.105	1.094	1.088
1996	1.098	1.084	1.076
1997	1.093	1.077	1.065
1998	1.081	1.066	1.058
1999	1.080	1.059	1.051
2000	1.069	1.057	1.048
2001	1.053	1.046	1.042