Technical inefficiency effects in a stochastic production function for managerial incentives in public water utilities

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ABSTRACT

Performance of state-owned water utilities in developing countries is often weak. This study estimates the impact of managerial incentives upon efficiency using a stochastic frontier production function with revenue water as the output. The empirical analysis utilises unbalanced panelled data consisting of revenue water, connections, operating expenditure, water delivered and staff, from Uganda's 19 National Water and Sewerage Corporation (NWSC) sub-utilities for a 9-year period, 2002–2010. The inefficiency effects are modelled as a function of utility-specific variables: service coverage, level of financial incentives, target difficulty, and year of observation. While financial incentives and increased service coverage improve efficiency, targets (such as the reduction of non-revenue water) that are perceived as excessive by employees may reduce it. The findings suggest some policy implications: utility managers in the public water sector need to incorporate monetary incentives and increase service coverage to reduce non-revenue water. However, targets need to be set with great care and with transparency.

Key words | incentives, stochastic frontier production function, Uganda, water utilities

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INTRODUCTION

Non-revenue water (NRW) is defined as the difference between the system input volume of water and billed authorised consumption (Lambert 2003). According to Kingdom *et al.* (2006), NRW is one of the major issues affecting water utilities in the developing world. High levels of NRW reflect huge volumes of water being lost through leaks, not being invoiced to customers (generally reflecting theft), or both. It seriously damages the financial viability of water utilities through lost revenues, increased operational costs, and reduced water quality. According to Asian Development Bank (2010), before cities consider expanding their distribution networks, they should first look to reduce NRW. This will lead to greater overall efficiency and financial sustainability. A key issue is whether state-owned water utilities are capable of providing managerial incentives and setting reasonable targets that promote performance improvements.

Increased levels of NRW can reflect large volumes of water being lost through leaks distributed across a network of water distribution pipes. There may be a much greater financial and environmental return on investment (ROI) from long-term inspection programmes focusing on large diameter distribution mains. Identifying and solving NRW issues early can lead to big savings over the lifetime of a water pipeline. Many utilities look towards increasing billable water by increasing treatment capacity at the plant; however by addressing and eliminating causes of non-revenue water, the overall efficiency of the network of distribution pipes can also be increased.

Clearly, from the definitions above, one of the surrogate ways of reducing NRW in a water utility is to maximise volumes of revenue water (sales), given a vector of operational inputs. This paper investigates factors that influence inefficiency using a stochastic frontier production function for revenue water operations of utilities in Uganda's National Water and Sewerage Corporation (NWSC). The model incorporates specific incentives facing water utility managers (proxied by the ratio of maximum incentive payment to

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employee expenses) as well as the difficulty of meeting reduction of NRW targets (captured by required percentage improvement). Specifically, the paper investigates the research question: does service coverage, NRW target difficulty, level of financial incentives and year of observation influence the level of utility inefficiencies in a production environment involving revenue water output?

NWSC PERFORMANCE AND CHALLENGES

NWSC is a public corporation, currently operating in the 23 largest towns in Uganda. The operational structure is organised in such a way that there is a Head Office that plays the oversight role (performance regulation). Operations management is carried out through 19 sub-utilities whose relationship with the Head Office is regulated by sets of internally delegated performance contracts, which specify obligations, targets and incentive arrangements, among others. Some of the sub-utilities are comprised of clusters of two or three towns. The sub-utilities have sufficient managerial autonomy, mainstreamed through the contracts, to conduct operations and maintenance, and carry out delegated investments and staff recruitments. All the sub-utilities are responsible for both water and sewerage operations.

Mugisha *et al*. (2007) outline a number of reform initiatives in NWSC since 1998. Table 1 documents the positive impacts of these initiatives. Notably, service coverage in urban areas has increased from 48 to 74% (about 3.5 M people are served as at 2010). In addition, new connections increased from 3,300 to 25,000 per year. This trend is attributed to the new connection policy that was introduced in 2004. The NWSC New Connection Policy involves provision of free new connection materials for both water and sewerage for the first 50 m of a customer's connection. It was introduced through a tariff adjustment of about 9% reflecting extra funding requirements. Non-revenue water (NRW) has fallen dramatically: from about 60 to 33% (Kampala is at 36%, while other areas are now at 15%). On the financial side, annual turnover (revenue) has improved from about US$10 million to US$65 million. Because of this performance, operating profit after depreciation has improved from losses of US$4.0 million to a surplus of US$12.5 million. Positive cash flows have financed network

Table 1 | NWSC performance, 1998–2010

Performance indicator	1998	2010
1. Service coverage	48%	74%
2. Total connections	50,826	261,000
3. New connections per year	3,317	25,000
4. Staff per 1,000 connections	36	6
5. Collection efficiency	65%	98%
6. NRW	60% (Kampala ~ 65%; others ~ 57%)	33.2% (Kampala ~ 36%; other towns ~ 15%)
7. Proportion metered accounts	65%	99.6%
8. Annual turnover (million USD)	10	65
9. Profit (before depreciation) (million USD)	4.0 (loss)	12.5 (surplus)

expansion and enabled maintenance programmes to be scheduled and implemented.

Despite the accomplishments, NWSC still faces challenges of high NRW, among others. Specifically, the level of NRW in Kampala still remains high and reflects suboptimal operational performance. Over the past decade, NWSC has designed incentive plans to improve performance. The most recent plans involve a Base Incentive, which is adjusted by meeting minimum service standards and rewards for improving operating margins, improving the working ratio, reducing NRW, and improving connection efficiency. The latter three terms are given specific weights – reflecting organisational priorities and local circumstances. In addition, reductions in total billing arrears are rewarded. An example of such an incentive plan for Kampala Water Supply Area is shown in Box 1 below.

Of course, partial performance measures need to be augmented by advanced statistical techniques to obtain more comprehensive indicators of performance. Such techniques help decision-makers understand the factors that influence inefficiency in a production process where the output is water sales (affected by NRW). Establishing such a production function can go a long way in informing policy formulation processes to address inefficiencies in key aspects of water utility operations in developing countries, specifically focusing on NRW management strategies. This

Box 1 | Incentive Formula for Kampala Water Supply Area (2008–2010)

The Incentive Fee (IF) is paid to the Operator on a prorated and weighted basis once the Operator exceeds the Minimum Performance Standards (MPS) for the parent indicators. The IF computation is prorated between the MPS and the desired target Performance Standards for parent indicators at the end of the Contract duration or the end of the respective months as the case may be. The improvements in a parent indicator that contribute to the IF are capped and are limited to the achievement of the desired target performance standard. If the Area improves performance beyond the desired target performance standards, that improvement beyond the desired performance standard, except for the cash operating margin, does not contribute to the IF: thus, the IF is capped. In this regard, the incentive fee for Kampala Water is computed as follows:

General Formula

$$IF = B_{IF}{*}\ (P/N) + \{X\%{*}(OM_E – OM_O){*}[aWR_{pa} + bNRW_{pa} + cCE_{pa}]\} + YTA_{pa}$$

Specific Formula

$$IF = 139{,}037{,}000{*}(P/N) + \{15\%{*}(OM_E – OM_O){*}[0.4WR_{pa} + 0.3NRW_{\mathrm{pa}} + 0.3CE_{pa}]\} + 10{,}000{,}000TA_{pa}$$

where:

B_{IF} = Ushs.139,037,000 is the Base Incentive (Ushs. – Ugandan Shillings)

P = the weighted number of minimum service standards that have been achieved for the given month

N = 100, is the total weighted number of minimum service standards to be achieved

$X\%$ = 15% is the agreed proportion (%) of the improvement in operating margin (OM) to be retained by the Operator as bonus

OM_O = Minimum cash operating margin based on the agreed operating expenditure (Base Fee + Performance Fee) and the set Minimum Standard for revenue collections

OM_E = the achieved cash operating margin during the month being evaluated

WR_{pa} = Percentage incremental achievement in the improvement of the *Working Ratio*

NRW_{pa} = Percentage incremental achievement in the reduction of *Non-Revenue Water*

CE_{pa} = Percentage incremental achievement in the increase in *Connection Efficiency*

TA_{pa} = Percentage incremental achievement in the reduction of *Total Arrears*

Z = Ushs.10,000,000 is the agreed incentive attached to reduction of arrears (debts)

a, b, & c = Area specific weights for Parent Targets for computing Incentive Fees where $a + b + c = 1$.

The percentage incremental achievement (PIA) is computed as follows:

$PIA = [(Ia – Im)/(It – Im)]{*}100$

where:

Im = the minimum performance standard for a given indicator

It = the desired target performance standard for a given indicator for the month or quarter in question

Ia = the actual achieved performance level for a given indicator for the month.

Source: NWSC (2006).

study aims at taking the analysis beyond partial efficiency measures to a more comprehensive technical efficiency analysis. The study results have strong implications for utility managers and regulators involved in design of incentive schemes and policies for NRW management in developing countries.

PAST STUDIES

The measurement of the technical efficiency of a firm relative to other firms or to the 'best practice' in an industry has been of interest to water utility regulators, performance monitors and researchers. Berg & Marques (2011) identify 120 quantitative journal articles on water utilities, but only three on Africa–which is somewhat surprising given the significant amount of international donor funding that has gone into the region. So this paper fills some gaps in literature by determining factors that influence inefficiency of water utilities. Therefore, this study increases the number of technical efficiency studies on Africa. Moreover, it is one of the few studies that investigate environmental factors that affect efficiency in a production function that incorporates NRW.

The study draws upon work by Battese & Coelli (1995) who proposed a model for technical inefficiency effects in a stochastic frontier production function for panel data. The model estimates the parameters of the stochastic frontier and inefficiency model simultaneously, given distributional assumptions associated with panel data on the sample firms. According to Coelli & Battese (1996), provided the effects are stochastic, the model permits the estimation of both technical change in the stochastic frontier and time varying technical inefficiencies. The current study applies this model to unbalanced panelled data of NWSC's utilities for the period 2002–2010.

There have been many applications of frontier production functions to water utilities over the years. These are summarised by Abbott & Cohen (2009) and illustrated further by Berg (2010). Mugisha *et al*. (2007) outline the use of internal incentive contracts to improve water utility performance for the case of Uganda's NWSC. They conclude that no simple recipe for promoting efficiency exists. However, they point out useful ingredients, including proper contract framework design, competition for managerial responsibility, effective business planning, performance monitoring and the use of managerial incentives. Correia & Marques (2011) apply a multiproduct translog cost function, using unbalanced panelled data to investigate the effects of ownership, size and diversification on efficiency in Portuguese water utilities. They find that private companies are slightly more efficient than public companies. Mugisha (2007) investigates the effects of incentive applications on technical inefficiencies for NWSC water sub-utilities. This study expands this analysis, using a bigger sample in a pooled framework (covering more years), to include more efficiency variables, and to determine the impact on technical efficiency by level of financial incentives, service coverage and target difficulty. In other words, the study is, partly, an extension of goal setting theory, which Mugisha (2007) does not cover.

EFFICIENCY FRONTIER MODEL FOR PANEL DATA

Consider a translog stochastic production frontier for panel data,

$$\begin{aligned} y_{nt} = \beta_0 + \sum_{i=1}^{K} \beta_i \ln x_{\text{int}} + \frac{1}{2}\sum_{i-1}^{K}\sum_{j=1}^{K} \beta_{ij} \ln x_{\text{int}} \ln x_{jnt} \\ + \sum_{i=1}^{K} \lambda_i \ln x_{\text{int}} t + \phi_1 t + \phi_2 t^2 + v_{nt} - u_{nt} \\ n = 1, 2, \ldots, N;\ t = 1, 2, \ldots, T \end{aligned} \quad (1)$$

where y_{nt} is the log of output (quantity of delivered water); ln x_{int} is the log of i-th input quantity; t is a time trend; v_{nt} is an error term (noise) that picks up what the model cannot explain; u_{nt} is the inefficiency term, preceded with a negative sign because inefficiency means less output; and the Greek letters depict unknown parameters to be estimated. According to Coelli *et al.* (1998), the v_{nt} is assumed to be independent and identically distributed (iid) $N(0, \sigma_v{}^2)$ random errors, distributed independently of u_{nt}. The u_{nt} term is a non-negative random variable, associated with technical inefficiency of production, which is assumed to be independently distributed, such that u_{nt} is obtained by truncation (at zero) of the normal distribution with mean, $z_{nt}\,\delta$ and variance, σ^2; z_{nt} is a $(1 \times m)$ vector of explanatory variables associated with the technical inefficiency of production for firms over time; δ is an $(m \times 1)$ vector of unknown coefficients to be estimated. The explanatory variables are discussed in greater detail in the next section.

Battese & Coelli (1995) state that the model of inefficiency effects can only be estimated if the inefficiency effects are stochastic; and the error distribution is specified. Hence, the analysis needs to include statistical hypothesis tests about the inefficiency effects. These and other null hypotheses of interest are tested using the generalised likelihood-ratio, LR, defined by Equation (2),

$$LR = -2\ln[L(H_0)/L(H_1)] \quad (2)$$

where $L(H_0)$ and $L(H_1)$ are the values of the likelihood function under the specifications of the null hypotheses, H0 and H1, respectively. Asymptotically, the LR statistic has a chi-square distribution with degrees of freedom equal to the number of restrictions involved. It should be noted that where the null hypothesis includes the restriction $\gamma = 0$ (a point on the boundary of the parameter space), the likelihood ratio statistics will have asymptotic distribution equal to a mixture of chi-square distribution $(1/2)\chi_0^2 + (1/2)\chi_1^2$. The maximum likelihood technique is proposed for simultaneous estimation of the parameters of the stochastic frontier and the model for the technical inefficiency effects. The likelihood function is expressed in terms of the variance parameters as shown in Equations (3) and (4),

$$\sigma_s^2 = \sigma_v^2 + \sigma^2 \quad (3)$$

$$\gamma = \sigma^2/\sigma_s^2 \quad (4)$$

The technical efficiency of production for the *n*-th firm at the *t*-th observation, which is between zero and one and is inversely related to technical inefficiency, is defined by Equation (5). The efficiencies are estimated using a predictor that is based on the conditional expectation *exp* $(-u_{nt})$, presented in Coelli *et al.* (1998), and is incorporated in *FRONTIER Version 4.1*.

$$\mathrm{TE}_{nt} = \exp(-u_{nt}) \quad (5)$$

DATA AND EMPIRICAL APPLICATION

Unbalanced panelled data on all NWSC sub-utilities (12–19 sub-utilities making 146 observations in a pooled framework) from Uganda for the period 2002–2010 are considered for empirical application of our model specified above. We chose this period because it represents the time when internal incentive contracts have taken root in NWSC operations. The efficiency variables considered in this study include; promised financial incentive, revenue water target difficulty, service coverage, and time trend, which are used to explain the differences in inefficiency effects among NWSC utilities. The use of these variables illustrates policy variables that are viewed as critical for NRW management in developing countries. A summary of the sample data on the different variables in the stochastic frontier and inefficiency model, used in this study, is presented in Table 2.

We take the model of the production function at a single connection level because this is the primary unit of focus in the management of NRW in developing countries. In addition, the production variables of water supplied, staff, operating expenditure and connections are all highly correlated and considering them as separate production input variables in that form would result in statistical bias. Moreover, dividing by connections, all through the variables, is aimed at estimating a production function at the level of individual connected unit in a variable returns to scale

Table 2 | Summary statistics for variables in the stochastic frontier production function for NWSC sub-utilities (per annum)

Variable	Sample mean	Standard deviation	Min. value	Max. value
1. Revenue water (m^3)	2,376,345	5,911,924	130,890	30,293,700
2. Water production (m^3)	3,649,026	10,044,216	166,951	50,444,455
3. Connections (No.)	9,528	23,259	597	146,243
4. Staff (No.)	62	121	8	715
5. Op.Ex. (×1000,Ushs)	2,519,540	6,215,943	198,316	39,692,746
6. Service coverage (%)	64	15	31	90
7. Max. earnable incentive (%)	53.92	30.65	8.50	218.22
8. Revenue water target difficulty (%)	106.24	7.15	92.09	142.86

Source: Analysis from NWSC Audited Reports, 2002–2010.

(VRS) framework. According to Coelli *et al.* (2003), once a model involves efficiency variables which relate to scale, the elasticity is given by the proportionate effect on production of changes in input variables and the environmental variable. Since all efficiency variables in this study are not related to scale, we do not express any of them per connection, except for input and output variables.

The stochastic frontier production function, at connection unit level, to be estimated, is obtained from Equation (1),

$$\begin{aligned}\ln(\mathrm{RW}_{it}) = {} & \beta_0 + \beta_1\ln(S_{it}) + \beta_2\ln(P_{it}) + \beta_3\ln(X_{it}) \\ & + \beta_4 t + 0.5\beta_5(\ln(S_{it}))^2 + \beta_6\ln(P_{it})\ln(S_{it}) \\ & + \beta_7\ln(S_{it})\ln(X_{it}) + \beta_8\ln(S_{it})t + 0.5\beta_9(\ln(P_{it}))^2 \\ & + \beta_{10}\ln(P_{it})\ln(X_{it}) + \beta_{11}\ln(P_{it})t + 0.5\beta_{12}(\ln(X_{it}))^2 \\ & + \beta_{13}\ln(X_{it})t + \beta_{14}t^2 + v_{it} - u_{it} \\ & i = 1, 2, \ldots, N(\text{number of utilities});\ t = 1, 2, \ldots, 9.\end{aligned} \tag{6}$$

where the subscripts i and t refer to the i-th utility and the t-th observed data, respectively. The technical inefficiency effects are assumed to be defined by

$$\begin{aligned}u_{it} = {} & \delta_0 + \delta_I(\text{Serv} - \text{Coverage}_{it}) + \delta_2(\text{Incentive}_{it}) \\ & + \delta_3(\text{Target} - \text{Diff}_{it}) + \delta_4(\text{Year}_{it})\end{aligned} \tag{7}$$

ln represents the natural logarithm (i.e., to base e)
RW represents revenue water (water sales) per connection (cubic m per connection)
S represents staff per connection (number per connection)
P is the water production per connection (cubic m per connection)
X is the operating expenditure per connection (Ushs per connection)
v_{it} is the error term (where noise is defined in the previous section)
Serv-Coverage is the proportion of target population that is served with water services (%)
Incentive is the percentage of maximum promised incentives to total employee costs (%)
Target-Diff is the proportion of negotiated RW target to average RW value for the previous 12 months (%)
Year/t is the year of observation (expressed in terms of 1, 2, ……….,9)
β_s are unknown coefficients to be estimated
δ_s are unknown scalar quantities to be estimated. A negative value of δ_j would mean that the corresponding environmental variable has a positive impact on the reduction of firm technical inefficiencies (see Equation (5)).

We use the time trend in both the production frontier estimation and the mean efficiency sub-equation because we want to observe the behaviour of revenue water output and inefficiency effects, over time. The expected signs of the β_s and δ_s in Equations (6) and (7) are not clear in all cases. However, in the NWSC case, the sum of the first-order input coefficients would be expected to be greater than unity, suggesting increasing returns to scale at a single connection level – in other words, a change in inputs results in a bigger change in outputs. This is because sub-utilities tend to favour increased single connections as a way of increasing service coverage and maximising water sales (output). Kingdom *et al.* (2006) suggest the need for strong incentives, autonomy and commitment for staff involved in NRW activities. In this case, the elasticity related to staff should have a positive sign, suggesting that increasing staff increases the production output of revenue water. However, extra staff may be involved in perpetuating illegal connections due to poor remuneration, greed and/or recruitment history, leading into negative elasticity. This observation is in line with a recent study by Delavallade (2012), which associates more corruption with firms that are less competitive. Moreover, additional staff may lack competencies in respect to NRW reduction and, by default, may not be helpful in water loss control activities.

Another variable we analyse in this study is water produced (P). An increase in water produced per connection is expected to result in increased revenue water if utility employees have strong incentives to maximise revenue water. In NWSC sub-utilities where revenue water is a priority for maximising cash operating margins (revenue collections minus expenditure), the elasticity with respect to this input is expected to be positive. However, more water per connection may mean that the network is more pressurised, leading to more leaks and bursts, resulting in a negative coefficient (interpreted as elasticity). Part of the additional water supply may also be consumed by inactive (suppressed) accounts whose consumption is not being monitored. The associated theft may not be deterred by utility managers and staff or it could be facilitated by bribes. All these factors can contribute to an increase in NRW.

The other input parameter in Equation (6) is operating expenditure (X). An increase in operating expenditure per connection is expected to improve capabilities and motivation of operating teams to increase revenue water; we would expect a positive elasticity for this input. In NWSC distribution utilities, there is a strong orientation towards cost optimisation: all performance priorities relate to increasing cash operating margins, which depends on increased revenue water. Therefore we expect a positive elasticity with respect to this input. However, if increased expenditures only end up financing unrelated activities like travel allowances, cleaning services, and meeting expenses, this scenario could result into a negative elasticity.

Turning to the inefficiency drivers, we consider coverage, incentives, and the stretch required to meet targets. In developing countries, low water service coverage is expected to be associated with high NRW due to illegal water uptake by small scale independent providers to meet unsatisfied demand. If this is the case, service coverage in the inefficiency equation (Equation (7)) is expected to have a negative sign. That is, we expect that greater levels of service coverage will be associated with smaller values of inefficiency effects. On the other hand, the sign of the coefficient for the incentive index is expected to be negative if increased level of promised incentives reduces production inefficiency. This expectation stems from research by Mugisha (2005) who finds that both financial and emotional incentives have positive effects on the level of technical efficiency in utility operations.

The sign of the coefficient of target difficulty in the inefficiency model is expected to have a positive sign to the extent that high targets put pressure on managers to innovate and increase performance. However, high targets which are set without a full acceptance by all 'shop' floor employees may yield resentment, especially after comparing their targets with those of perceived peer utilities. High targets are in the interest of NWSC utility managers who win contracts through their competing for 'lead-partner' responsibilities, where the main evaluation criteria incorporate competitive targets. After selecting a lead partner, he/she then selects a team and obtains agreement for specified 'winning' targets. Therefore, target difficulty is self-imposed through a competitive managerial process. However, target difficulty can be a strong perverse incentive leading to internal squabbling and complaints. Consequently the sign of the coefficient is unclear in the case of NWSC utilities: it could be positive or negative, depending on the feasibility of meeting targets and employee perceptions of fairness.

The sign of the *Year* variable in the model for the inefficiency effects (Equation (7)) is expected to be negative. This implies that the levels of inefficiency effects of utilities should tend to decrease over time. That is, utility managers are expected to make their utilities more efficient as they gain experience and expertise. In addition, this time-trend is expected to pick up the influence of factors that vary systematically through time which are not included in the inefficiency model.

In line with Estache *et al*. (2004) and Coelli *et al*. (2003), this study sets all period numbers to 1 and the utility numbers vary from 1 to 146 (even though the data are from 12 to 19 firms over a period of 9 years). This is done to ensure that the Frontier program treats each observation individually. According to Coelli *et al*. (2003), if this is not done, we would be imposing a restriction on the model that the technical efficiency of the i-th firm must be constant across all the 9 years (which is imposed by the Frontier program when panel data are used). Using this methodology, also in line with Berg & Lin (2008), we utilise pooled data. In addition, Coelli *et al*. (2003) point out that in order to interpret the estimated first order parameters in the stochastic frontier analysis (SFA) function as production elasticities easily, evaluated at the sample means, we can express all data in deviations from the sample means. Consequently, in this analysis, all data have been computed as deviations from the column sample means. The time trend variable is also in deviation from the mean, that is, as the mean of the time trend variable is 4.658 (un-panelled data) in this instance, the mean corrected trend variable is converted from (1, 2, 3, 4, 5, 6, 7, 8, 9) to (−3.658, −2.658, −1.658, −0.658, 0.342, 1.342, 2.342, 3.342, 4.342). Furthermore, according to Berg & Lin (2008), multi-collinearity influences the statistical significance of the model. The robustness of a model can be checked through a *multi-collinearity test*, to determine whether two or more independent variables are very highly correlated: if two independent variables are highly correlated, there is no way to tell how much effect each has separately. In our case, after running a multiple correlation test with all regressors, we do not find high correlations between them (the range is 0.007–0.65).

RESULTS AND DISCUSSION

The maximum likelihood estimates from the Frontier 4.1 program for the translog specification in Equation (6) and inefficiency model in Equation (7) are shown in Table 3. The signs of the estimated β-coefficients of the first order parameters of stochastic frontier are as expected. Also, as expected, the sum of the first-order input parameters is greater than one, implying that a large number of connections is preferred. The estimated coefficients of water production and operating expenditure variables, 0.911 and 0.216, respectively, are significant, signifying a strong relationship between these two inputs and output. Specifically, production input refers to the amount of water that the utility takes from the environment and makes available for distribution. It has the highest elasticity and consequently would imply that utilities would be able to better consolidate their results in terms of monetisation of delivered volumes by acting on the stage of water purification. In addition, the variable of water produced becomes crucial in determining a positive elasticity of staff factor. The small and insignificant value of the staff coefficient could be due to a relatively high number of employees that are not directly involved in revenue water enhancement activities. The coefficient for the *Year* indicates that the value of output has tended to increase by a small but significant rate over the 9-year period. The squared and multiplicative terms for the Translog model indicate that revenue water falls off with the square of staff size, but the coefficient on the multiplicative term ($S*P$) is positive and significant. This interaction between staff and production variables shows that the net effect of staff per connection on revenue water depends on the level of water production input per connection. From our evidence, the only significant interactive effect (at $p = 0.05$) of staff increment on revenue water at average values of expenditure per connection is given by $0.311*P–0.103*S$. The effect is obtained by taking first order derivatives of dependent variable with respect to natural logarithm of staff per connection, for only significant coefficients. That means the effect of staff on revenue water depends, partly, on the level of water production input per connection. The evidence also shows that expenditure has a significant effect ($p = 0.01$) on revenue water. This means utilities with higher levels of production and higher levels of expenditure are likely to sell more water (at the connection unit level) than those with correspondingly low inputs.

Table 3 | Maximum likelihood estimates

Type (logged variable)	Coefficient	Standard error	t-ratio
beta 0	0.211	0.008	25.274
beta 1 (ln S)	0.026	0.030	0.862
beta 2 (ln P)	0.911	0.028	31.966
beta 3 (ln X)	0.216	0.045	4.778
beta 4 (t)	0.008	0.005	1.597
beta 5 $(\ln S)^2$	−0.103	0.049	−2.105
beta 6 (ln S*ln P)	0.311	0.130	2.387
beta 7 (ln S*ln X)	0.124	0.129	0.960
beta 8 (ln $S*t$)	−0.015	0.021	−0.735
beta 9 $(\ln P)^2$	−0.222	0.124	−1.801
beta10 (ln (P)*ln(X))	0.095	0.138	0.691
beta11 (ln(P)*t)	0.002	0.026	0.085
beta12 $((\ln X)^2)$	−0.097	0.240	−0.403
beta13 (ln$X*t$)	−0.023	0.026	−0.900
beta14 ($t*t$)	−0.009	0.005	−1.879
delta 0	−0.210	0.246	−0.851
delta 1 (*Serv-Coverage*)	−0.006	0.001	−5.189
delta 2 (*Incentive*)	−0.276	0.082	−3.364
delta 3 (*Target-Diff*)	0.242	0.223	1.083
delta 4 (*Year*)	0.015	0.012	1.281
sigma-squared	0.019	0.003	6.582
Gamma	0.962	0.003	301.331

All variables shown in Table 3 are logged. Log likelihood function $= 1.714 \times 10^2$; LR test of the one-sided error $= 9.508 \times 10^1$ with number of restrictions = 6 [note that this statistic has a mixed chi-square distribution]; number of iterations = 29; mean efficiency = 0.86954030.

We analyse the marginal productivities at different input domain thresholds (quartiles) as shown in Table 4 to assess the consistency of the elasticities obtained in Table 3. Clearly, Table 4 shows consistency in the signs and magnitudes of marginal productivities. The magnitudes of the elasticities are also consistent.

The estimated coefficients in the inefficiency model for all data points, at the mean, are of particular interest in this study. The *Service Coverage* coefficient is negative and significant, which suggests that utilities with higher service penetration are more efficient than those where service coverage is low. Of course, lower service coverage may also be due to the higher costs of reaching potential customers in low density areas. Future work should incorporate network density into the model, since this should contribute to efficiency. The negative and significant estimate for *Incentive* implies that utilities with higher target incentives as a proportion of total employee costs tend to be less inefficient. In other words the effect of incentives on inefficiency (elasticity of 0.28) is significant ($p = 0.01$) at average values of service coverage, target hurdle and time trend. This evidence suggests that a 10% increase in promised level of incentives results in a 2.8% reduction in inefficiency of producing a revenue water output. This result in turn shows that without the incentive plan, the average efficiency for the 146 observations would have been about 0.83 instead of 0.87. Similarly, target difficulty has a large but insignificant negative effect of 24.2% on inefficiency at average values of service coverage, promised incentive level and time trend. If significant, the findings would suggest that 1% increase in target difficulty results in 0.24% increase in inefficiency of producing the output, indicating that without effects of target difficulty, the average efficiency of 146 observations would have been 0.9 instead of 0.87. In other words, the positive coefficient for *Target-Difficulty* signifies that utilities with more hard-to-achieve revenue water targets could be more inefficient. This issue warrants more attention in future studies.

The positive but small coefficient of *Year* suggests that the inefficiencies of production of the utilities have tended to increase in the 9-year period. Judging from the trend of performance programmes in NWSC, this is not surprising given that a significant number of re-engineering policies were implemented between 2002 and 2005, while the period 2006–2010 has been devoted to consolidation and learning from change management challenges encountered. Specifically, some re-engineering programmes introduced include: internal contracts in 2000–2004, stretch-out and one-minute management programme in 2003–2004, and a new connection policy in 2004. After 2005, only internally delegated area management contracts (IDAMCs) have been used as a management tool; and the impact of this technique seems to have hit a plateau. In 2011, the corporation embarked on major innovative programmes like e-payments, and Performance, Autonomy, Creativity and Empowerment (PACE) contracts to return to earlier (more rapid) efficiency trends. Therefore, since the *Year* variable in the model may represent the scale of performance improvement programmes (PIPs) over the study period, the positive sign is not surprising. This result is in line with research by Colon (2011) who concludes that although internal contractual tools with their incentives

Table 4 | Analysis of marginal productivities at different input domain levels

% Quartile	25	50/median	75	Mean
beta 0	0.110**	0.165**	0.231**	0.211**
beta 1 (ln *S*)	– 0.030	– 0.006	– 0.008	0.029
beta 2 (ln *P*)	0.857**	0.902**	0.954**	0.911**
beta 3 (ln *X*)	0.228**	0.174**	0.184**	0.216**
beta 4 (*t*)	0.040*	0.016*	– 0.017*	0.008*
beta 5 (ln *S*)^2	– 0.126*	– 0.109*	– 0.116*	– 0.103*
beta 6 (ln *S**ln *P*)	0.373**	0.318**	0.366**	0.311*
beta 7 (ln *S**ln *X*)	– 0.020	0.082	0.076	0.124
beta 8 (ln *S*t*)	– 0.026*	– 0.021*	– 0.029*	– 0.015
beta 9 (ln *P*)^2	– 0.146*	– 0.243*	– 0.178*	– 0.222*
beta10 (ln (*P*)*ln (*X*))	0.139*	0.144*	0.131*	0.095
beta11 (ln(*P*)**t*)	– 0.022*	0.000	– 0.013	0.002
beta12 ((ln*X*)^2)	– 0.367*	– 0.231*	– 0.225*	– 0.097
beta13 (ln*X*t*)	– 0.012	– 0.022	– 0.015	– 0.023
beta14 (*t*t*)	– 0.006*	– 0.007*	– 0.005*	– 0.009*
delta 0	– 0.040	– 0.003	– 0.034	– 0.210
delta 1 (*Serv-Coverage*)	– 0.008**	– 0.005**	– 0.006**	– 0.006**
delta 2 (*Incentive*)	– 0.414**	– 0.253**	– 0.277**	– 0.276**
delta 3 (*Target-Diff*)	1.619*	0.971*	1.035*	0.242*
delta 4 (*Year*)	– 0.004	0.009	0.006	0.015*

(*) represents statistical significance at 5% level while (**) represents 1%.

mechanisms have brought positive changes in NWSC (decentralisation, better corporate culture, capacity building and knowledge management), there is need for a new set of re-engineering programmes to turn around recent performance trends. On the other hand, the estimate of the variance parameter, γ, is close to one, which indicates that the inefficiency effects are likely to be highly significant in the analysis of value of output of the utilities.

Generalised likelihood-ratio tests of null hypotheses, that the inefficiency effects are absent or have simpler specifications are presented in Table 5. The first null hypothesis specifies that a Cobb-Douglas function is a suitable specification: it is strongly rejected. The second null hypothesis, which specifies that inefficiency effects are not stochastic, is also strongly rejected. The third null hypothesis, which suggests that the inefficiency effects are absent in the model is strongly rejected. Lastly, the fourth null hypothesis, which suggests that inefficiency effects are not a linear function of service coverage, incentive, target difficulty and year of observation, is also strongly rejected at 1% level of significance. These tests imply that the joint effects of these four explanatory variables on the inefficiencies of production are significant although the individual influences may differ in levels of statistical significance.

Clearly, the inefficiency effects in the stochastic frontier production function are stochastic and are related to service coverage, level of incentives, target difficulty and time of observation.

Table 5 | Tests of hypotheses for parameters of the inefficiency frontier model

Null hypothesis	Log likelihood	$\chi^2_{0.99}$ value	Test statistic[a]
Given model (from Equation (6))	171.42		
H_0: Cobb-Douglas; $\beta_5 = \beta_6 \ldots\ldots = \beta_{14} = 0$	136.03	21.67	70.78[a]
H_0: $\gamma^b = 0$	123.88	11.34	95.08[a]
H_0: $\gamma = \delta_0 = \delta_1 = \delta_2 = \delta_3 = \delta_4 = 0$	139.89	18.48	63.06[a]
H_0: $\delta_1 = \delta_2 = \delta_3 = \delta_4 = 0$	139.81	13.28	63.22[a]

[a]On the value of test statistic indicates that it exceeds the 99th percentile for the corresponding χ^2-distribution: so the null hypothesis is rejected.
[b]If the parameter γ is zero, then the variance of the inefficiency effects is zero and the model reduces to a traditional mean response function in which the variables, service-coverage, incentive and target difficulty are included in the production function. In this case, the parameters δ_0 and δ_4 are not identified. Hence the value of the test statistic for this null hypothesis is obtained from χ^2_3-distribution.

The discussions above do reinforce the findings of past studies. For example, the evidence obtained in this study shows consistent results with those obtained by Mugisha (2007). In the latter study, a log-linear input distance function is used with financial incentives being the only explanatory variable in the inefficiency sub-equation. In addition, the connections are modelled as output. Clearly, this study shows that with the inclusion of more explanatory variables in the inefficiency sub-equation, the significance of the incentive variable is enhanced. The study also finds consistency with the assertion that monetary incentives promote efficiency in public water utilities. Moreover, this study enhances our understanding of target setting in water utilities, given that the attributes of a good target are largely inconclusive in goal setting theory. According to Li and Butler (2004) the results of a laboratory study demonstrated that goal rationales were especially important for increasing goal commitment when goals were assigned rather than participatively set. Similarly, Zetik & Stuhlmacher (2002), through a meta-analysis, find that more difficult goals lead to higher outcomes than less difficult goals. In our study, the results seem to be the reverse: perceived difficult goals result in poor operating efficiencies. In the present analysis, it appears that inadequate participation of most NWSC utility employees in target setting may be damaging employee motivation, leading to a potential impact of *Target-Difficulty* on performance. The result suggests that the current target-setting process, which is mainly set through a competitive bidding process associated with top managers, needs to be improved.

CONCLUSIONS

The diffusion of water utility incentive programmes in Africa is documented in Mugisha (2011). Managerial incentives have been adopted in Tanzania, Zambia, Kenya, some Nigerian states, and in other nations. The performance improvements stimulated by managerial incentives bring hope to those who have doubted the ability of developing nations to overcome the many hurdles faced by decision-makers (including political patronage, corruption, lack of transparency, weak governance, and poor information systems). The results of this model for technical inefficiency effects using a stochastic frontier production function suggest that these programmes can be expected to improve performance. However, experience suggests that developing and implementing appropriate incentives is an evolutionary process. Furthermore, excessively stringent targets (such as for reductions in NRW) can actually reduce efficiency, although the channels leading to the negative effects are still unclear. In addition, resources might have been devoted to improving other dimensions of performance, such as an increased number of hours of service per day.

The study uses a model of technical inefficiency effects, involving a constant term, service coverage, incentives, target difficulty and year of observation; these factors are shown to be significant components in the inefficiency sub-equation of the stochastic frontier production function. Specifically, we find that utilities with higher levels of service coverage and incentives are more technically efficient. Our evidence suggests that incorporating incentive plans can result in approximately 4% (0.83 to 0.87 efficiency score) increase in revenue output. Using the NWSC's annual revenue output of 48,260,661 m^3, at a current average tariff of US$0.7 per m^3, a 4% change in output translates directly to about US$1.4 million in a US$60 million turnover utility.

On the other hand, utilities with easier to achieve targets are more efficient than their counterparts with more difficult targets. This result suggests that an examination of the target-setting process is warranted. Our evidence suggests that effects of target difficulty can cause inefficiencies to the tune of about US$1.0 million revenue losses per annum in a US$60 million annual turnover utility. More applied work is called for: a multi-output and multi-input production technology, using a distance function specification, would enable an expansion of output variables to include service quality (such as hours of operation per day) as well as other inputs. Of course, as usual, data availability is the major constraint for analysts.

The empirical evidence points towards a number of policy implications. First, utility managers need to incorporate financial incentives in their performance improvement plans if they want operating teams to have sufficient momentum to improve production. Second, the evidence suggests that utilities with higher service coverage levels are more efficient in reducing NRW. The evidence suggests that investing in NRW reduction without contingent service coverage enhancement plans (expansion plans) may not yield optimal results. Third, target difficulty was found to be promoting inefficiency, clearly showing that performance targets need to be set with care and transparency. In conclusion, the results support the trend towards greater public sector accountability, through benchmarking activities by regulators and managers and a more commercial (less political) orientation for state-owned enterprises. However, this is easier said than done in practice. This is because most water utilities in developing countries are faced with challenges of political interference, corruption and nepotism tendencies. All these are practical constraints to moving towards better performance and governance. The results contribute to the growing literature on the impact of explicit managerial incentives on state owned enterprises (SOE) performance. The study also suggests several lines of further research related to the development and implementation of managerial incentives. More comparative studies need to be conducted to overcome the weaknesses of this study resulting from small values of elasticities and poor statistical significance of the parameters in the translog specification. The possibility of use of a Cobb-Douglas functional form could be explored, using a different data set, although the LR test rejects it in this study.

REFERENCES

Abbott, M. & Cohen, B. 2009 Productivity and efficiency in the water industry. *Utilities Policy* **17**, 233–244.

ADB 2010 *The Issues and Challenges of Reducing Non-Revenue Water*. Asian Development Bank, Publication Stock No. RPT102319.

Battese, G. E. & Coelli, T. J. 1995 A model for technical inefficiency effects in a stochastic frontier production function for panel data. *Empirical Econ*. **20**, 325–332.

Berg, S. V. 2010 *Water Utility Benchmarking: Measurement, Methodologies and Performance Incentives*. IWA Publishing, London.

Berg, S. V. & Lin, C. 2008 Consistency in performance rankings: The Peru water sector. *J. Appl. Econ* **40** (6), 793–805.

Berg, S. & Marques, R. 2011 Quantitative studies of water and sanitation utilities: a benchmarking literature survey. *Wat. Policy* **13**, 591–606.

Coelli, T. J. & Battese, G. E. 1996 Identification of factors which influence the technical inefficiency of Indian farmers. *Aust. J. Agric. Econ.* **40** (2), 103–128.

Coelli, T., Prasada Rao, D. S. & Battese, G. E. 1998 *An Introduction to Efficiency and Productivity Analysis*. Kluwer Academic Publishers, Dordrecht, The Netherlands.

Coelli, T., Estache, A., Perelman, S. & Trujillo, L. 2003 *A Primer on Efficiency Measurement for Utilities and Transport Regulators*. WBI Development Studies, World Bank, Washington, DC.

Colon, M. 2011 Re-balancing commercial and engineering activities: A way forward for NWSC. *The Water Herald, NWSC-Uganda* **3** (1), 8–13.

Correia, T. & Marques, R. C. 2011 Performance of Portuguese water utilities: How do ownership, size, diversification and vertical integration relate to efficiency? *Wat. Policy* **13** (3), 343–361.

Delavallade, C. 2012 What drives corruption? Evidence from North African firms. *J. Afr. Economies* **21** (4), 499–547.

Estache, A., Rossi, M. A. & Ruzzier, C. A. 2004 The case for international coordination: Evidence from the measurement of efficiency in South America. *J. Regul. Econ.* **25** (3), 271–295.

Kingdom, B., Liemberger, R. & Marin, P. 2006 The Challenge of reducing Non-Revenue Water (NRW) in Developing Countries – How the Private Sector Can Help: A Look at Performance-Based Service Contracting. Water Supply and Sanitation Sector Board Discussion Paper Series, Paper No. 8, 2006, World Bank, Washington, DC.

Lambert, A. 2003 Assessing Non-Revenue Water and its Components. *Water 21*, August 2003.

Li, A. & Butler, A. B. 2004 The effects of participation in goal setting and goal rationales on goal commitment: An exploration of justice mediators. *J. Bus. Psychol.* **19** (1), 37–51.

Mugisha, S. 2005 Effects of Managerial Incentives Intensity and Performance Monitoring Modes on Water Utility Efficiency and Productivity Growth: Findings National Water and Sewerage Corporation, Uganda. Unpublished PhD Thesis, Makerere University.

Mugisha, S. 2007 Effects of incentive applications on technical efficiencies: Empirical evidence from Ugandan water utilities. *Utilities Policy* **15** (4), 225–233.

Mugisha, S. 2011 *Utility Benchmarking and Regulation in Developing Countries: Practical Application of Performance Monitoring and Incentives*. International Water Association, London.

Mugisha, S., Berg, S. V. & Muhairwe, W. T. 2007 Using internal incentive contracts to improve water utility performance: The case of Uganda's NWSC. *Wat. Policy* **9** (3), 271–284.

NWSC 2006 *Kampala Water Internally Delegated Area Management Contract* (2006–2010). NWSC Unpublished document, P.O. Box 7053, Plot 39, Jinja Road, Kampala, Uganda.

Zetik, D. C. & Stuhlmacher, A. F. 2002 Goal setting and negotiation performance: A meta-analysis. *Group Processes Intergroup Relations* **5** (1), 35–52.

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