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Stochastic Production Frontier Analysis of Water Supply Utility of Urban Cities in the State of Madhya Pradesh, India

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ABSTRACT

In the Era of Globalization, Urbanization and Industrialization there is a major task of Public utility to fulfill the requirement of the people quatitavely and qualititatively in developing countries like India. In India till now performance assessment and efficiency evaluation of public utility (water supply and sanitation utility) by use of benchmarking methodologies, not in a regular practice. Benchmarking gives a clear idea about the significance of indicators which affect the efficiency of a utility directly or indirectly to the regulators, stakeholders and law makers. By applying Stochastic production function on Water utility of urban cities in the State of Madhya Pradesh we get the results that Municipality of Bhopal, Indore, Guna, Jabalpur, Satna, Khargone, Neemuch and Vidisha urban city performed better and scored highest estimated efficiencies while evaluation is based on SFA production function.

Key Words: Stochastic frontier analysis, Benchmarking, water supply utilities, Production function, efficiency evaluation.

1. Introduction

Water is basic need of the human being, and water sector is nowadays a thrust area for econometrician and technical people. Water Sector is already established industry in devolved country, but in developing country like India there is a heavy load on the water utility to full fill the requirement of the people effectively and efficiently in a matter of quality and quantity. This is the period of developing countries facing urbanisation and industrialisation which causes mismanagement of existing infrastructure.

Sectoral demands for water are growing rapidly in line with urbanization (estimates suggest that by 2025, more than 50 per cent of the country's population will live in cities and towns), population increases, rising incomes and industrial growth, and urban India is fast emerging as centers of demand growth, As a result, per capita water availability has been falling (Planning Commission of Govt. of India, India assessment 2002). The National Commission for Integrated Water Resources Development (NCIWRD) has adopted figures of 1581 million and 1346 million as the high and low projection of population by the year 2050 where it is assumed will get stabilized. In their estimate urban population in the year 2050 is likely between 646 million and 971 million (XIth five year plan). Indian comprises 16% of the global population, but the country is endowed with a mere 4% of its total freshwater resources (Planning Commission, 2007).With the

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population having grown to over a billion now, the per capita water availability has fallen to barely 2,000 cubic meters per year and the actual per capita usable quantity is around 1,122 cubic meters per year (Planning Commission, 2002). The utilizable water resources of the country have been assessed at 1123 BCM, of which 690 BCM is from surface water and 433 BCM from ground water sources (Planning Commission, 2007), and the total water utilization for all uses is estimated to increase to 1,422 BCM by the year 2050 (Planning Commission, 2002).

At the beginning of the century India has 27.8% population living in urban areas and 10.3% of its population in metropolitan cities. Madhya Pradesh with a population 60.3 million and second largest state in the country has 26.5 % urban population and account for 5.6 % of country’s urban population (UN-HABIBTAT report, 2006).

1.1 Working area – Madhya Pradesh, India

Madhya Pradesh is centrally located in the country, sharing boundary with five states namely Uttar Pradesh and Rajasthan in the north, Maharashtra in the south, Gujarat in the west and newly formed Chhattisgarh on the east. The state has a large geographical expanse with 9 per cent of the country’s total landmass whereas the population is 6 per cent of the country’s total population. Thus, the population density is comparatively low and the habitations are sparsely located .According to Census 2001, 27.8% of Indians, i.e. 286 million people or 55 million households live in urban areas and the urban population would have grown to 368 million by 2012 (Urban water & sanitation policy, 2002)

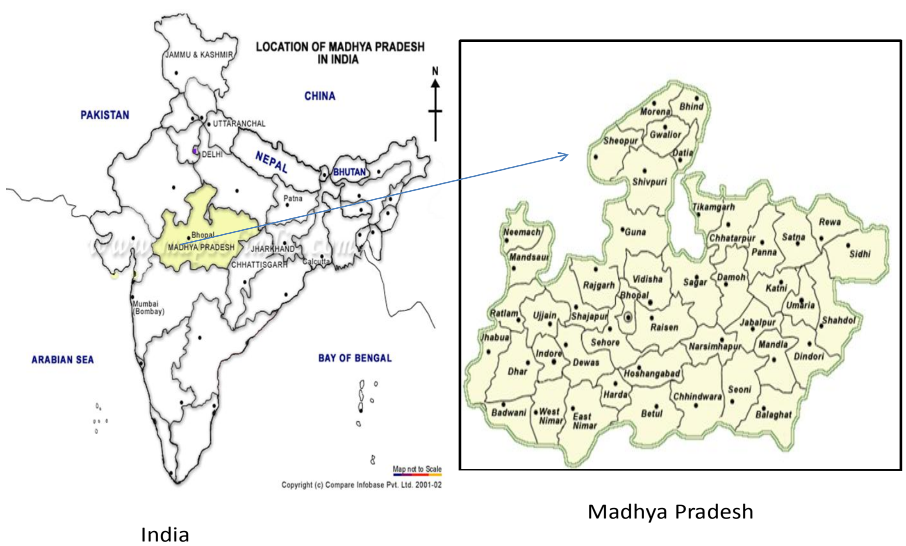

Figure 1: Map of India (Source: mapindia.org)

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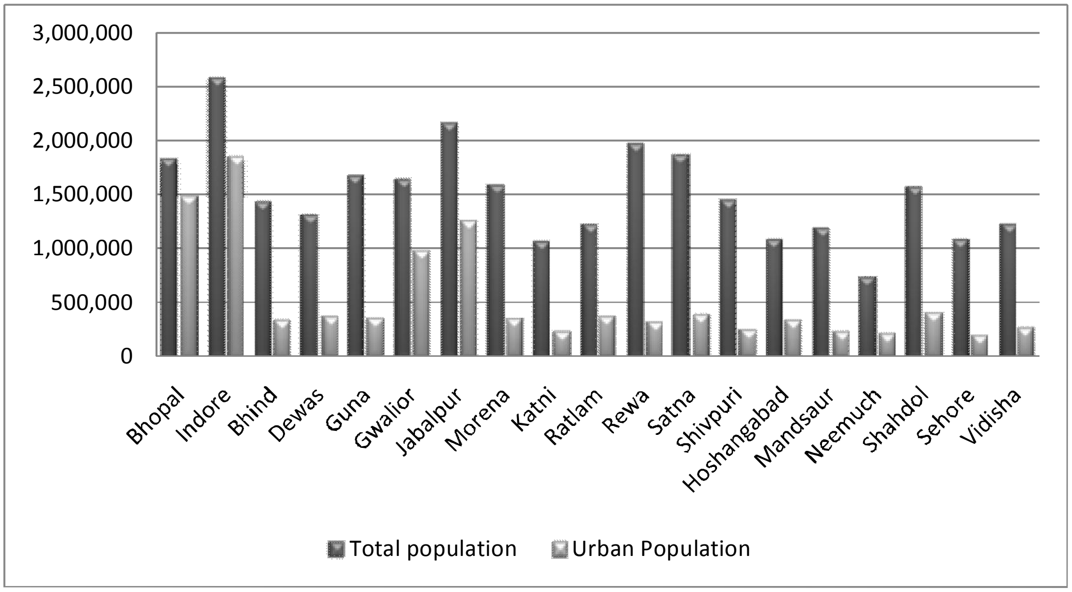

Figure 2: Total population and urban population (census 2001) of urban city of Madhya Pradesh, India

Table 1: Percentage urban population of Madhya Pradesh and growth rate of urban population (Source: Kundu 2003)

Year	1971	1981	1991	2001
Urban population (%)	16.29	20.31	23.21	26.67

Table 2: Annual exponential growth rate (%) of urban population of Madhya Pradesh, India (Source: Kundu 2003)

Duration in Years	1971-1981	1981-1991	1991-2001
Annual exponential growth rate (%)	4.45	3.71	2.71

The objective of the study is to evaluate the efficiency and the performance assessment of water utility of selected urban cities of Madhya Pradesh. Sample urban cities have been taken from the classification based on the population as metropolitan city, class-I and class-II city (CPHEEO, 2005).

In the following paper parametric approach is used to determine the efficiency. Benchmarking is a very systematic approach to evaluate the efficiency and the performance assessment of any utility by using parametric or non parametric approach. This is one of the first studies on efficiency evaluation and performance assessment of water utilities of sample urban cities in the State of Madhya Pradesh, India.

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2. Review of the relevant studies

We have got a dearth of literatures using efficiency techniques like SFA and DEA to assess the performance of water utility in urban India. Especially for Madhya Pradesh we are unable to find any study done so far applying the techniques like stochastic frontier analysis of performance assessment of water utility of urban cities. Gupta et al. (2006) analysed Output oriented DEA approach to assess the performance of Indian urban cities are : Agra, Ahmedabad, Amritsar, Bhopal, Bhubaneswar, Chandigarh, Coimbatore, Guwahati, Hyderabad, Indore, Itanagar, Ludhiana, Mathura, Meerut, Mumbai, Madurai, Mysore, Nagpur, Nanded, Nashik, Pune, Raipur, Rajkot, Surat, Vadodara, Vijayawada, and Visakhapatnam. Authors find that Mathura, Bhopal, Visakhapatnam, Nashik and Itanagar are the worst performing cities. Fraquelli et al. (2005) analyses the ongoing reform of the Italian water sector, with particular attention to the industry cost efficiency and to the assessment of scale economies at ATO level, by estimating a stochastic cost frontier. Author estimated a trans-logarithmic cost frontier to assess the behavior of returns to scale, the inefficiency score and the impact of network characteristics. Faria et al. (2005) compares the technical efficiency of Brazilian public and private companies in water supply. To measure efficiency a stochastic production frontier model is estimated using two competitive distributions for the inefficiency error component: truncated normal and exponential. The exponential distribution showed a superior fit and was used to assess differences in technical efficiency between public and private companies. The statistical results show that private companies are only marginally more efficient than public ones. Moshiri et al. (2006) study showed that non-parametric approach is represented by Data Envelopment Analysis (DEA) while the parametric approach is represented by Stochastic Frontier Analysis (SFA). Both yield relative efficiency ratings on a 0 (worst-practice) to 1 (best-practice) scale based on a comparison between the observed performance of individual production units and a best-practice frontier. Renzetti (2001) studied to develop an econometric model of water utility in order to examine the effect of variation on the quantity and quality of raw water supplies. The raw water input was represented by a sub-function in which the average water level, variability of water level and water quality are the characteristic. The estimation provided valuable insights. First, increasing water availability leads to decrease in cost. Second, increasing variability in raw water availability leads to increase in cost. Third, increase in the contaminants in raw water leads to increase in cost of treatment and supplying a given quantity of output. Filippini et al. (1995) estimates cost inefficiency and economies of scale of Slovenian water distribution utilities over the 1997-2003 periods by employing different stochastic frontier methods. The results showed that significant cost inefficiencies are present in the utilities. An introduction of incentive-based price regulation scheme was suggested as the possible solution to this problem. Different models produce fairly robust results with respect to estimates of economies of output density, customer density, and economies of scale. The optimal size of a company is found to closely correspond to the sample median. Economies of scale were found in small-sized utilities, while large companies exhibit diseconomies of scale. Ruggiero (1998), tests the validity of stochastic frontier cross-sectional model by the use of Monte carlo study. Author find specified stochastic frontier model does not reliably decompose the overall error term. The results suggest that the technique does not accurately decompose the total error into inefficiency and noise components.

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3. Institutional arrangement of the Water Utility

In Urban cities of Madhya Pradesh Public health Engineering departments (PHEDs) and Municipal Corporation are responsible to supplying the water, the proper management and development of water system of the utility (CPHEEO, 2005). There is no private public partnership to distribution of water and operational and management of water system of the utility in M. P. urban cities (see Table 3.0). Because of the monopoly of the public utilities, there should be a systematic approach to assess the performance of these public utilities to know the right way through which utility can achieve its maximum output/profit goals.

Table 3: Institutional Arrangements for Water Supply (Source: CPHEEO, 2005)

CITY / TOWN	CAPITAL WORKS	OPERATION & MAINTENANCE	COLLECTION OF REVENUE	WATER QUALITY MONITORING AGENCY
Bhopal	Corporation	Corporation	Corporation	Corporation
Indore	Corporation	Corporation	Corporation	Corporation
Bhind M	Municipality & PHED	Municipality & PHED	Municipality	PHE
Guna M	PHED	Municipality	Municipality	PHE
Gwalior	Corporation	Corporation	Corporation	Corporation
Jabalpur M. Corp.	Corporation	Corporation	Corporation	Corporation
Morena M	Municipality	Municipality	Municipality	Municipality
Ratlam M. Corp.	PHED	Corporation	Corporation	PHE
Rewa M. Corp.	PHED	PHED	PHED	PHE
Satna M. Corp.	PHED	PHED	PHED	PHE
Shivpuri M	PHED	Municipality	Municipality	Municipality
Hoshangabad M	Municipality	Municipality	Municipality	Municipality
Khargone M	Municipality	Municipality	Municipality	Municipality
Mandsaur M	Municipality	Municipality	Municipality	Municipality
Neemuch M	Municipality	Municipality	Municipality	Municipality
Sehore M	Municipality	Municipality	Municipality	Municipality
Shahdol M	Municipality	Municipality	Municipality	Municipality
Vidisha M	Municipality	Municipality	Municipality	Municipality

4. Model Specification and Methodology

The econometric approach (stochastic frontier analysis) was first originated almost simultaneously by Aigner, Lovell, and Schmidt (1977), Meeusen and van den Broeck (1977), and Battese and Corra (1977). Data envelopment method is the first choice of many econometricians to use of benchmarking, but there is no place to account of noise in this method. Stochastic frontier analysis overcome the problem of unaccountability of noise and includes an error variable ui in the function Stochastic frontier method of benchmarking is a

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parametric approach and requires an assumption of functional form either Cobb-Douglas function or Translog Function.

The present study uses a parametric approach (Stochastic production frontier) to estimate the technical efficiency of urban water utility of selected 18 urban cities of Madhya Pradesh. Selection of urban cities is restricted because of dependence of available data of selected indicators. In estimating the efficiency frontier, SFA makes the assumption that the residual from the simple regression approach can be divided into two factors, statistical error and inefficiency. Inefficiency is assumed to be non-negative (a utility that has zero inefficiency is on the efficiency frontier) and to follow a particular statistical distribution (for example, a 'half normal' distribution or truncated normal distribution). The stochastic Frontier production function for (unbalanced) panel data which has firm effects which are assumed to be distributed as truncated normal random variables which are also permitted to varying systematically with time, the basic model may be expressed as

$$y_{it} = x_{it}(\beta) + v_{it} - u_{it}, \ldots\ldots \quad i=1,2,3\ldots.n; \text{ and } t=1,2\ldots\ldots T$$

(v_i the random error account for measurement of error and other random factors, such as the effects of weather, strikes, luck, etc…on the value of the output variables, together with the combined effects of unspecified input variables in the production function). Where, Y_{it} is (logarithm) the production of the i^{th} firm in t^{th} time period, Xi is a KX1 row vector (transformation) of the input quantities of i^{th} firm in the t^{th} time period . β_0, β_1, β_2…. β_n are a KX1 column vector of unknown parameters to be estimated known as elasticity.

The error term, V_{it} is assumed to be independently and identically distributed (iid) $N(0,\sigma v^2)$. In order to separate the stochastic and inefficiency effects in the model, a distributional assumption has to be made for U_{it}. Two main distributional assumptions have been proposed: a normal distribution truncated at zero, $U_{it} \sim N(\mu,\sigma u^2)$ (Aigner et al., 1977) and a half-normal distribution truncated at zero, U_{it} $N(0,\sigma u^2)$ (Jondrow et al., 1982). In addition, the inefficiency can also be considered to have a time invariant component, such that $U_{it} = \{\exp[-\eta(t-T)]\}U_i$ (Battese and Coelli, 1992), where T is the terminal time period (i.e. $U_{it} = U_i$ when $t = T$) Where η is an unknown scalar parameter to be estimated (Ines Herrero, 2004). The firm-specific distance function (technical efficiency), represented by the random variable $\exp(-u_i)$, is not directly observable. Jondrow et al. (1982) proposed the conditional expectation of u_i, conditioned on the realized value of the composed error term ε_i as an estimator of u_i. Battese and Coelli (1988) generalized the cross-sectional results in Jondrow et al. (1982) to panel data models. Technical efficiency measures for individual firms based on the estimated stochastic frontiers are obtained by using the conditional expectation of u_i given ε_i. Table 4 shows descriptive statistics of Data used to estimate SFA production function.

In significant Model 2, Translog production function can be defined as:

$$\ln(Q) = \beta_0+\beta_1 \ln(L/'000) +\beta_2 \ln(Len) + \beta_3 \ln(C) + \tfrac{1}{2}\beta_4 \ln(L/'000)^2 + \tfrac{1}{2}\beta_5 \ln(Len)^2 + \tfrac{1}{2}\beta_6 \ln(C)^2 + \beta_7\ln(L/'000)\ln(Len) +\beta_8 \ln(L/'000)\ln(C) + \beta_9\ln(Len)\ln(C) + V_i - U_i,$$

and $\mu = \delta_o+ \delta_1\ln(Dens) + \delta_2\ln(UFW)$

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Table 4: Descriptive Statistics of Data (CPHEEO, 2005)

VARIABLE DESCRIPTION	VARIABLE NOTATION	MEAN	STANDARD DEVIATION	MAXIMUM	MINIMUM
Average daily clear water production (MLD)	Q	51.44444	83.46413	270	5
Staff per thousands connections	L/'000	15.47778	6.971501	25.1	2.6
Length of the piped network (Km)	Len	339.8889	681.2024	2800	19
Installed production capacity (MLD)	C	61.61111	97.15309	322	7
Density of customers (population '000/ Area in Km^2).	Dens	5.4232	3.531765	15.95197	1.331689
% Unaccounted for water (loss) (MLD)	% UFW	10.79889	8.721361	30	0.38

5. Discussion on the Results of technical efficiency effect of Translog Production Function

The production function parameters and the efficiency scores are estimated using FRONTIER 4.1 for selected urban water utilities in the State of Madhya Pradesh, India.

Table 5: Functional form of significant model with estimated elasticity

Model-2 (TE effect Model with Translog production function)	log (Q) = 0.192+ (0.0514) ln(L/'000) + (0.529) ln (Len) + (0.372) ln(C) + ½ (-0.362) ln(L/'000)2 + ½ (0.755) ln(Len)2 + ½ (-0.209) ln(C)2 + (-0.975) ln(L/'000) ln(Len) + (0.128) ln(L/'000) ln(C) + (-0.271) ln(Len) ln(C) + Vi – Ui, and μ = 0.114 + (-0.2678) ln (Dens) + (-0.308) ln (UFW)

Table 6: Estimated efficiencies of Water supply Utilities

Utility	Estimated efficiency (Model 2)
Bhopal	91.15
Indore	93.99
Bhind M	75.75
Guna M	99.27
Gwalior	88.65
Jabalpur M. Corp.	91.35
Morena M	74.23
Ratlam M. Corp.	88.77
Rewa M. Corp.	74.5

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Satna M. Corp.	90.4
Shivpuri M	85.08
Hoshangabad M	68.13
Khargone M	98.27
Mandsaur M	96.45
Neemuch M	96.17
Sehore M	45.31
Shahdol M	63.34
Vidisha M	99.63
Mean efficiency	84.47%

Table 7: Requirement of % increase in Water supply (mld)

Water Supply Utility	Requirement of %increase in water supply (mld)
Bhopal	8.511493
Indore	5.660945
Bhind M	23.96868
Guna M	0.361337
Gwalior	11.02078
Jabalpur M. Corp.	8.31075
Morena M	25.49433
Ratlam M. Corp.	10.90033
Rewa M. Corp.	25.22333
Satna M. Corp.	9.264278
Shivpuri M	14.60403
Hoshangabad M	31.61698
Khargone M	1.365051
Mandsaur M	3.19181
Neemuch M	3.47285
Sehore M	54.52173
Shahdol M	36.42477
Vidisha M	0

Following observations can be made regarding the estimated elasticity of the variables:

1. Staff per thousand connections reflects Operational efficiency of a firm. According to Tynan et al. (2002) a high ratio of staff per thousand connections may indicate use of inefficient use of Staff. Indore, Gwalior, Jabalpur, Rewa, Shivpuri and Sehore Municipality, reports more than 20 staff per thousand connections. These high ratios in these urban cities may mean that single water connections are serving multiple households. Or they may reflect loose employment practices, often a result of political interference in the water utility's operation (Tynan et al. (2002)). Elasticity of Staff per thousand connection (0.0514) has a positive sign and significant.

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2. Elasticity of the length of the network is positive and significant, plays very important role in the production of the water by the utility in. If length of the network will increase by 10% then production of the utility will increase by 5.29% in Model 2.
3. Elasticity of the production capacity (0.372) is positive and significant. If we increase 10% production capacity then production of the utility will increase by 3.72%. It means production capacity of the plant plays a major role to increase production of the utility
4. Density variable is negative (ML estimate is equal to -0.2678) and indicate that by ten percent increment in density (population/area of service) inefficiency of a utility will increases by 2.678%.
5. Unaccounted water loss has a negative sign (ML estimate of this parameter is equal to (-0.308) shows that ten percent increment in unaccounted water loss will increase inefficiency of utility by 3.08%.
6. The Maximum Likelihood estimation for γ is 0.9999983, which indicates that the stochastic frontier model may not be significantly different from deterministic frontier, in which there is no random error in the production function.

7. Conclusion

The present study has analyzed the production efficiency of water utility of urban cities in the state of Madhya Pradesh, India. This is first time to study about the efficiencies of urban water utilities in the state of Madhya Pradesh by using stochastic production frontier benchmarking technique. Significant Model shows that Municipality of Bhopal, Indore, Guna, Jabalpur, Satna, Khargone, Neemuch and Vidisha urban city performed better and scored highest estimated efficiencies while evaluation is based on SFA production function.
The Mean efficiency is 84.47%, which suggest that Water supply utilities could maximize their output by 15.21% without maximizing their inputs (see Barrosa et al. 2007). The utilities having mean efficiency 84.47%, to attain the most efficient utility of the state, would experience a maximize volume of water supply by 15.21% {1 – 84.47/99.63)*100}% , (see Mbanasor et al., 2008)

Least efficient utility of Sehore Municipal Corporation would increase output by {(1 – 45.31/99.62)*100}% = 54.52% in output quantity of volume of water supplied by the utility in Mld, if that utility is to attain the efficiency level of most efficient utility for water supply in the state of Madhya Pradesh, India.
Table 5.4 shows the requirement of % increase in water supply (MLD) by the urban water supply utilities to attain the level of most efficient utility of the state.

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