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Utilities Governance, Incentives, and Performance: Evidence from the Water Sector in India

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Keywords Governance and regulation; socioeconomic and environmental performance; stochastic frontier analysis; sustainability; urban water supply in India.

JEL Classification L97, L95, L51, L43, R52.

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1. Introduction

Network utilities such as water, electricity, gas and telecommunication develop and operate essential infrastructure services and play a key role in the social and economic development of cities and countries (Marvin and Graham, 1993; Loughlin, 1985; Simpson, 1983; CEC, 1990). These industries, although different in various ways, are natural monopolies that share important underlying technical and economic features. This implies that many economic, governance, and policy evidence and lessons are transferable across them.

Water supply utilities across the world need to achieve a diverse set of social welfare, economic efficiency, and environmental performance objectives (Venkatesh et al., 2015). However, managing the trade-offs between these objectives in developing countries, in the context of weak institutions and independent regulatory tradition, is a difficult task.

There are strong political interests directing policies towards social objectives leaving behind the economic and environmental concerns. Water prices are generally not determined in markets and, as such, do not reflect resource scarcity (Olmstead, 2010). In consequence, there has been a discernible absence of policy to provide incentives that may encourage efficient water usage, and a lack of thrust on conserving water (Kulshrestha et al., 2012).[1] Allocation mechanisms are highly political, and even when faced with resource scarcity, management institutions are reluctant to raise prices (Olmstead, 2010). As a result, most utilities operate with financial losses implying continued dependence on government subsidies, and poor access to services and quality. The literature suggests that, as a result, public firms have distorted objective functions that also involve the pursuit of politician's individual goals by transfer of value to voters at the expense of other objectives (Shleifer and Vishny, 1993, 1994). Examples of this type of political interference in public utilities in India are abundant (see Dubash and Rajan, 2001; Dubash and Rao, 2007; Dubash, 2008; Singh, 2014).

Universal access to water remains a very relevant issue in urban India. Urban water supplies are state-controlled monopolies whose policies are focused on drinking water provisioning

[1] Due to the lack of recognition as an economic good, water has conventionally been considered as a free commodity and large quantities of potable water are employed for non-potable uses (Kulshrestha et al., 2012).

for their growing populations. However, these are less concerned with long-term sustainability, efficiency and commercial viability of the utilities (Nyathikala and Kulshrestha, 2017). As a result, while the connected households have significant issues in terms of quantity, quality of supply and service, the remaining 40% of urban households does not have access to public piped water supply (IIHS, 2014).

During the past decade and a half, India has sought reforms in the water sector on two fronts: i) economic/financial reforms and ii) governance/institutional reforms. These reforms are based on principles of full cost recovery, rationalisation of tariffs, introduction of public-private partnerships and establishment of regulatory authorities (MoUD and PA, 2004; MoWR, 2016; MoUD, 2012).[2] As frequently highlighted, the process of initiating and undertaking reforms is disjointed at various levels of governance institutions resulting in no major improvements in service delivery (Wagle et al., 2011; Kulshrestha et al., 2012). The literature suggests that the quality of institutions affects productivity and economic performance of utilities and constrain them from realising their technical potential (Jamasb et al., 2018; Borghi et al., 2016).

The absence of national level regulator and the prevalence of fragmented governance structures makes it difficult for Indian water supply sector to achieve various reform objectives across different states.[3] Other utility sectors operating under fragmented set ups and political intervention can face similar constraints, where reforms seem to lack the mechanisms for achieving policy objectives. This highlights the need to assess the performance of utility networks and their determinants. The Indian urban water supply sector provides a suitable case for such a study.

[2] The draft National water framework bill, 2016, released by the Ministry of Water Resources (MoWR) discusses water pricing and suggests a graded pricing system, with full cost-reflective pricing for domestic water supplies for high-income groups (MoWR, 2016). Further, an advisory note on improving urban water supply and sanitation, from Ministry of Urban Development, recommends the states to set up regulatory mechanisms through an independent authority for setting standards, monitoring performance and adjusting tariffs (MoUD, 2012).

[3] The institutional set up in Indian water supplies is currently characterised by the absence of National level water regulatory authority and the emergence of state-level Independent Water Regulatory Authorities is a recent phenomenon shaping up in at least seven states (Swaniti, 2016). Further, most of the state water regulatory authorities do not include provisions for regulating water service provisioning and are solely named as water resource regulatory authorities (see PRAYAS, 2009). Moreover, the existence of multiple institutions and lack of co-ordination results in duplication and ambiguity of functions and hinders fixing up of responsibility for failure to implement stated policy (Kulshrestha et al., 2012).

This paper analyses the performance of Indian urban water supply utilities in 3 states from 2010-11 to 2015-16 considering socioeconomic and environmental aspects.[4] We use a Stochastic Frontier Analysis (SFA) approach to estimate a multi-input multi-output distance function. The paper specifically focuses on:

i. Evaluating the performance of Indian urban water supply utilities taking into account social, economic and environmental dimensions,
ii. Examining the economic characteristics of sector's technology and the impact of specific factors on utilities' performance,
iii. Assessing the behaviour of the utilities based on the type of incentives relative to the results obtained from the analysis, and
iv. Drawing policy recommendations concerning the sector and its reforms.

The paper is structured as follows. Section 2 presents a synopsis of the literature on the performance of the water supply sector and focuses on the Indian case. Section 3 describes the methodology of the study. Section 4 reports the results and discussion of results from a policy perspective. Section 5 is concluding remarks and policy recommendations.

2. Literature Review on Water Utility Performance

Efficiency and productivity analysis studies are common in networks, distribution, manufacturing, regulated, service industries, public sector, and academic research to measure performance, minimise costs, improve service delivery, and ensure greater accountability (see Coelli and Lawrence, 2006). Kulshrestha and Vishwakarma (2013) and Vishwakarma et al. (2016) are examples of literature reviews about the broad application of performance assessment in different sectors. These studies show application of nonparametric (such as Data Envelopment Analysis, DEA) and parametric (such as SFA) methods across various sectors in different parts of Asia, Africa, Europe, America and Australia.

[4] India is composed of 29 states and 7 union territories. The present study includes three Indian states (Gujarat, Maharashtra, and Chhattisgarh) due to data restrictions. These three states represent 18% of the total water connections in India (MHUPA, 2013) and reflect the structural, technical and economic features of the Indian urban water supply sector. Further, they portray the way water utilities operate in the country. The results from the present study provide useful lessons to improve urban water supply services in all states. Additionally, many economic, governance and policy recommendations are transferable across the states.

These methods are used by sector regulators for tariff and revenue setting, assessing the effectiveness of reforms and social and economic policies (Jamasb et al., 2006; Li and Waddams, 2012). Much emphasis has been laid on improving water supply services and hence on performance measurements in US, UK and parts of Europe since the 1970s.[5] Abbott and Cohen (2009) summarise the performance measurement studies in water sector over the period 1969-2007 across UK, USA, parts of Europe and Australia. The study reviews the various measures used to gauge productivity and efficiency and summarises the key structural findings on economies of scale and scope, public versus private ownership and the impact of regulation.

Most studies are focused on the effect of ownership arrangements (public vs private), changes in regulation, and governance on performance (see Guerrini et al., 2011). These studies further investigate scale and scope economies of water utilities (see Carvalho et al., 2012; Mercadier et al., 2016), choice of public versus private considering factors such as cost of funds, differences in efficiency scores, transaction costs, and political cost of privatisation (see Perard, 2009). Recent studies also include service quality recognising its social, political, economic and environmental implications (see Romano et al., 2017). The importance of including quality measures in cost minimisation studies of water utilities is highlighted by Lin (2005) and Picazo-Tadeo et al. (2008), as a higher quality is associated with higher costs and the difference between conventional and quality-adjusted evaluations viewed as the opportunity cost of maintaining quality.

On the other hand, recent theoretical and empirical studies examined the relevance of structures and institutions to public utility performance and stressed the importance of the institutional environment on performance (Borghi et al., 2016). Beecher (2013) examined the effect of structural and institutional dimensions on performance focusing on US water sector. The model includes three structural dimensions (ownership type, practice standards, and enterprise autonomy) and three institutional dimensions (market contestability, external review, and economic regulation) in the analysis. In summary, the study suggests that each of the dimensions may be complementary or substitutive while a pragmatic approach is to

[5] Performance measurement of water utilities has become a standard practice in developed countries due the presence of a dedicated sector regulator as water supplies evolved in the form of an industry with increasing private participation as in other network industries (Kulshrestha, 2005; CEPT, 2013).

strengthen the core governance capacities which ultimately matter most in relation to performance priorities.

2.1 Studies in the Indian Water Supply Sector

As highlighted by Berg and Marques (2011), research on water utility performance is not a high-status activity in comparison to other sectors and data availability affects the pace and patterns of analysis. This has been particularly the case in developing countries (especially in Asia), because of the lack of appropriate data, and above that the water supplies are yet to take on the form of an industry. The absence of a sector regulator also discourages performance measurement in the sector.

Performance measurement in Indian water sector has mainly been limited to researchers and was not inbuilt in the system, unlike many developed nations.[6] Although there have been efforts to measure performance of Indian urban water utilities by national and international organisations (e.g., CPHEEO, 2005; ADB, 2007; World Bank, 2008) their purposes have ranged from providing baseline information to exploring the use of benchmarking practices and are mostly one-time efforts using different set of indicators in each study. Thus, there was no common ground on which the performances of utilities could be measured to monitor progress and develop accountability. With the introduction of Service Level Benchmarks (SLBs) by the Ministry of Urban Development in 2008 (MoUD, 2009), a weighted index approach (wherein each indicator is given equal weight) is used to assess the performance of utilities with respect to service level indicators (see PAS, 2014). However, this approach does not give much information about the utilities in terms of operations, expenditures, and efficiency which are important from a sustainability viewpoint.

Table 1 summarises the studies on the performance of Indian urban water sector. An early attempt to lay down a framework for efficiency evaluation was initiated by Kulshrestha (2005). The study used cross-sectional data from the year 1999 for the analysis and other

[6] A number of water and waste water utility associations and regulatory agencies across the world have used different benchmarking methods since the late 1990's to assess performances, increase competitiveness, and to improve efficiency in water supply, sewerage operations and service delivery. This has mainly been the case in Latin America, most of Europe, Australia, Mozambique, and Zambia. Other countries such as Brazil, South Africa, Tanzania, Ecuador, and Uganda adopted these methods to measure the progress of selected government initiatives with respect to water supply and sewerage and prioritise funding options (CEPT, 2010).

authors have subsequently used the same data (e.g., Kulshrestha, 2006; 2009; Singh et al., 2010; 2011; 2014). Some recent studies use a limited number of utilities and have focused on efficiency measurements and cost-saving. This reflects the data constraints in Indian water supply as highlighted by most studies in Table 1. Further, these studies have mostly relied on a DEA approach due to its simplicity and the imposition of fewer assumptions on the shape of firm's technology.[7]

Singh et al. (2010, 2011) added the sustainability dimension to the analysis whereas Kumar and Mangi (2010), Tiwari and Gulati (2011), Nag and Garg (2013) incorporated a quality dimension in their analysis. Vishwakarma et al. (2016) used SFA to evaluate cost efficiencies of Indian water utilities. The study used cross-sectional data on a limited number of utilities (18) and focuses solely on one state (Madhya Pradesh). Further, the study is limited to a narrow set of indicators (exclusive of quality measures) due to data restrictions thereby affecting policy decisions needed to improve performance of the sector. Further, Nyathikala and Kulshrestha (2017) was the first attempt to develop a framework to measure X-factors for a possible sector regulation. The study used panel data to measure performance and productivity of Indian water supply utilities.

Most reform programs in Indian urban water sector are introduced since 2004 as a means to achieve Millennium Development Goals (MoUD and PA, 2004). The above studies mostly rely on cross-sectional data from 1999 portraying the past setup of the sector. Studies that use recent data (2002, 2005, 2010, and 2012) have been restricted to a particular year due to the lack of consistent indicator base (see Table 1). Although, Nyathikala and Kulshrestha (2017) measure performance of Indian water utilities using 1999 and 2010 data, the study could not measure their performance along different dimensions of reforms. The study also highlighted the issues of consistency in the data.

[7] Moreover, DEA also avoids convergence issues and the well-known "wrong-skewness" problem in the SFA literature.

Table 1. Summary of studies of performance of Indian water utilities

Study	Utilities Count	Period	Methodology	Description
Kulshrestha (2005, 2009)	147	1999	Input-oriented DEA and Scorecard	Earliest attempts to develop two frameworks to measure performances in the water supply operations. The study evaluates possible savings in Opex and Unaccounted-for Water (UFW)
Kulshrestha (2006)	5 cities	1999	Scorecard	Proposes a generic framework to formulate a scorecard to measure performances using a specific set of indicator clusters.
Gupta et al. (2006, 2012)	27	2004-05	Output-oriented DEA	First attempt to use the concept of total factor productivity to estimate technical efficiencies within two groups (municipal corporations and parastatals)
Singh et al. (2010)	18	1999	Input-oriented DEA	Added sustainability dimension to the analysis.
Singh et al. (2011)	35	1999	Input-oriented DEA	Sustainability-based performance assessment.
Kumar and Mangi (2010)	20	2005	DEA	Incorporated quality dimension to performance analysis using variables such as Accounted-for Water (AFW), hours of supply and quality of water.
Tiwari and Gulati (2011)	31 cities	2005	DEA	Analyses performance in the delivery of services.
Kulshrestha and Vishwakarma (2013)	20	2010	Input-oriented DEA	Evaluates relative inefficiencies in water supply services and estimates possible savings in Opex, UFW and Staff.
Nag and Garg (2013)	127	2002	DEA	Measures performance in water service delivery.
Singh et al. (2014)	12	1999	DEA and Index Method	Compares and analyses the efficiency scores using two methods.
Vishwakarma et al. (2016)	18	2010	SFA (Cost function)	Evaluates cost efficiencies and estimates possible savings in operating and maintenance costs.
Jaladhi et al. (2016)	+400 cities	2010-2015	Indicator to Indicator comparisons	Developed an online interface to track performances of each utility with respect to benchmarks set by MoUD (2009) over time.
Gill and Nema (2016)	311	2012	DEA	First attempt to develop a framework to explore efficiencies and measure performances in rural utilities.
Nyathikala and Kulshrestha (2017)	21	1999 and 2010	Malmquist-DEA	First study using panel data to measure performance and productivity. Developed a framework to measure X-factors for possible sector regulation

Additionally, at a global level there are very few multidimensional performance studies of utility networks in general and in water supplies in particular. The review of the literature at present identified only two studies (Singh et al., 2010; 2011), that focus on multi-dimensional performance analysis of water supply utilities. Although the variables used in Singh et al. (2010, 2011) are incorporated in most efficiency evaluation studies (see Romano et al., 2017), the focus of these studies were to assess performance accounting for service quality and not on multi-dimensional performance analysis. The indicators thus used in the studies summarised by Romano et al. (2017) include quality measures in their analysis (see Lin, 2005; Romano et al., 2017) and are not specifically grouped in to multiple dimensions. Singh et al. (2010, 2011) estimate performance of Indian urban water utilities incorporating a range of sustainability parameters grouped in to key sustainability dimensions (social, environmental and financial). These studies used cross-sectional data from the year 1999 and made use of DEA to estimate multi-dimensional performance of Indian water utilities. As in many other studies, the study was restricted to a limited number of utilities (18 utilities in Singh et al., 2010; 35 utilities in Singh et al., 2011) and to a particular year due to data restrictions, and depicts the past set up and performance of the sector.

Recently, Jaladhi et al. (2016) provided a platform to compare the progress of water utilities with respect to service level benchmarks (SLBs) set by MoUD (2009) over time (2010-2016). We use this data in the first panel data multi-dimensional (socio-economic and environmental) performance analysis of Indian urban water supply utilities. Although, the present study seems to be on a similar note to that of Singh et al. (2010, 2011), we use different set of indicators to capture multiple dimensions of reform objectives and analyse the performance of water supply utilities using a recent panel data set over the period 2010-2015.[8] Our study further examines the conduct of the utilities with a view to design better governance and incentives to improve efficiency in the sector.

[8] The reform programmes and central government policies introduced in the Indian urban water sector during the period 2007-2017 (Planning Commission, 2008; MoUD, 2012; NITI Aayog, 2017) focused on the aspects of universal access, full cost recovery, reducing losses, improving service delivery and incorporating efficient water management practices at all levels of water uses. Therefore, it is important that the current study incorporates multiple dimensions of reform objectives to evaluate performance of water supply utilities.

3. Methodology

3.1 Definition of an Output-Oriented Distance Function

This section describes the methodology adopted in this paper to analyse the performance of Indian urban water supply utilities. This approach enables us to examine some economic characteristics of the sector's technology. In general terms, the production technology P(x) of the sector can be defined as:

$$P(x) = \{y \in R_{+}^{M}: x \text{ can produce } y\} \quad (1)$$

where x denotes a non-negative vector of inputs$\left(x \in R_{+}^{k}\right)$, y denotes a non-negative vector of outputs, $(y \in R_{+}^{M})$ and P(x) represents the output possibility set which is assumed to satisfy the axioms listed in Fare (1988).

Distance functions provide a characterisation of production technology when multiple inputs are used to produce multiple outputs. They may be specified as input-oriented or output-oriented. The input-oriented approach has been adopted by most studies of performance of Indian urban water sector (see Table 1). However, this approach may be not appropriate for decentralised governance systems such as the Indian water supply sector,[9] where the prime objective of local authorities has been to extend the capacity and water service to meet the unmet demand of a developing economy and growing population. An output-oriented approach, i.e., the maximisation of outputs from a given level of resources, is theoretically appropriate and compatible with the objectives of the authorities.[10] Therefore, we use an output-oriented distance function to characterise the production technology of the sector.

An output distance function takes an output expanding approach to the measurement of the distance from a producer to the boundary of production possibilities. It gives the minimum amount, θ, by which an output vector can be deflated and remain producible with a given input vector (Kumbhakar and Lovell, 2003).

[9] The 74th Amendment to the Constitution of India, 1992 (Constitution (Seventy-Fourth Amendment) Act, 1992) required the state governments to constitute urban local entities in the form of various municipal level bodies for decentralised administration and accordingly the primary responsibility for providing drinking water services rests with the State Governments, and, more specifically, with the local bodies in urban areas. The Central government provides funds and ensures that funds are also provided in State budgets.

[10] The government has announced an ambitious target of providing universal water coverage by 2019 (MoEF and UNDP, 2015) and the Twelfth plan (2012-2017) aims for 100% coverage, provision of piped and 24×7 supply (Planning commission, 2013).

The output distance function, as introduced by Shephard (1970), is defined on the output set, P(x), as:

$$D_O(x,y)=\min\left\{\theta:\left({}^{y}/_{\theta}\right)\in P(x)\right\} \quad (2)$$

The distance function, $D_O(x,y)$, is non-decreasing in y and non-increasing in x, and linearly homogenous and convex in y. It takes a value less than or equal to one if the output vector, y, is an element of the feasible production set, P(x), and will take a value of unity if y is located on the "frontier" of the production possibility set (Coelli and Perelman, 1996).

3.1.1 Choice of the Functional Form

In a parametric framework such as SFA, one of the first decisions is the selection of an appropriate functional form which would be ideally flexible, easy to calculate and permit the imposition of homogeneity. It is also convenient to choose a functional form that expresses the log-distance as a linear function of inputs and outputs.

The present study makes use of both the Cobb-Douglas and Translog specifications to estimate the parameters of the model. The Cobb-Douglas distance function for the case of M outputs and K inputs can be specified as:

$$\ln D_{0i}=\alpha_0+\sum_{m=1}^{M}\alpha_m \ln y_{mi}+\sum_{k=1}^{K}\beta_k \ln x_{ki}, \quad i = 1,\ldots,N \quad (3)$$

where i denotes the i^{th} observation in the sample, and α and β are the coefficients to be estimated. The more flexible standard translog distance function is expressed as:

$$\ln D_{0i}=\alpha_0+\sum_{m=1}^{M}\alpha_m \ln y_{mi}+\frac{1}{2}\sum_{m=1}^{M}\sum_{q=1}^{M}\alpha_{mq}\ln y_{mi}\ln y_{qi}+\sum_{k=1}^{K}\beta_k \ln x_{ki}$$
$$+\frac{1}{2}\sum_{k=1}^{K}\sum_{l=1}^{K}\beta_{kl}\ln x_{ki}\ln x_{li}+\sum_{k=1}^{K}\sum_{m=1}^{M}\rho_{km}\ln x_{ki}\ln y_{mi}, \quad i = 1,\ldots,N \quad (4)$$

where ρ represents the additional coefficients to be estimated that are linked with the interaction between inputs and outputs. A convenient method of imposing the homogeneity of degree +1 in outputs upon Equation (4) is presented by Lovell et al. (1994). Homogeneity implies that:

$$D_0(x,\omega y)=\omega D_0(x,y) \quad \text{for any } \omega>0 \quad (5)$$

Hence if we arbitrarily choose one output (e.g., the M-th output), and set $\omega = 1/y_M$, we obtain:

$$D_O(x, y/y_M) = D_O(x,y)/y_M \quad (6)$$

By using this property in the context of a translog specification (represented here by TL) such as the one expressed in Equation (4), we obtain:

$$\ln(D_{Oi}/y_{Mi}) = TL(x_i, y_i/y_{Mi}, \alpha, \beta, \rho) \quad (7)$$

After rearranging terms we obtain:

$$-\ln(y_{Mi}) = TL(x_i, y_i/y_{Mi}, \alpha, \beta, \rho) - \ln(D_{Oi}), \quad i=1,\ldots,N \quad (8)$$

The SFA literature starting from Aigner et al. (1977) and Meeusen and van den Broeck (1977) highlights that deviations between actual firms' production (cost) functions should be attributed to random shocks and managerial inefficiency. These seminal papers proposed a specification that includes two random terms that capture both sources of deviations. By incorporating a symmetric error term, v_{it}, to capture statistical noise in Equation (6) and changing the notation of $-\ln(D_{Oit})$ to u_{it}, which accounts for technical inefficiency, we obtain a stochastic output distance function that can be presented as:

$$-\ln(y_{Mi}) = TL(x_i, y_i/y_{Mi}, \alpha, \beta, \rho) + v_i + u_i, \quad i=1,\ldots,N \quad (9)$$

where v_i follows a normal distribution and is independently and identically distributed (iid), i.e., $v_i \sim N(0, \sigma_v^2)$, and u_i is a non-negative iid random term that follows a half-normal distribution, i.e., $u_i \sim N^+(0, \sigma_u^2)$, and captures the technical inefficiency of the utilities.

3.1.2 Introduction of Inefficiency Determinants

In order to examine the factors causing inefficiency, several heteroscedastic models that allow to introduce inefficiency determinants have been developed in the SFA literature.[11] In this paper we use the approach proposed by Reifschneider and Stevenson (1991), Caudill and Ford (1993) and Caudill et al. (1995) (commonly referred to as RSCFG model). The specific

[11] For a brief summary see Llorca et al. (2016).

characteristic of this type of model is that satisfies the scaling property, i.e., changes in the inefficiency determinants affect the scale but not the shape of u_i (Alvarez et al., 2006).

In the RSCFG model, the inefficiency term, u_{it}, can be decomposed as follows:

$$u_{it}(z_{it}, \delta)=h(z_{it}, \delta)u_{it}^{*} \quad (10)$$

where $h(z_{it}, \delta)$ is a scaling function that is always positive and presents an exponential functional form, z_{it} represents the inefficiency determinants, δ is the additional set of parameters to be estimated and u_{it}^{*} is a measure of raw inefficiency that does not depend on z_{it} and follows a half-normal distribution. By substituting Equation (10) in (9) the output distance function that we obtain can be expressed as:

$$-\ln(y_{Mit})=TL(x_{it,}\, y_{it}/y_{Mit}\, , \alpha,\beta,\rho) +v_{it} + h(z_{it}, \delta)u_{it}^{*} \quad (11)$$

3.2 Model Specification and Data

3.2.1 Dimensions of Analysis and Selection of Input and Outputs

The indicators used in this paper are classified into five different groups based on socioeconomic and environmental dimensions. Keeping in view major reform programs introduced in Indian urban water supply sector, Sustainable Development Goals (SDG) targets and action plans formulated by the Government of India,[12] it is important to analyse the performance of water supply services in these three major dimensions and comprehend the trade-offs between social, economic and environmental objectives. Table 2 presents the input and output variables used in the present study.

A detailed definition of the variables is presented in Appendix A. These set of variables are adopted from benchmarking literature in the water supply sector which included

[12] During the past decade, the Indian water supply sector has seen major economic reforms and the recent three-year (2017-2019) action plan of the Government of India emphasises on achieving continuous piped water supply to every household and calls for state level specific policies to restructure the pricing mechanisms and enhance financial viability of the sector through cost reflective pricing (NITI Aayog, 2017). Further, the SDG targets aspire to achieve universal and equitable access, improve water quality, ensure sustainable withdrawals and protect water related ecosystems (UN, 2015). The goals and targets are multi-dimensional in nature as it is important to understand the trade-offs between social, economic and environmental objectives to ensure sustainability in the water sector.

sustainability and quality dimensions in the analysis (see Singh et al., 2010; Romano et al., 2017). An additional variable included in the present study that has not been considered in the literature before is groundwater. This variable is a resource use indicator to reflect the degree of reliance of utilities on groundwater sources and environmental sustainability as a part of resource conservation practice.[13] It is defined as the share of groundwater with respect to total water supplied.

Table 2. Input, Outputs, Indicator Groups and Dimensions of Analysis

Inputs	Outputs	Indicator Groups	Dimension
▪ Operating Expenditure Opex (Rs) ▪ Capital Expenditure Capex (Rs)	▪ Total water supplied (MLD) ▪ Total water connections (No.s)	Access	Social
	▪ Supply hours (Hrs)	Quality of supply / Supply reliability	
	▪ Complaint efficiency (%)	Service efficiency	
	▪ Efficiency in bill collections (%) ▪ Cost recovery (%)	Financial viability	Economic
	▪ Groundwater (%) ▪ Extent of non-revenue water (%)	Environmental sustainability	Environmental

Note: MLD: Million Litres Per day; Rs= INR=Indian Rupees; Hrs= Hours per day.

In addition, we introduce two dummy variables (SD1 and SD2) to control for the unobserved heterogeneity existing between the three states where the utilities of our sample are located. Further, we use a time trend variable, t, which interacts with the other variables in the model allowing the estimation to capture non-neutral technical change.

[13] It should be noted that unregulated ground water withdrawals and the absence of abstraction charges is a major sustainability issue concerning Indian water supply sector (see Kulshrestha et al., 2012). In fact, India ranks 1st among top 10 ground water abstraction countries, with an average abstraction rate of 251 km^3/year (IGRAC, 2010). This spells problems for water supplies in the long run due to rapidly falling groundwater tables, increased abstraction costs and pollution of aquifers.

3.3.2 Inefficiency Determinants

As mentioned earlier it is important to identify the determinants of inefficiency in the sector in order to understand the impact caused by specific factors on the performance of the sector and the utilities. The present study examines the effect of both physical and financial indicators on utilities' performance using two models. Table 3 shows the inefficiency determinants included in both models. Model I captures the effect of physical variables on the utilities' performance and on a similar note, Model II captures the effect of financial variables on the utilities' performance.

Table 3. Models of Inefficiency Determinants

Model I (Physical Indicators)	**Model II (Financial Indicators)**
• Quality of water supplied (ws_qlty) (%)	• Cost Recovery (cr) (%)
• Extent of Non- Revenue Water (nrw) (%)	• Billing efficiency (bill_eff) (%)

These indicators used in our analysis are specifically selected taking into account the particular features of the Indian urban water supply sector, their issues and challenges as mentioned by Kulshrestha et al. (2012) and examining the database provided by PAS (2017). Amongst the various issues concerning the Indian urban water supplies, the variables presented in Model I and Model II reflects several technical and financial shortcomings in the sector (see Kulshrestha et al., 2012; IIHS, 2014; Prabhu, 2012 and WaterAid India, 2005). Model I captures two major technical issues concerning the sector which are the quality of the water supplied and the non-revenue water.[14]

Another key factor affecting water situation in India since past decade is the absence of cost reflective pricing leading to low coverage (often leaving the poor unconnected), poor service delivery (intermittent supplies), high subsidies and unsustainable and inefficient use of water. Model II captures the financial shortcomings in the sector using two variables: cost recovery

[14] One of the biggest issues concerning Indian urban water supplies particularly at the household level remains that of water contamination, and its consequent impact on health and human wellbeing. Even though the water supplied through public systems is treated as per the standards, contamination occurs in the systems due to leakage before it reaches consumer end owing to lack of monitoring.

and billing efficiency. The variables used in both the models (Model I and Model II) are utility-specific and of relevance to local authorities and utility managers to fulfil several reform objectives. This paper explores the link between the above specified indicators and utilities' performance by introducing them as environmental variables in the inefficiency term of the RSCFG model (see Equation 11). This will help us observe the effect of each indicator on utilities' performance and provide a way to prioritise factors on which utilities should focus to improve their performance and achieve targets.

3.4 Data

We use an unbalanced panel data set including information on 304 utilities over a total of 462 which operate in 3 Indian states and are observed over a 6-year period from 2010-2015, leading to 1,540 observations.[15] Table 4 presents the descriptive statistics of the variables included in the analysis. It can be noted that the variation in maximum and minimum values for all the parameters and the standard deviation for selected parameters of the sample utilities is large indicating that considerable differences exist in operational characteristics and sizes within utilities as reflected by output variables. Note that the variables, supply hours show value as low as 0.1hrs and non-revenue water has a value as high as 90.5% (nrw) reflecting the current challenges facing the Indian urban water supply sector.[16]

The correlation coefficients of the variables are presented in the Appendix B. The correlation among some technical variables, Capex, and Opex, are relatively large as expected in efficiency studies carried out for distribution networks. On the other hand, the correlation among other variables defining the quality of supply, service efficiency, financial viability and environmental sustainability including variables introduced as inefficiency determinants in the model are much smaller.

[15] The states included in the study are Gujarat, Maharashtra, and Chhattisgarh. During the period of data collection (August, 2017) from the database (PAS, 2017), only 3 states possessed information on input variables and a set of output variables which are classified in "access" grouping in the study. The scope of the analysis in this paper is therefore limited to three states. It should be noted that urban water supply services in India are managed by government, mostly through urban local bodies and the water supply utilities in the current study are operated by local government authorities (Constitution (Seventy-Fourth Amendment) Act, 1992).

[16] This is a common situation in Indian cities, where most urban centers receive water every alternate day for few hours and in some cases after several days (Shaban and Sharma, 2007). In addition, water supplies in India suffer from heavy losses due to poor operation and maintenance and the absence of adequate metering (Kulshrestha et al, 2012). This pattern of figures (Table. 4) with respect to variables: supply hours (sh) and Non-revenue water (nrw) can be observed in the empirical literature that focused on measuring performance of Indian urban water supplies (see Nag and Garg, 2013; Vishwakarma et al, 2016).

Table 4. Descriptive statistics

Variable	Unit	Mean	Std. Dev.	Min.	Max.
Operating Expenditure (Opex)*	Mill. rupees	44.17	157.77	393.99	1,668
Capital Expenditure (Capex)*	Mill. rupees	45.35	225.95	0.001	4,303
Total Water Connections (wconn)	No. of	13,668	47,090	36	1,474,093
Total Water Supplied (ws)	MLD	23.27	102.700	0.10	2,000
Ground Water (gw)	%	22.48	33.32	0	100
Supply Hours (sh)	Hours	1.41	2.01	0.10	24
Complaint Efficiency (compl_Eff)	%	85.36	18.00	7.7	100
Cost Recovery (cr)	%	65.46	38.23	1.6	301.30
Billing Efficiency (bill_eff)	%	58.93	23.99	0.40	100
Non-Revenue Water (nrw)	%	25.16	12.54	0.90	90.5
Quality of water supplied (ws_qlty)	%	94.84	10.30	18.90	100

Data source : PAS database, Available: www.pas.org.in
Note: MLD= Million Litres per Day, *Opex and Capex are deflated using GDP deflator considering base year as 2011, No. of observations = 1,540.

4 Results and Discussions

In this section we present and discuss the parameter estimates of our output distance function. We alternatively use a Cobb-Douglas and a translog functional form and we follow the distributional assumptions from Aigner et al. (1977) (henceforth ALS model) for the inefficiency term. We also estimate the RSCFG model as described in Section 3.3.2, and as shown in Equation (11), that allows us to introduce inefficiency determinants. The dependent variable in the model is total amount of water supplied (ws).

The first model to estimate is the ALS model assuming a Cobb-Douglas functional form. This model does not include inefficiency determinants. As expected from an output distance function, the coefficients of all output variables are positive and mostly significant. Similarly, the coefficients of the input variables are negative and statistically significant. The coefficients of the state dummy variables are not significant, indicating that the differences among the three states have no considerable impact on the performance of their respective utilities.[17] The parameter estimates of the models are presented in Table 5. The second model is an output distance function with a translog specification in which we do not incorporate inefficiency determinants either. Overall, the model behaves in a similar fashion as the Cobb-Douglas with slight changes noted in first-order coefficients and significance levels of a certain variables.

The first-order coefficient of the output variable, Non-Revenue Water (nrw) changes sign from positive in the ALS model with Cobb-Douglas specification to negative when the translog specification is used and remains significant in both cases. The variable does not show the expected sign in the Cobb-Douglas specification but behaves well under the translog specification. The negative sign in the translog model indicates that as non-revenue water increases, the total water supplied also increases. This is an expected outcome as non-revenue water, which includes both physical and apparent losses, is an undesirable by-product. On the other hand, in the translog specification, the first-order coefficient of the outputs complaint efficiency (compl_eff) and groundwater (gw) are significant while the coefficient of the time trend variable (t) is no longer significant.

The coefficients of the interactions of the time trend with some variables are significant in the translog specification, implying that they reflect some non-neutral technical change. This can be specifically observed in non-revenue water (nrw) and ground water (gw) variables. The coefficients of both variables change their signs relative to their first-order coefficients when interacted with the time trend. The negative sign of the coefficient of the interaction between ground water and the trend indicates that, over time, reduction in the ground water share results in more reduction in total water supplied. Similarly, the positive sign of the coefficient of the nrw with trend implies that, over time, reduction in non-revenue water results in less reduction in total water supplied. The estimates of other variables seem to be robust as all the first-order coefficients of output and input variables remain significant with the expected signs, while most of the interactions between variables are also significant.

[17] Major Institutional and financial reforms are introduced in the states of Maharashtra and Gujarat among them proposals for public-private partnership for water infrastructure and maintenance (see Wagle et al., 2011; NIUA, 2015; IIHS, 2014). The types of reforms introduced vary in different states and there are considerable differences among them in terms of geography, availability of water resources and rainfall patterns, among other things. This heterogeneity is controlled through the state dummy variables in our study.

Table 5. Parameter estimates of the models

Variables Dep. Var., -log (ws)	ALS (Cobb-Douglas) Est.	ALS (Cobb-Douglas) Std. Err.	ALS (TL) Est.	ALS (TL) Std. Err.	RSCFG (TL) Model I Est.	RSCFG (TL) Model I Std. Err.	RSCFG (TL) Model II Est.	RSCFG (TL) Model II Std. Err.
Frontier								
Intercept	-2.109***	0.077	-1.611***	0.064	-1.994***	0.068	-1.788***	0.058
log wconn	0.564***	0.023	0.647***	0.024	0.644***	0.023	0.638***	0.022
gw	0.001	0.001	0.033***	0.004	0.031***	0.004	0.031***	0.004
log sh	0.233***	0.012	0.223***	0.011	0.216***	0.011	0.200***	0.010
compl_eff	0.000	0.004	0.017*	0.008	0.017*	0.009	0.015*	0.008
bill_eff	0.002	0.002	0.031***	0.006	0.024***	0.007	0.004	0.007
cr	0.007***	0.001	0.061***	0.004	0.059***	0.004	0.030***	0.004
nrw	0.016***	0.002	-0.050***	0.013	-0.005	0.018	-0.039***	0.012
log opex	-0.612***	0.014	-0.591***	0.014	-0.609***	0.014	-0.629***	0.013
log capex	-0.013*	0.007	-0.023***	0.006	-0.020***	0.006	-0.017***	0.006
t	0.016**	0.006	0.001	0.005	0.002	0.006	0.003	0.005
½ (log wconn)^2			0.235***	0.029	0.234***	0.029	0.262***	0.028
½ (log sh)^2			0.077***	0.016	0.054***	0.015	0.008	0.015
½ compl_eff^2			-0.002*	0.001	-0.002*	0.001	-0.002*	0.001
½ bill_eff^2			-0.001	0.001	-0.001	0.001	-0.001	0.001
½ cr^2			0.000	0.000	0.000	0.000	0.000	0.000
½ gw^2			-0.001	0.000	0.000	0.001	-0.001	0.001
½ nrw^2			0.001	0.003	0.001	0.004	-0.001	0.003
½ (log opex)^2			-0.008	0.02	-0.031	0.021	-0.100***	0.020
½ (log capex)^2			-0.003	0.004	0.000	0.005	0.000	0.004
½ t^2			0.000	0.007	0.004	0.008	0.008	0.007
log wconn · log sh			-0.069***	0.02	-0.093***	0.021	-0.085***	0.021
log wconn · compl_eff			0.005	0.015	0.002	0.017	-0.013	0.016
log wconn · bill_eff			-0.039***	0.012	-0.019	0.013	-0.017	0.012
log wconn · cr			0.027***	0.008	0.034***	0.009	0.019**	0.009
log wconn · gw			-0.014	0.009	-0.015	0.009	-0.008	0.009
log wconn · nrw			-0.048**	0.021	-0.058***	0.021	-0.081***	0.020
log sh · compl_eff			0.021**	0.01	0.017	0.010	0.007	0.010
log sh · bill_eff			0.013*	0.006	0.008	0.007	-0.011*	0.006
log sh · cr			0.011**	0.004	0.015***	0.004	0.004	0.004
log sh · gw			0.008	0.005	0.002	0.005	0.000	0.005
log sh · nrw			0.025**	0.012	0.012	0.012	0.011	0.011
compl_eff · bill_eff			0.000	0	0.000	0.001	0.000	0.001
compl_eff · cr			0.001	0.001	0.001	0.001	0.002**	0.001
compl_eff · gw			0.000	0	-0.001	0.000	-0.001***	0.000
compl_eff · nrw			0.002	0.002	0.003	0.002	0.002	0.002
bill_eff · cr			0.001*	0	0.001**	0.000	0.000	0.000
bill_eff · gw			0.000	0	0.000	0.001	0.000	0.001
bill_eff · nrw			0.002*	0.001	0.004***	0.001	0.003***	0.001

cr · gw			0.001***	0	0.001***	0.000	0.001**	0.000
cr · nrw			0.000	0.001	0.000	0.001	-0.001	0.001
gw · nrw			0.000	0.002	0.000	0.002	-0.001	0.002
log opex · log capex			-0.005	0.007	-0.009	0.008	0.005	0.007
log wconn · log opex			-0.049**	0.023	-0.070***	0.023	-0.096***	0.022
log wconn · log capex			0.026*	0.013	0.007	0.014	0.018	0.013
log sh · log opex			0.067***	0.014	0.038**	0.015	-0.017	0.014
log sh · log capex			-0.025***	0.006	-0.018***	0.007	-0.006	0.007
compl_eff · log opex			0.016	0.012	0.012	0.011	-0.001	0.012
compl_eff · log capex			0.003	0.004	0.004	0.003	-0.001	0.004
bill_eff · log opex			-0.008	0.008	-0.007	0.008	-0.019**	0.008
bill_eff · log capex			0.003	0.003	0.005	0.004	0.007**	0.004
cr · log opex			-0.023***	0.004	-0.019***	0.004	-0.022***	0.004
cr · log capex			0.002	0.002	0.001	0.002	0.002	0.002
gw · log opex			-0.008	0.005	-0.016***	0.006	-0.020***	0.005
gw · log capex			-0.003	0.002	-0.008***	0.002	-0.005***	0.002
nrw · log opex			0.046**	0.018	0.001	0.017	0.008	0.015
nrw · log capex			0.011	0.007	0.011	0.007	0.017***	0.007
log wconn · t			-0.004	0.013	-0.011	0.013	-0.001	0.012
log sh · t			-0.003	0.006	-0.004	0.006	-0.003	0.006
compl_eff · t			0.007*	0.004	0.007	0.004	0.005	0.004
bill_eff · t			0.001	0.002	0.000	0.003	0.000	0.003
cr · t			0.001	0.002	-0.001	0.002	0.001	0.002
gw · t			-0.005*	0.002	-0.007***	0.002	-0.007***	0.002
nrw · t			0.019***	0.006	0.016**	0.007	0.016***	0.006
log opex · t			-0.004	0.007	-0.006	0.007	-0.001	0.007
log capex · t			0.008**	0.003	0.007**	0.004	0.005	0.003
SD1	0.053	0.073	0.043	0.063	-0.012	0.062	-0.042	0.058
SD2	0.064	0.072	0.054	0.062	0.019	0.061	-0.015	0.057
Noise Term (σ_v^2)	-1.961***	0.087	-2.252***	0.065	-2.394***	0.111	-2.263***	0.039
Inefficiency term (Variance)								
Intercept	-1.871***	0.217	-3.533***	0.234	-2.252***	0.285	-6.308***	0.596
ws_qlty					-0.030***	0.006		
cr							-0.103***	0.013
bill_eff							-0.020***	0.006
nrw					0.019**	0.008		
Observations	1,540		1,540		1,540		1,540	
Log-Likelihood	-928.887		-638.091		-618.378		-515.129	
Chi-squared LR test	581.592***		39.426*** Model I 245.924*** Model II		-		-	
(Degrees of freedom)	(54)		(2)					

Significance code: *** p<0.01, ** p<0.05, * p<0.1

The Likelihood Ratio (LR) test allows us to compare nested models such as those estimated here (i.e., Cobb-Douglas vs translog, and ALS vs RSCFG).[18] The values of the LR test are presented in Table 5 and show a value of 581.59 when the first two models are compared indicating that the Cobb-Douglas specification is rejected over the translog specification. Therefore, we use the translog specification to estimate the RSCFG model that incorporates inefficiency determinants. In addition, if we compare the two RSCFG models against the ALS model with translog specification, the ALS translog model is rejected over both RSCFG models and hence these are our preferred models.

The parameter estimates in the frontier of Model I and Model II have in general similar signs and order of magnitude to those in the ALS model with a translog specification. Nevertheless, incorporation of inefficiency determinants changes the significance levels of two output variables, Non-revenue water (nrw) in Model I and billing efficiency (bill_eff) in Model II, in the frontier, as these variables are introduced as inefficiency determinants in respective models and show their effect in the inefficiency term.[19] However, the significance of the cost recovery (cr) variable remains the same in the frontier and shows its effect in the inefficiency term. This result seems to suggest that it is preferable to include the cost recovery variable both as an explanatory variable in the frontier and as an inefficiency determinant. However, in case we have to choose, the variables Non-revenue water (nrw) and billing efficiency (bill_eff) should be introduced as inefficiency determinants rather than as variables to define the frontier of best-performance.

For the variable groundwater (gw), used as an sustainability indicator, the first-order coefficient in Model I and Model II is positive and significant. This shows the dependence of the water utilities on groundwater sources which also makes the sector environmentally unsustainable in the long run. These findings are in line with the current situation where more than 80% of India's drinking water needs are served by groundwater resources (Planning Commission, 2012) as surface water sources are depleted (due to low and moderate rainfall)

[18] Cobb-Douglas is a special case of translog in which the second-order parameters are equal to zero. In addition, from comparing Equations (11) and (10) we can observe that the ALS model is similar to an RSCFG model in which the δ-parameters associated to the inefficiency determinants are assumed to be equal to zero. For further details on this discussion, see Lai and Huang (2010).

[19] Non-revenue water and billing efficiency are introduced in the distance function in the form of ratios normalised by the output total water supplied. The additional incorporation of these outputs separately (i.e., without being normalised) as inefficiency determinants (is standard in the SFA literature and) does not yield any econometric problem derived from collinearity.

and polluted in many urban areas (due to unregulated waste disposals) creating pressure on urban aquifers which are not recharged. These findings are in line with those of Olmstead (2010) where, in a literature survey on economics of managing scarce water resources highlights that urbanisation has a negative impact on groundwater recharge and reduces the ability of urban areas to withstand drought. This further raise concerns over the limits of groundwater withdrawals and calls for action to manage the water bodies.[20]

The variable supply hours (sh) is an output and its coefficient is significant and positive in both models using the RSCFG specification of the inefficiency term. This is of relevance to design engineers and utility managers who often assume that intermittent water supplies are economical and need less water than the continuous ones, which may not be true. Kulshrestha et al. (2012) argue that restricted time supplies result in capital lock-up since the required water will be supplied in a limited time necessitating a higher diameter network.[21] Also, alternative cycles of supplies and cut-offs lead to greater maintenance requirement for the distribution networks and higher operations and maintenance costs. Additionally, although governing authorities frequently resort to supply cuts as a rationing method to limit water consumption the estimates from Roibas et al. (2007) and Roibas et al. (2018) suggest that supply cuts had a higher impact on consumer welfare losses than price rationing. Accordingly, supply interruptions do not seem to be the preferred rationing method in terms of welfare.

The findings of the present study on supply hours (sh) are in line with those of Roibas et al. (2007; 2018) and is of relevance to both developed and developing countries facing water supply interruptions whose rationing policies frequently include supply cuts as a means to conserve water. Thus, designing the network for continuous supply is a viable option considering its overall effect on utilities' performance. Similarly, the outputs cost recovery (cr) and complaint efficiency (compl_eff), which are often not a priority for local authorities, show significant positive impact on utilities' performance in both models.

[20] The situation warrants immediate attention, particularly with respect to drinking water security especially when no comprehensive legal framework is in place for regulating groundwater withdrawals (Kulshrestha et al., 2012). In terms of water security, urban centres need to recognise that current levels of water use are unsustainable, and policies need to develop action plans to manage and preserve water bodies and replenish groundwater sources rather than exploiting shrinking reserves.

[21] Note that water supplies in India are predominately intermittent and network size is the highest expenditure (sometimes over 70% of total asset cost) (Tynan and Kingdom, 2002), and hence pipe diameters on the field matter with respect to initial investments. Further, it was found that the value of peak factor (used in the design of networks) under intermittent supply varied from 2 to 6.4, in contrast to the range of 1.66-3 for continuous supplies, depending upon duration of supply and carrying capacity of the system (Paramasivam, 2017).

Additionally, we observe that all the variables in the inefficiency term in Model I and Model II are significant and show the expected sign. The coefficient of the variable ws_qlty in Model I is negative and significant. This implies that as the quality of water supplied increases, inefficiency declines, or in other words, i.e., efficiency augments. On the other hand, the variable Non-revenue water (nrw) in Model I is positive and significant. This implies that as the Non-revenue water (nrw) increases, inefficiency increases, or in other words, efficiency declines. Furthermore, the coefficients of the variables cr and bill_eff in Model II are negative and significant. This implies that as the cost recovery and billing efficiency increases, inefficiency declines, or in other words, efficiency increases.

It should be noted that the variables Non-revenue water (nrw), cost recovery (cr) and billing efficiency (bill_eff) show significant impact on utilities' performance in the frontier under translog specification and when introduced as inefficiency determinants under the RSCFG specification. This implies a well-defined relationship exist between these variables and the performance of utilities in the sector. It further highlights the need for utility managers and local authorities to focus on improving cost recovery, billing efficiency and reducing losses (non-revenue water) to achieve service delivery targets, expand coverage and induce efficiency measures in the sector. Some countries have managed to improve such indicators in their utilities sectors (see WBG, 2009; WBG, 2016; WSP, 2008). However, the current institutional set ups in Indian urban water sector, characterised by the absence of effective regulator makes it difficult to benchmark the performance of Urban Local Bodies (ULBs) within and across states leaving minimal incentives for local authorities and utility managers to improve performance. Therefore, it is imperative to establish national level regulatory authority, strengthen institutions and governance capacities as a prerequisite to these potential improvements.

Finally, the first-order coefficient of the time trend variable (t) is not significant in the RSCFG models. As in the case of the ALS model with the translog specification, the coefficients of some interactions of the time trend with other variables are significant, what reflects the existence of non-neutral technical change.

Figure 1 presents the evolution of efficiency scores in our preferred (RSCFG) models. Note that the two RSCFG models show similar pattern of results albeit different efficiency levels. These models do not clearly show convergence or divergence in utilities' performance over time during the analysed period. Overall, the evolution of the performance scores suggests that no significant change in the level of efficiencies is noted during the period of analysis in the two models. This indicates that little focus has been laid on efficiency improvements and that policies are directed towards achieving quality and quantity targets though not on creating the incentives to improve operating and service efficiencies.[22]

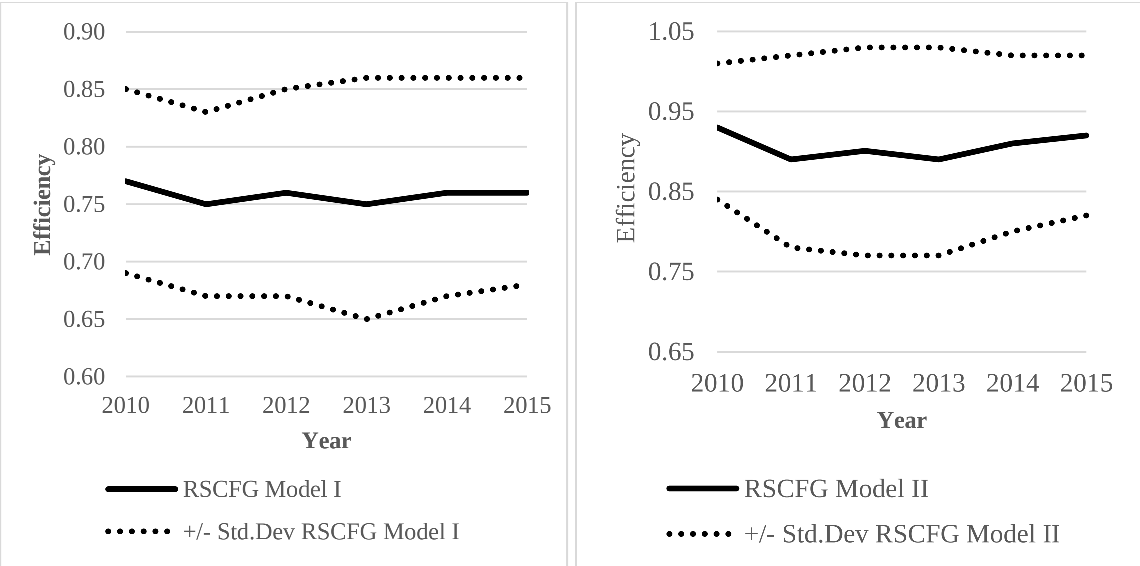

Figure 1. Annual evolution of efficiency in water distribution

These results are different to those by Nyathikala and Kulshrestha (2017), who analysed the performance of 21 Indian urban water supply utilities for the period 1999 and 2010 using a non-parametric DEA method. They found a decline in the average performance of water supply utilities over the analysed period. The difference in the results may be due to diverse reasons such as the application of an alternative approach, the analysis of another sample period and group utilities, or the incorporation of socio-economic and environmental aspects in the present study to measure the technical efficiency of water supply utilities.

[22] Major central government policies from 2002-2017 emphasis on extending water services to uncovered populations and rationalising water tariffs to recover operating and maintenance costs (see Locussol et al., 2006; TERI, 2010, NITI Aayog, 2017), no major focus has been laid on improving operational and service efficiencies of utilities. Although, thirteenth finance commission (2010-2015) of India (a unique Indian federal structure appointed every five years with the intension to share resources between the centre and state), recommended performance grants (FCI, 2009) to improve service level benchmarks (MoUD, 2009) for urban local bodies (ULBs), only few states qualify and claim the grant (see NIUA, 2018).

5 Conclusions and Policy Recommendations

Since the past decade and a half, India has seen major reform efforts in water supply sector on economic and institutional fronts. These reforms are based on the principles of rationalising water tariffs with a view to achieve full cost recovery, introducing public-private partnerships and establishing state regulatory authorities to achieve universal and equitable access to clean and safe drinking water as mandated by major central government policies.

At the same time, literature suggests that quality of institutions have an impact on the performance of utilities and constrain them from realising their technical potential. In such a case, utilities operating under fragmented set ups and politically dominant environments can face constraints over achieving reform objectives. Indian urban water supply sector provides a suitable case to examine the performance of utilities operating in such an environment. Moreover, studies that depict a complete picture of Indian urban water supply services are missing so far, and this paper attempts to understand the state of utilities considering socio-economic and environmental perspectives.

We use a recent dataset and a set of stochastic frontier models to estimate a multi-input-multi-output distance function in order to analyse the production characteristics and performance of Indian urban water supply utilities. The paper further focuses on determining the effect of specific factors on utilities' performance. The results show that an increase in supply reliability, service efficiency and financial viability of utilities improves their performance. In addition, the results show that utilities need to focus on reducing non-revenue water, which has a negative impact on the utilities' performance. Furthermore, utilities should reduce their dependence on utilisation of groundwater sources and develop action plans to manage water bodies.

Even though the focus of utilities and local authorities so far is to achieve social objectives (e.g., coverage targets), our results show that focusing on economic factors and environmental dimensions would not only help utilities achieve their social objectives, but also helps the financial and environmental sustainability of the sector. This holds also the case of other utility networks operating under politically dominant environments. Therefore, utility managers and local authorities should improve cost recovery, billing efficiency and reduce their losses (non-revenue water) which have a significant impact on their performance. This helps the utilities achieve service delivery targets, expand coverage and induce efficiency in the sector. This, in turn, establishes a trade-off between socioeconomic and environmental objectives ensuring sustainability in the sector. Policymakers should consider these factors and design economic incentives to improve the performance of water utilities enabling them to achieve their social objectives and long-term sustainability.

The paper also expresses concern over the current institutional set ups in Indian urban water sector, characterised by the absence of effective regulator leaving minimal incentives for local authorities and utility managers to improve performance. The study therefore highlights the need to establish and mandate national level regulatory authorities, strengthen the institutions and governance capacities as a prerequisite to achieve the above-mentioned potential improvements.

The Indian water supply sector can learn from their counterparts in other utility sectors such as electricity, gas and telecom and establish a central independent regulatory commission. The national level regulatory commission can in turn coordinate with state-level water regulatory authorities and monitor the performance of utilities across states. Moreover, the establishment of state water regulatory authorities should be mandated in all the states and be given legally defined powers. The powers of state water regulatory authorities should extend from allocating and regulating water resources to regulating water service provisioning, act as a tariff setting authority and limit political intervention. Further, there is an urgent need to establish performance benchmarking systems in the Indian water supply sector to help oversee the functioning of urban local bodies within the states, build accountability, transparency and track the progress of reform programs.

References

Abbott, M. and Cohen, B. (2009), "Productivity and efficiency measurement in the water industry", *Utilities Policy*, 17 (3), 233-244.

ADB (2007), *2007 Benchmarking and data book of water utilities in India*, Asian Development Bank, Manila, Philippines.

Aigner, D., Lovell, K. and Schmidt, P. (1977), "Formulation and Estimation of stochastic frontier production function models", *Journal of Econometrics*, 6, 21-37.

Alvarez, A., Amsler, C., Orea, L. and Schmidt, P. (2006), "Interpreting and testing the scaling property in models where inefficiency depends on firm characteristics", *Journal of productivity analysis*, 25, 201-212.

Beecher, J.A. (2013), "What matters to performance? Structural and institutional dimensions of water utility governance", *International review of applied economics*, 27 (2), 150-173.

Berg, S. and Marques, R. (2011), "Quantitative studies of water and sanitation utilities: A benchmarking literature survey", *Water Policy*, 13 (5), 591-606.

Borghi, E., Del Bo, C. and Florio, M. (2016), "Institutions and Firms productivity: Evidence from electricity distribution in the EU", *Oxford Bulletin of Economics and Statistics*, 78 (2), 170-196.

Carvalho, P., Marques, R.C. and Berg, S. (2012), "A meta- regression analysis of benchmarking studies on water utilities market structure", *Utilities Policy*, 21, 40-49.

Caudill, S.B. and Ford, J.M. (1993), "Biases in frontier estimation due to heteroscedasticity", *Economic Letters*, 41, 17-20.

Caudill, S.B., Ford, J.M. and Gropper, D.M. (1995), "Frontier estimation and firm specific inefficiency measures in the presence of heteroscedasticity", *Journal of Business and Economic Statistics*, 13, 105-111.

CEC (1990), *Green paper on the urban environment*, EU Document Number: COM (90) 2018, Brussels.

CEPT (2010), *Performance measurement framework for urban water and sanitation*, *Volume I: Approach and Framework*, CEPT University, Ahmedabad, India.

CEPT (2013), *A review of performance benchmarking urban water supply and sanitation,* Performance Assessment System Project, Centre for Environment Planning and Technology University, Ahmedabad, India.

Coelli, T.J. and Perelman, S. (1996), *Efficiency measurement, multiple-output technologies and distance functions: With application to European railways*, CREPP Discussion Paper 96/05, University of Liège, Belgium.

Coelli, T and Lawrence, D. (eds.) (2006), *Performance measurement and regulation of network utilities*, Edward Elgar.

Constitution (Seventy-Fourth Amendment) Act. (1992), Government of India, New Delhi.

CPHEEO. (2005), *Status of water supply, sanitation and solid waste management in urban areas.* Research study series No. 88, Central Public Health and Environmental Engineering Organization, Ministry of Urban Development, Government of India, New Delhi.

Dubash, N.K. and Rajan, S, C. (2001), *The politics of power sector reform in India*, World Resource Institute, Washington, DC.

Dubash, N.K. and Rao, D.N. (2007), *The practice and politics of Regulation: Regulatory governance in Indian electricity*, Macmillan India, New Delhi.

Dubash, N.K. (2008), "Independent regulatory agencies: A theoretical review with reference to electricity and water in India", *Economic and Political Weekly*, 43 (40), 46-54.

Fare, R. (1988), *Fundamentals of production theory*, Lecture Notes in Economics and Mathematical systems, Berin, Springer- Verlag.

FCI (2009), *Thirteenth Finance Commission 2010-2015*, Volume I: Report, December 2009, Finance Commission India, Government of India, New Delhi.

Gill, D. and Nema, A.K. (2016), "Benchmarking of Indian rural drinking water supply utilities", *Water Utility Journal*, 13, 29-45.

Guerrini, A., Romano, G. and Campedelli, B. (2011), "Factors affecting the performance of water utility companies", *International Journal of Public Sector Management*, 24 (6), 543-566.

Gupta, S., Kumar, S. and Sarangi, G. K. (2006), *Measuring the performance of water services providers in urban India: Implications for managing water utilities*. National Institute of urban affairs (NIUA) Working Paper, WP 06-08.

Gupta, S., Kumar, S. and Sarangi, G.K. (2012), "Measuring performance of water service providers in urban India: Implications for managing water utilities", *Water Policy*, 14, 391-408.

IGRAC (2010), *Global Groundwater Information System (GGIS)*, International Groundwater Resources Assessment Centre, Delft, Netherlands.

IIHS (2014), *Sustaining policy Momentum: Urban water supply and sanitation in India*, IIHS RF paper on water supply and sanitation, Indian Institute for Human Settlements, Bangalore.

Jaladhi, V., Dhruv, B., Utkarsha, K. and Mahroof, M. (2016), "Online performance assessment system for urban water supply and sanitation services in India", *Aquatic Procedia,* 6, 51-63.

Jamasb, T., Newbery, D., Pollitt, M.G. and Triebs, T. (2006), *International benchmarking and regulation of European gas transmission utilities*, Report prepared for Council of European Energy Regulators (CEER).

Jamasb, T., Llorca, M., Khetrapal, P. and Thakur, T. (2018), *Institutions and performance of regulated firms: Evidence from electric utilities in the Indian states*, EPRG working paper 1809 and Cambridge working paper 1823.

Kulshrestha, M. (2005), *Performance assessment and efficiency evaluation for the urban water supply operations of Indian utilities*, PhD Dissertation, IIT-Delhi, New Delhi.

Kulshrestha, M. (2006), "A scorecard for measuring the water supply utility performance: The case of large Indian metropolises", *International Journal Management & Decision Making*, 7 (4), 418-437.

Kulshrestha, M. (2009), *Efficiency evaluation of urban water supply utilities in India*, 8th International Conference on Applied Infrastructure Research, 9–10 October, Berlin, Germany.

Kulshrestha, M., Vishwakarma, A., Sanjay, S.P. and Thakur, T. (2012), "Sustainability issues in the water supply sector of urban India: Implications for developing countries", *International Journal of Environmental Engineering*, 4 (1/2), 105-136.

Kulshrestha, M. and Vishwakarma, A. (2013), "Efficiency evaluation of urban water supply services in an Indian state". *International Journal Water Policy*, 15, 134-152.

Kumar, S. and Managi, S. (2010), "Service quality and performance measurement: Evidence from the Indian water sector", *International Journal of Water Resources Development*, 26 (2), 173-191.

Kumbhakar, S.C. and Lovell, C.A.K. (2003), *Stochastic frontier analysis*, Cambridge University Press, Cambridge.

Lai, H. and Huang, C.J. (2010), "Likelihood ratio tests for model selection of stochastic frontier models", *Journal of Productivity Analysis*, 34, 3-13.

Lin, C.H. (2005), "Service quality and prospects for benchmarking: Evidence from the Peru water sector", *Utilities Policy*, 13 (1), 230-239.

Li, Y. and Waddams, C. (2012), *Effect of regulatory reform on the efficiency of mobile telecommunications*, CCP Working paper 12-1.

Llorca, M., Orea, L. and Pollitt, M.G. (2016), "Efficiency and environmental factors in the US electricity transmission industry", *Energy Economics*, 55, 234-246.

Locussol, A.R., Misra, S., Makino, M., Hunt, C. and Alavian, V. (2006), *India: Water supply and sanitation - Bridging the gap between infrastructure and service*, Washington, DC: World Bank.

Loughlin, M. (1985), Apportioning the infrastructure costs of urban land development, Chapter in *Land Policy: Problems and Alternatives*, Barrett, S. and Healey, P (ed.), 229-248, Gower Publishing Company.

Lovell, C.A.K., Richardson, S., Travers, P. and Wood, L.L. (1994), "Resources and functionings: A new view of inequality in Australia", Chapter in *Models and Measurement of Welfare and Inequality*, W. Eichhorn (ed.), 787-807, Springer.

Marvin, S. and Graham, S. (1993), "Utility networks and urban planning: An issue agenda", *Planning practice and research*, 8 (4), 6-14.

Meeusen, W. and van den Broeck, J. (1977), "Efficiency estimation from Cobb-Douglas production functions with composed error", *International Economic Review*, 18 (2), 435-444.

Mercadier, A.C., Cont, W.A and Ferro, G. (2016), "Economies of scale in Peru's water and sanitation sector", *Journal of productivity analysis*, 45, 215-228.

MHUPA (2013), *State of Housing in India: A Statistical Compendium 2013,* Ministry of Housing and Urban Poverty Alleviation, Government of India, New Delhi.

MoEF and UNDP (2015), *Achieving the sustainable development goals in India: A study of financial requirements and gaps*, Ministry of External Affairs, Government of India, New Delhi.

MoUD (2012), *Improving urban water supply & sanitation services*: Advisory Note, Ministry of Urban Development, Government of India, New Delhi.

MoUD (2009), *Handbook of Service level Benchmarking*, Ministry of Urban Development, Government of India, New Delhi.

MoUD and PA (2004), *Guidelines for sector reform and successful public-private partnerships*, Ministry of Urban Development and Poverty Alleviation, Government of India, New Delhi.

MoWR (2016), *Draft national water framework bill, 2016,* Ministry of Water Resources, Government of India, New Delhi.

Nag, T. and Garg, A. (2013), *Strategies to improve urban water delivery in West Bengal, India: An analysis of water institutions and benchmarking of water delivery organizations*, Indian Institute of Management Ahmedabad (IIM Ahmedabad) working paper, 2013-04-02.

NITI Aayog (2017), *Three year action agenda 2017-18 to 2019-20*, National Institute for Transforming India, Government of India, New Delhi.

NIUA (2015), *Compendium of good practices: Urban water supply and sanitation in Indian cities,* National Institute of Urban Affairs, New Delhi.

NIUA (2018), *14th Finance Commission's Performance Grant to ULBs*, National Workshop on Service Level Benchmarking for Urban Sanitation Services with focus on FSSM, 25th April, Ahmedabad, India.

Nyathikala, S.A. and Kulshrestha, M. (2017), "Performance and productivity measurement of urban water supply services in India", *Water Science and Technology: Water Supply*, 17(2), 407-421.

Olmstead, S.M. (2010), "The economics of managing scarce water resources", *Review of Environmental Economics and policy*, 4 (2), 179-198.

Paramasivam, R. (2017), "Water supply engineering: Some reflections", *Journal of Indian Water Works Association*, 49 (1), 18-23.

PAS (2014), *Water and Sanitation Service Levels in Cities of India (2011-12 and 2012-13)*, Performance assessment system project, CEPT university, Ahmedabad, India.

PAS (2017), *Performance assessment system. Service level benchmarks for water supply*, www.pas.org.in.

Perard, E. (2009), "Water supply: Public or private?", *Policy and Society*, 27 (3), 193-219.

Picazo-Tadeo, A.J., Saez-Fernandez, F.J. and Gonzalez-Gomez, F. (2008), "Does service quality matter in measuring the performance of water utilities?", *Utilities Policy*, 16 (1), 30-38.

Planning Commission (2008), *Eleventh Five-Year Plan 2007-2012*, Volume II: Social Sector, Government of India, New Delhi.

Planning Commission (2012), *Report of the steering committee on drinking water supply & sanitation (rural & urban) for Twelfth Five year plan (2012-2017),* Government of India, New Delhi.

Planning Commission (2013), *Twelfth Five-Year Plan (2012-2017)*, Volume II: Economic sectors, Government of India, New Delhi.

Prabhu, S.P. (2012), *India's water challenges*, Atlantic council ideas, influence, impact issue brief, The Atlantic Council of the United States, Washington, DC.

PRAYAS (2009), *Independent water regulatory authorities in India: Analysis and interventions*, Compendium of Analytical Work by PRAYAS 2006-2009, Pune.

Reifschneider, D. and Stevenson, R. (1991), "Systematic departures from the frontier: A framework for the analysis of firm inefficiency", *International Economic Review*, 32, 715-723.

Roibas, D., Garcia-Valinas, M.A. and Wall, A. (2007), "Measuring welfare losses from interruption and pricing as responses to water shortages: an application to the case of Seville", *Environmental and Resource Economics*, 38 (2), 231-243.

Roibas, D., Garcia-Valinas, M.A. and Fernandez-Llera, R. (2018), "Measuring the Impact of Water Supply Interruptions on Household Welfare", *Environmental and Resource Economics*, https://doi.org/10.1007/s10640-018-0255-7

Romano, G., Senante, M.M. and Guerrini, A. (2017), "Water utility efficiency assessment in Italy by accounting for service quality: An empirical investigation", *Utilities Policy*, 45, 97-108.

Shaban, A. and Sharma, R, N. (2007), "Water Consumption Patterns in Domestic Households in Major Cities", *Economic and Political Weekly*, 42 (23), 2190-2197.

Shephard, R.W. (1970), *Theory of cost and production functions*, Princeton University Press, Princeton.

Shleifer, A. and Vishny, R.W. (1993), "Corruption", *Quarterly Journal of economics*, 108, 599-618.

Shleifer, A. and Vishny, R.W. (1994), "Politicians and firms", *Quarterly Journal of Economics*, 1094, 995-1025.

Simpson, B. (1983), *Site Costs in Housing Development*, Construction Press.

Singh, M.R., Upadhyay, V. and Mittal, A.K. (2010), "Addressing sustainability in benchmarking framework for Indian urban water utilities", *Journal of Infrastructure Systems*, 16, 81-92.

Singh, M.R., Upadhyay, V. and Mittal, A.K. (2011), "Benchmarking of north Indian urban water utilities", *Benchmarking: An International Journal* 18(1), 86–106.

Singh, S. (2014), "Decentralising water services in India: The politics of institutional reforms", *Asian Survey*, 54 (4), 674-699.

Singh. M., Mittal, A.K. and Upadhyay, V. (2014), "Efficient water utilities: Use of performance indicator system and data envelopment analysis", *Water Science and Technology: Water supply*, 14 (5), 787-794.

Swaniti (2016), Water resources regulation in India examining the framework for efficient water governance with focus on Maharashtra, a Swaniti initiative thematic brief, New Delhi.

TERI (2010), *Review of current practices in determining user charges and incorporation of economic principles of pricing of urban water supply*, Report prepared for Ministry of Urban Development, New Delhi, Project No. 2009|A02: April.

Tiwari, P. and Gulati, M. (2011), "Efficiency of urban water supply utilities in India", *International Journal of Water Resources Development*, 27 (3), 361-374.

Tynan. N. and Kingdom. B. (2002), *A water scorecard: Setting performance targets for water utilities*, World Bank: Private Sector and Infrastructure Network, No. 242, Washington, DC.

UN (2015), *UN Sustainable Development Goals*, United Nations, http://www.un.org/sustainabledevelopment/sustainable-development-goals.

Venkatesh, G., Brattebo, H., Saegrov, S., Behzadian, K. and Kapelan, Z. (2015), "Metabolism-modelling approaches to long-term sustainability assessment of urban water services", *Urban Water Journal*, 14 (1), 11-22.

Vishwakarma, A., Kulshrestha, M., Nyathikala, S.A. and Kulshrestha, M. (2016), "Cost efficiency benchmarking of urban water supply utilities: The case of an Indian State", *Water and Environmental Journal*, 30, 77-87.

Wagle, S., Deekshit, P. and Pol, T. (2011), "Review of reforms in urban water sector", Chapter in: *India Infrastructure Report 2011: Water: Policy and Performance for Sustainable Development*, Tiwari, P. and Pandey, A. (ed.), 199-209, Oxford University Press.

WaterAid India (2005), *Drinking water status and sanitation in India: Coverage, financing and emerging concerns*, Water Aid India, New Delhi.

World Bank (2008), *Phase II: Benchmarking urban water utilities in India (English). Water and sanitation program*. Washington, DC: World Bank.

WBG (2009), *Reducing technical and non-technical losses in the power sector,* Background Paper for the World Bank Group Energy Sector Strategy, Washington, DC, World Bank Group.

WBG (2016), *Financial viability of the electricity sector in developing countries: Recent trends and effectiveness of World Bank interventions*, Independent evaluation group IEG learning product, Washington, DC, World Bank Group.

WSP (2008), *Performance improvement planning developing effective billing and collection practices*, Water and Sanitation Program WSP Field note, 44119.

Appendix A

Table A.1: Definitions of variables

Indicator	Definitions
Operating Expenses OPEX (Rs)	Expenses incurred in operating water utility. It includes the following expenses: Regular staff and administration expenses + Contract staff costs + Electricity charges+ Chemicals cost + Repair/Maintenance cost + Bulk water charges + Other costs
Capital Expenditure CAPEX (Rs)	Expenditure invested by water utility in development projects and schemes. It includes following expenditure: Projects, Schemes + Principle repayment of loans + Other expenses
Total water supplied (MLD)	Total water supplied to the customers expressed in Million litres per day.
Total Water connections (No.s)	Total number of connections to the water supply network with a private service connection.
Continuity of supply (Hrs)	Continuity of supply is measured as average number of hours of pressurised water supply per day.
Complaint Efficiency (%)	Total number of water supply related complaints redressed within time as stipulated in service charter of the ULB, as a percentage of the total number of water supply related complaints received in the year.
Cost Recovery (%)	Percentage of total operating revenues from water supply related charges to total operating expenses on water supply.
Billing Efficiency (%)	Percentage of current year revenues collected from water supply related taxes and charges as a percentage of total billed amount (for water supply).
Non-Revenue Water (%)	Difference between total water produced (ex-treatment plant) and total water sold expressed as a percentage of total water produced. Non-revenue water includes: a) consumption which is authorised but not billed, such as public stand posts; b) apparent losses such as illegal water connections, water theft and metering inaccuracies; c) real losses which are leakages in the transmission and distribution networks.
Ground water (%)	Percentage of ground water extracted to total water supplied.
Quality of water supplied (%)	Percentage of water samples that meet standards at treatment plant outlet and consumer end.

Appendix B

Table B.1: Correlation matrix of variables

	opex	capex	wconn	ws	gw	sh	compl_eff	cr	bill_eff	nrw	ws_qlty
opex	1	0.52	0.70	0.91	-0.12	0.28	-0.02	0.06	0.07	0.07	0.04
capex	0.52	1	0.34	0.53	-0.08	0.13	0.01	0.06	0.08	0.03	0.03
wconn	0.70	0.34	1	0.67	-0.07	0.14	-0.03	0.05	0.04	0.06	0.05
ws	0.91	0.53	0.67	1	-0.09	0.25	0.02	0.09	0.09	0.07	0.05
gw	-0.12	-0.08	-0.07	-0.09	1	0.02	0.12	-0.03	-0.08	0	0
sh	0.28	0.13	0.14	0.25	0.02	1	0.13	0.14	0.19	-0.03	0.05
compl_eff	-0.02	0.01	-0.03	0.02	0.12	0.13	1	0.05	0.13	-0.06	0.09
cr	0.06	0.06	0.05	0.09	-0.03	0.14	0.05	1	0.01	-0.04	0.06
bill_eff	0.07	0.08	0.04	0.09	-0.08	0.19	0.13	0.01	1	-0.17	0.11
nrw	0.07	0.03	0.06	0.07	0	-0.03	-0.06	-0.04	-0.17	1	-0.09
ws_qlty	0.04	0.03	0.05	0.05	0	0.05	0.09	0.06	0.11	-0.09	1