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Electrical Utility Pricing and Review of Regulatory Policy in Bangladesh

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Abstract

The paper postulates a dynamic optimization model of electricity pricing, incorporating the Ramsey theorem, analytical technique of LRMC and dynamic demand function. Basic objective of the model in regard to electrical distribution utility is to achieve a quasi optimal set of rates, with maximization of sum of consumer and producer surplus, constrained by revenue requirement.
The demand function – an improvement on present precarious nature of available estimates in Bangladesh - and the pricing model, pertains to Dhaka power distribution company (DPDC), Bangladesh. The model which can be comprehensive encompassing all customer groups, would promote partial deregulation of distribution agencies, enabling them to ascertain cost and price, based on their respective franchise.
Model prices are lower than relevant marginal cost, with significant welfare gain to the tune of taka 329 and taka 2144 per unit per quarter of residential and light industrial group, respectively.
Dynamic model will provide, to distribution utility and commission, in a developing economy, systematic basis of departure from marginal cost and act as an index of welfare.

Keywords: Bangladesh, DPDC, Ramsey pricing model, Electricity demand function

JEL Classification D4,L1

1. Introduction

A key question in electricity resource economics is whether current price of electricity produces an efficient allocation of resource at a period of time, that is, if net benefit is maximized in terms of consumer and producer surplus (Berrie & Anari, 1986). In the electricity system in Bangladesh, engineering economics of cost minimization is the principle which form the basis of optimum development and production (M/O Power, 2002). However, it does not include much demand side data as little is claimed to be known quantitatively about customer behavior in relation to price of electricity. Precept that demand for electricity is virtually inelastic in relation to price proved to be faulty. Cost minimization criterion has been one of the factors leading to wrong planting and incorrect pricing (Berrie & Anari, 1986).

Lately, regulatory commission in Bangladesh has recommended prorated accounting cost pricing of electricity to different customer groups – a criterion which is inefficient, as basic economic principles would affirm (BERC, 2008). The problem is exacerbated, in countries like Bangladesh by deficiency of demand studies, leading to precarious estimates and by insolvency of electrical utilities (Hossain, 1993 and M/O Planning, 1998). In this context, a gradual change from cost minimization or accounting cost prices to net benefit maximization technique would aid rationalization of pricing and efficient allocation of resources, as indicated by energy policy makers (Berrie & Anari, 1986).

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In the following, relevant literature is reviewed in Section 2, the model is introduced in Section 2, results are provided in section 3, section 4 provides a discussion and conclusion and policy implications are explained in Section 5.

2. Literature review

Authors studying utility rates have applied the Ramsey pricing model mostly with a view to policy evaluation, rather than economic application by Commissions and utility firms, as indicated by works of Kopsakangus and Savolainen (2003), Nelson (1982) and others. Imperial college long run marginal cost (LRMC) model and benefit maximization (BM) model have been applied by utilities and Commissions-former in Bangladesh (London Economics, 1996) and latter in U.K. (Berrie and Anari,1986). In developing economies as Bangladesh, with electrical utilities incurring deficit and with redistribution objective, rate setting process has been ad-hoc rather than systematic (M/O Planning,1998).

Renshaw (1979) noting that LRMC can ease deficit of utilities, overlooks variation in marginal cost between customer groups and related question of price differentiation by electrical utilities. Paucity of reliable elasticity data, which author recounts, is a factor retarding work of utility commissions.

Mansoer (1986) notes underpricing of electricity in Indonesia due to distributional objective and recommend cost based prices, ignoring demand aspect. Ramsey model has been applied by authors, including Nelson et al (1987), to appraise electricity prices in USA. The latter study relate to vertically integrated utilities, although production and distribution components have been separated in many regions including Bangladesh (M/O Planning, 1998). The authors do not include LRMC, adding to complexity in pricing.

Present study approaches from a single utility perspective, namely Dhaka power distribution company (DPDC) in Bangladesh, with the objective of optimum pricing, with profit constraint, providing a dynamic model of systematic price differential (Baumol and Bradford, 1970), reducing volatility (Turvey, 1969) and maximizing welfare effects i.e. consumer and producer surplus (Berrie and Anari, 1986 and Kahn, 1988).

3. Data and Methods

The study utilizes data from secondary sources. These include DPDC (Commercial operation statistics) data for demand appraisal; London Economics (1996), Ministry of Power (2002) and Planning Commission sources for cost appraisal. In estimating demand, 4 data (1994 Q3 =1995 Q2) are omitted, as electricity use by residential customers, during these 4 quarters were unusually low. CPI is based on publications of Bureau of statistics and Bangladesh Bank Other data were obtained from Census of Manufacturing Industries. UN (2007) and IMF (2002) publications were utilized to obtain PPI. Published books, journals & PhD dissertation were accessed, where relevant.

The main objective of the research is to develop a dynamic model of electricity pricing to ascertain prices of electricity to various groups of consumers of DPDC, in Dhaka, Bangladesh. In postulating the model, Ramsey pricing theorem by Baumol and Bradford (1970), the analytic technique of LRMC (Berrie and Anari, 1986 and Turvey,1969) and dynamic demand functions of energy are used as the theoretical framework of research.

3.1 Ramsey theorem

Basic theorem by Baumol & Bradford (1970) can be written as:

$$\frac{p_i - MC_i}{p_i} = \frac{1+\lambda}{\lambda}\frac{1}{E_i} \tag{1}$$

where, elasticity of output ‘i’ of a firm, $E_i = -\left(\frac{p_i}{x_i}\right)\left(\frac{dx_i}{dp_i}\right)$, and p_i, MC_i, x_i are price, marginal cost and output respectively, while $\frac{1+\lambda}{\lambda}$ is a factor of proportionality.

The principal variant of the theorem is as follows:

With regard to each product of an utility producing for different customer group, for a given level of profile profit (π), prices are to satisfy the condition that for all output or product j –

$$t_j = \frac{p_j - MC_j}{p_j} \cdot \eta_j = (\pi) \tag{2}$$

where, p_j, MC_j and η_j are price, marginal cost and demand elasticity of output j, respectively, and t_j is referred to as Ramsey number (Baumol & Bardford, 1970 and Nelson et al, 1987).

3.2 Long run marginal cost (LRMC)

Marginal costs, in an analysis of system cost in an enterprise, should emerge as by-products of the search for a minimum cost solution. It emerges from the decisions designed to minimize the present worth of the future costs of providing a given time- stream of output. A change in the required time- steam or in the discount rate or in the expected future values of capital and running costs will require re-optimization and will yield new values of marginal cost. The time path of output is given as X_0, X_1, X_2....... The amount it is to produce in period t is X_t , t=0 to infinity.

Cost of new capacity might be expected to change through time and so might the running cost per unit of output of new capacity. In addition running cost may rise as capacity gets older.

c^v = present worth now of the capital cost of a unit of new capacity which come into use in t=v

r^v = present worth of unit running cost of capacity in period t which become operational in t=v

Superscript ‘v’ thus stands for the vintage of the capacity. O^v_t means output produced in period ‘t’ by capacity of vintage v.

Following Turvey (1971), summing all vintages give the present worth of the enterprise’s total cost.

$$TC = \sum_{v\geq 0}(c^v Q^v + \sum_{t\geq v} r_t^{\,v} . O_t^v) \tag{3}$$

Q^0 is held to be given amount of capacity inherited from the past, $\overline{Q}_0$, and available free at present at the beginning of period 0, so that $c^0 = 0$.

Lagrangian function to be minimized can be expressed as below (Turvey, 1971). All monetary terms in it are present worth’s.

$$L(Q^v, O^v_t, k^v_t, m_t, u^o_o) = \sum_{v\geq 0} (Q^v \,.\, c^v + \sum_{t\geq v} O^v_t r^v_t)$$

$$+ k^v_t (O^v_t - Q^v) \text{ for all v and } t \geq v \tag{4}$$

$$+ m_t (X_t - \sum_{v=0}^{t} O_t^v) \text{ for all t}$$

$$+ u_0^o (Q^o - \overline{Q_0})$$

It can be added that m_t is the effect upon the objective function (equation 4) of a unit change in X_t. It is, thus, the discounted marginal cost of period t.

Following Turvey (1971), from equation (4) with Kuhn-Tucker condition of minimization -

$$\frac{\partial L}{\partial O_t^v} \geq 0; \quad r_t^v + k_t^v - m_t \geq 0$$

Thereby -

$$m_t = r_t^v + k_t^v ; O_t^v > 0 \qquad (5)$$

'k', as the dual of the capacity constraint, is the effect on the present worth of system costs of a unit change in the amount of capacity of that vintage in that period. The effect, during the whole economic lifetime of the capacity, sums as the present worth of that new capacity.

$$\sum_{t \geq v} k_t^v = c^v \qquad (6)$$

The optimal investment rule is that capacity cost is equal to (weighted) savings from increasing availability of generating capacity (Andersson & Bohman, 1985).

Marginal cost of any year is excess of (a) present worth in that year of system costs with unit permanent output increment starting then, compared to (b) present worth in that year of system costs with the unit permanent output increment postponed to following year (Turvey1971). Therefore:

$$\sum_{t \geq v} (m_t - r_t^v) = c^v \qquad (7)$$

Following a process of iteration, it can be derived and expressed in generalized form:

$$m_i = c^i + \sum_{t \geq i} r_t^{\ i} - (c^{i+1} + \sum_{t \geq i+1} r_t^{\ i+1}) \qquad (8)$$

Discounted marginal cost is expressed as effect on present worth of system costs of bringing forward (or postponing) the acquisition of one unit of capacity for one period.

LRMC (of generation or transmission & distribution) might be approximated by cost of advancing 1 kilowatt of plant capacity. Bringing forward the capital outlay by one year is conceptually equivalent to annuitising the investment.

Average incremental cost (AIC) method, is utilized to arrive at the LRMC described above. AIC of capacity is given by –

$$AIC = \frac{\left[\sum_{i=0}^{T}\frac{I}{(1+e)^{i}}\right]}{\left[\sum_{i=L}^{L+T}\frac{\Delta MW_{i}}{(1+e)^{i}}\right]} \tag{9}$$

Where, I and ΔMW are increase in investment cost and demand respectively, e is the discount rate, T is planning horizon and L is average commissioning delay. AIC is annuuitised during lifetime of the plant or firm, to yield LRMC (Munnasinghe and Warford,1982).

3.3 Demand Function

3.3.1 Industry

Following Baxter & Rees (1968), letting electricity be kth input, demand function of electricity is:

$$X_k = \beta_0 P_1^{\beta_1} P_2^{\beta_2} \ldots\ldots\ldots\ldots\ldots\ldots . P_k^{BK} Q^{\beta_{k+1}} \tag{10}$$

Where, demand for electricity is an exponential function of k input prices and output Q, and β_i are parameters of the relationship.

Given significance of time trend as evident from earlier demand studies (Baxter & Rees,1968 and Beenstock&Willcox,1981) and production being time trended as indicated by studies in the region (BBS, various issues and IBRD 2002), a time trend (t) was introduced, substituting for Q and productivity gain, for want of a superior representation of the variable, due to data deficiency (BBS, various issues).

In accord with Baxter& Rees (1968), given other prices and output, demand function of electricity in industrial sector, with minor adjustment, is then postulated as:

$$X_t = B\, P_k^{B_k} e^{\delta t} \tag{11}$$

Variables are defined as follows:

X_t = Quarterly kwh (kilowatt hour) demand for electricity per light industrial unit (in period t).

P_k = Average price of electricity per kwh to light industries

t = time trend

Equation (6) can be expressed in logarithmic form as:

$$x_t = \alpha + B_k p_k + \delta t \tag{12}$$

Where, α = *lnB* and lower case letters denote natural logarithm of variables.

3.3.2 Empirical methodology

Proceeding within the framework of Beenstock & Willcox (1981), Griffin (1979), our basic model is to estimate a dynamic model, with minor adjustment, of the form:

$$ln\, X_t = \alpha + \beta(L) lnP_t + \delta t + \epsilon_t \tag{13}$$

Where, L is a lag operator and ε_t is a random and serially independent error term of constant variance.

Compared to Beenstock & Willcox (1981), present study is limited, dealing with only one electricity district, Dhaka, in a country Bangladesh, and studies an energy sector, i.e. electricity only; the model is estimated with lags upto one quarter, using quarterly data as it is in a limited perspective. Inclusion of large number of lagged prices also imply multicollinearity. There are also constraints on degrees of freedom (Murrary, et al, 1977).

Following Thomas (1992), distributed lag *β(L)* is written as:

$$\beta(L) = \frac{r(L)}{\omega\,(L)} = \frac{r_0 + r_1 L + r_2 L^2 \ldots\ldots\ldots r_k L^k}{1 + \omega_1 L + \omega_2 L^2 \ldots\ldots\ldots \omega_l L^l} \quad (14)$$

where, k and l are co-efficient of P and X, respectively. With one lag:

$$\beta_L = \frac{r\,(L)}{\omega\,(L)} = \frac{r_0 + r_1 L}{1 + w_1 L} \quad (15)$$

Following Beenstock &Willcox (1981) and Thomas (1992), equation to be estimated then, with rearrangement, is of the form:

$$ln\,X_t = \alpha_1 - \omega_1\, lnx_{t-1} + \sum_{i=0}^{1} r_i lnP_{t-i} + \delta t + \vartheta_t t \quad (16)$$

where, $\vartheta_t = e_t + \omega_1 e_{t-1}; \alpha_1 = \alpha(1 + \omega_1)$

The equations are estimated for 1992Q3-2004Q4 period, in the present study, with data from DPDC (DESA, 2008, 2003, 2001, 2000). Prices are deflated with 1985 as base year (Bangladesh Bank, 2003, 2002). Results obtained by Stock (1987) and represented by Thomas (1992), is introduced here in regard to auto correlation and co-integration. If two series x and y are co-integrated, then OLS estimators of relevant parameters of the relationship between variables would be consistent & efficient, whether or not there is a correlation between explanatory variable and disturbance in the equation, if sample size is fairly adequate.

As explained by Pindyck & Rubinfeld (1998) and Thomas (1992), test of stationarity of variables, not detailed here, and co-integration technique is then applied as a method of model fitting (Table A1, A2, A3 Appendix A). As variables are co-integrated, following ADF technique and LM test, it is possible to proceed to estimate equation (11).

Parameters in steady state from of equation (11) are, given one lag, as follows:

$$\beta_k = \frac{\sum r_j}{\sum \omega_j} = \frac{r_0 + r_1}{1 + \omega_1} \quad (17)$$

$$\alpha = \frac{\alpha_1}{1 + \omega_1}$$

In regard to serial auto correlation, it might be added that, first order autocorrelation can be reasonable approximation, as indicated by earlier researchers (Pindyck & Rubinfeld, 1998 and Thomas, 1992). Following estimation of the dynamic demand equation, LM statistics, to appraise first order autocorrelation in the residuals, is applied (Beenstock & Willcox, 1981).

3.3.3 Residential

Residential demand represents variation in utilization rate of stock of appliances and size of stock, especially in the long run (Wills, 1981). Earlier models have been based on simplifying approach, whereby appliance holding depend on other variables as price of electricity, income, temperature (Murray et al, 1977). Data on appliance holding and their saturation rate i.e. periodic acquirement of appliance by percentage households, are not readily available in

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Bangladesh. However, with average annual income per capita of taka 20,000 (Bangladesh currency), equivalent to $384, variable is unlikely to be significant, compared to advanced economies (BBS 2004). A framework on appliance holding is given by Murray et al (1977).

With prices of other goods & services given, residential demand for electricity would depend on prices of electricity and income –

$$X^d = f\ (P^d,\ Y^d) \tag{18}$$

where, X^d, P^d& Y^d represent consumption of electricity, price and income of customers.

Firstly, to appraise stationarity of variables $lnX^d, lnP^d,$ and lnY^d, ADF test are computed, which are not detailed here. It indicates that while consumption and price variables are I(1), income is I(2). Latter is unlikely to yield stable estimate of related parameters.

In view of deficiency in income data for Dhaka urban area (BBS, 1992, 2004), following Beenstock and Willcocks (1981) and Baxter& Rees (1968), a time trend is introduced (cf. Section3.3.1).

Variables are defined as follows:

X_t^d= Average quarterly kwh electricity consumed per residential customer.

P_t^d = Average price per kwh to residential customer.

t = time trend.

Analogous to industrial demand equation, an empirical version of the basic model of residential demand to estimate would be:

$$lnX_t^d = \alpha_2 + w_1^d lnX_{t-1}^d + \sum_{i=0}^{1} r_i^d\ lnP_{t-i}^d + \ \delta t + v_t \tag{19}$$

Co-integration technique is then followed (Table A4, A5, A6 Appendix A) and diagnostic guides are also applied as an approach to dynamic model fitting technique, as explained in Section 3.3.2.

3.3.4 Rate structure & price specification

Limitations of data make it impractical to model the demand relationship based on pricing periods, and instead, representative average prices, which combine peak, and off peak components are utilised (Beenstock&Willcox, 1981, DESA, 2004, 2001 and Murry et al, 1977). Reliability of these published rates by DESA were appraised, as these are aggregative, in an earlier study (Farooque, 2010) comparing these with S. E. Asian utilities.

Residential customers in Bangladesh are priced with ascending block rates and estimated average quarterly price of residential customers can be defined as:

$$P = \frac{B^*}{Q^*} \tag{20}$$

where, $B^*$is total quarterly expenditure, and Q^* is quarterly electricity consumed. Billing and Agthe, as stated in Dubin (1985), indicate that correct price is marginal or average price and income should be adjusted by an appropriate rate structure premium (RSP).

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Foster & Beattie (1981) as referred to in Dubin (1985) opine that distinction between average and marginal price is inconsequential and latter as well as Wills (1981) emphasizes that RSP variable is not of a significant magnitude. Dubin (1985) indicate that consumers respond to a summarizing rate for the quaintly – dependent rate structure, as average price. Other studies also utilize average price as the relevant variable (Murrary et al, 1978 and Nelson et al, 1987).Average price may be inferred, thereby, as adequately representing relevant variable, especially in a developing economy with data constraint.

3.4 Ramsey model of electrical utility pricing

The pricing model is formally developed with a view to ascertaining prices of electricity to two groups of customers – light industrial and residential – of DPDC, which fulfill Ramsey criterion, while ensuring certain level of profit of the utility.

Description of the Model

Ramsey equation:

$$\frac{P_0 - MC_0}{P_0}\beta_0 = \frac{P_d - MC_d}{P_d}\beta_d \tag{21}$$

Demand equation:

for light industrial customer:

$$Q_0 = \alpha_0 P_0^{-\beta 0} \tag{22}$$

for residential customer:

$$Q^d = \alpha_d P_d^{-\beta d} \tag{23}$$

Profit Constraint

$$\sum P_i Q_i - \sum M\,C_i(Q_i) = \pi_o \tag{24}$$

where, i = light industry, residential

Notations:

$P_0, P_d -$ Price of electricity to light industry and residential unit, respectively.

MC_0, MC_d – Marginal cost (LRMC) to light industry and residential unit, respectively.

$\beta_0, \beta_d -$ Elasticity of demand for electricity of light industrial & residential units, respectively.

Q_0, Q^d = demand for electricity of light industry and residential unit, respectively.

π_0 = utility's observed level of profit or break even profit.

Four equations are solved, substituting values of P_d, Q^d&Q_0. We have:

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$$\left(\frac{MC_d\beta_d P_0}{\beta_d P_0 - \beta_0 P_0 + MC_0\beta_0}\right)\alpha_d\left(\frac{MC_d\beta_d P_0}{\beta_d P_0 - \beta_0 P_0 + MC_0\beta_0}\right)^{-\beta d} - MC_d\alpha_d\left(\frac{MC_d\beta_d P_0}{\beta_d P_0 - \beta_0 P_0 + MC_0\beta_0}\right)^{-\beta d} + P_0\alpha_0 P_0^{-\beta_0} - MC_0\alpha_0 P_0^{-\beta_0} = \pi_0 \tag{25}$$

Equation (25) is solved with π = ($\pm$) profit, earned by utility, DPDC, during the period of study. Ramsey prices derived, if different from existing prices, would increase consumer and producer surplus, with possible reallocation of welfare gain.

Change in consumer surplus, following Nelson et al, (1987) is given by:

$$\Delta CS_i = \frac{P_i^* Q_i^*}{1-\beta_i}\left[1 - \left(\frac{P_i}{P_i^*}\right)^{1-\beta_i}\right] \tag{26}$$

where i = light industrial, residential, and asterisk are Ramsey prices and quantities.

4. Results and Discussion

In present section model results regarding light industrial, residential demand, marginal cost (LRMC) and average economic cost derived, are provided. Optimal or Ramsey prices estimated by the model in equation (25) are presented in section 3.4.

4.1 Light industrial demand

4.1.1 Specification of the Model

As the variables of the industrial demand model are co-integrated and consequently a long-run relationship exists between the variables x_t, quarterly per unit demand for electricity and p_t, average price(deflated) per kwh of electricity, levied on light industry with lower case letters denoting logarithm of variable, the study proceeds with estimation of dynamic form of the model postulated in equation (16). Compared to Beenstock & Willcocks (1981), as the present study's demand function estimation is within a narrower perspective, the estimation commences with lags up to one quarter, with quarterly data.

4.1.2 Estimation Procedure

The demand model is estimated applying quarterly data, for 1992Q3-2004Q4 period, of DPDC's light industrial customers. The study proceeds by estimating an unrestricted model, postulated in equation (11), with one lag. The exercise then proceeds in stages, with the testing down procedure using diagnostic statistics, to arrive at a final model which would be valid data and model coherent specification.

4.1.3 Analysis of Results

The various model of industrial demand for electricity, as postulated by equation (11), are estimated empirically, seeking efficient estimates of α, β_k and σ, for the light industrial customers of DPDC. Detailed results of the unrestricted model are provided in TableA7 and Table A8 in the appendix.

Results of the unrestricted model postulated in equation (11) are derived as:

$$x_t = 6.1650 - 0.6304p_t + 0.373\,p_{t-1} + 0.2764x_{t-1} + 0.0026t \tag{27}$$

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It is observed from results of the unrestricted equation that, based on t-ratios, electricity price variable, p_t, and lagged demand variable x_{t-1}, are significant at the 0.05 level of significance (with n-j=48-5=43 d.f., critical t-ratio is $t_{0.05}$ =1.68).

Value of R^2 is 0.508. Due to the reason that the variables of the model are co-integrated, possibility of a spurious relationship can be discounted and R^2 of 0.508 obtained in the equation is meaningful (Pindyck & Rubinfeld, 1998). Durbin-Watson statistics (DW) is applied to test first-order autocorrelation in the residuals. Its value is fairly close to 2, indicating no autocorrelation. However, presence of the lagged dependent variable, x_{t-1}, in the equation in Table A7, means DW statistics is biased toward 2 (Thomas1992).

Lagrangian Multiplier (LM) approach is valid, in appraising first and higher-order autocorrelation problem, in the presence of a lagged dependent variable. In case of an equation of first order autoregressive scheme, for instance, auxiliary equation of residuals of the original equation is estimated. Given the null hypothesis of no autocorrelation, LM statistics, computed as nR^2, from estimation of the auxiliary equation would have a χ^2 distribution. Null hypothesis of no autocorrelation is not accepted, if nR^2 exceeds relevant critical value taken from χ^2 table (Thomas1992).

Table A8 indicates that the LM statistics for first-order autocorrelation is 0.913. Since 0.05 percent critical levels for χ^2 (with 1 d.f) is 3.84, there is no evidence of autocorrelation problem in the unrestricted equation in TableA7. It might be added that the LM approach can also be termed as a test for misspecification (Thomas1992). Due to the reason that equation in TableA7 passes the test and following Murrary (1978) and others, it can be inferred that lags of higher than first order are not likely to be required in estimating the model. Coefficients of the unrestricted model are provided in Table 1.

Table 1. Coefficients of unrestricted model of light industrial demand

Lag	Coefficient	
I	w	r
0	-1	-0.63045
1	0.27648	0.373738
Σ	-0.72352	-0.25671

Restrictions are nested and testing down procedure proceeds in relation to equation in TableA7, identifying lag distributions insignificant terms are omitted, subject to the constraint of a random residual correlogram (Beenstock & Willcox, 1981, Pindyck & Rubinfeld, 1998, Thomas, 1992). In the modified equation, pt-1 is omitted and rt-1 is constrained to zero.

Detailed results of the restricted model are provided in appendix TableA9 and TableA10. From Table A9, electricity price variable, pt, can be inferred to be significant at the 0.05 level of significance. Lagged demand variable, xt-1, have a t-ratio near the critical value (with 44d.f, t0.05 = 1.68). Coefficients of the restricted model are provided in Table 2.

Table 2. Coefficients of restricted model of light industrial Demand

Lag	Coefficient	
I	w	r
0	-1	-0.42088

1	0.2325	0
Σ	-0.7675	-0.42088

Value of R2 being 0.490, declines marginally in relation to unrestricted model. As indicated earlier, variables being co-integrated, R2 of 0.490 imply a meaningful relationship, in the absence of a spurious relationship.

DW statistic mildly declined, but do not indicate significant problem of autocorrelation. However, as indicated earlier, DW values are not very useful in the presence of a lagged dependent variable, xt-1, as an explanatory variable in the equation.

Table A10 shows that the LM statistic for first-order autocorrelation is 1.770.Critical value of $\chi 2$ (with 1 d.f.) at 0.05 percent level is 3.84; there is no evidence of autocorrelation problems. The LM statistic also indicates that there is no dynamic specification, error in the model as explained earlier.

In selecting final model, diagnostic statistics relating to equation in TableA7 and A9 are appraised. Table 3 summarizes the diagnostic statistics to help identify the model which would be valid data and model coherent specification.

Table 3. Diagnostic Statistics of Light Industrial Demand Model

Equation	Test type	
	S	LM
Unrestricted Model	0.0929	0.913
Restricted Model	0.0935	1.770

Proceeding to nest restriction in relation to unrestricted model in equation (16), as estimated by equation in Table A7, the preferred model is determined based on diagnostic statistics, employing the testing down procedure.

Despite LM values indicating no autocorrelation or specification problem in both equations, LM increases from 0.0913 in unrestricted equation in Table A7 to 0.1770 in restricted equation in Table A9, following omission of the variable pt-1 . Standard error(s) rises from 0.0929 in unrestricted equation in Table A7 to 0.0935 in restricted equation in Table A9. R^2 of unrestricted equation in TableA7 is 0.508; it marginally reduces to 0.490 in the nested version of the equation in TableA9.

It is noticed; however, that variable pt-1 in the unrestricted equation has a low t-ratio, but exceeds unity. It can be retained, as suggested by Thomas in an exercise estimating a dynamic equation relating to a group of industries (Thomas, 1992).

Preceding analysis of results of the dynamic model fitting methodology indicates that equation in Table A7 is preferred model, compared to equation in Table A9. The specifications in equation are valid, due to the reason that S (standard error) is lower and LM falls, while indicating that the randomness of residual correlogram can not be rejected, thereby implying no autocorrelation problem. Due to the reason that proceeding progressively with attempts at simplification increased S and LM, it may be inferred that unrestricted model in equation (A7) is the valid data and model coherent specification.

Steady state or long run parameters in the form of equation (11) and (12), from preferred model in TableA7 are given by:

$$\alpha = -\frac{\alpha_1}{-1+\omega_1} = -\frac{6.16509}{-1+0.27648} = 8.52096$$

$$\beta_{k} = -\frac{r_0 + r_1}{-1+w_1} = -\frac{-0.63045+0.373738}{-0.72352} = -0.354807$$

$$\sigma = -\frac{0.002672}{-0.72352} = 0.00369305 = 0.00369$$

The long-run light industrial demand for electricity is given by:

$$lnX_t = 8.52096 - 0.354807 lnP_t + 0.00369t \qquad (28)$$

The price elasticity of light industrial demand for electricity βk is –0.354807. Price elasticity value, implies that for a 1% increase in electricity price, consumption of electricity by light industrial unit would reduce by 0.354 %.It indicates that electricity use decisions of industries are quite responsive to the changes of electricity price, on an average. There is a significant negative relationship between electricity prices and industrial demand for electricity.

Dropping the time trend influenced the statistical properties of the industrial demand model, to a certain extent. The model with 't', time trend omitted, not detailed here, has a 't' value at 0.10 percent level which is significant. Variable 't' can thus be retained (Beenstock & Willcocks,1981, Thomas,1992). The sign of 't' is positive but not large, implying that growth in output and other additional factors expressed in the form of a function of time, has a positive effect, however low, on industrial demand for electricity in the model postulated, as represented by equation in TableA7. Since data are quarterly, σ value of 0.00369 is apparently consistent with a priory expectation, given the lag length of one quarter.

The long-run steady state demand relationship is –

Xt = 6331.26078 P-(0.354807) e0.0027 t (29)

4.2 Residential Demand

4.2.1 Specification of the Model

Due to the reason that the variables of the residential demand model are co-integrated, as indicated in section3.3.3, a long-run relationship exists between the variables xtd , average quarterly kwh demand for electricity per residential customer, and ptd , average price of electricity per kwh in residential sector, with lower case letter denoting logarithm of variables. Estimation proceeds with the dynamic form of the model postulated in equation (19)

Since the present study, as explained earlier in section 4.1, is within a narrower perspective, being applicable to only one sector, namely residential, and in a district in one country, the estimation commences with lags up to one, using quarterly data (c.f. section 3.3.2).

4.2.2 Estimation Procedure

The demand model is estimated applying quarterly data for 1992Q3-2004Q4 period of DPDC's residential customers.

4.2.3 Analysis of Results

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The models of residential demand for electricity as postulated in equation (19) are estimated empirically, seeking efficient estimates of α d, βd and δd for residential customers of DPDC. Detailed results of the unrestricted residential model are provided in appendix Tables A11.

It is observed from results of the unrestricted equation in Table A11 that , based on t-ratio, ptd is significant at the 0.05 level of significance (with n-j=44-5=39 d.f. critical t-ratio is t0.05 = 1.70). Coefficients of the unrestricted model are provided in Table 4.

Table 4. Coefficients of unrestricted model of residential demand

Lag	Coefficient	
Lag i	w_1^d	r^d
0	-1	-0.95232
1	0.19629	-0.17643
Σ	-0.80371	-1.12875

Due to the reason that the variables of the model are co-integrated, possibility of a spurious relationship can be discounted and R2. of 0.673 obtained in the equation is meaningful. DW statistics is applied to test for autocorrelation of residual. It's value is 1.78, which is fairly close to 2; however, it is not as conclusive as DW statistics of Industrial demand models. Presence of lagged dependent variable, x_{t-1}^{d} in the equation in Table A11, imply that DW statistics is not applicable, however, as explained earlier.

Lagrangian multiplier (LM) approach, valid in appraising first and higher-order autocorrelation problem, in the presence of a lagged dependent variable, implies that presence of autocorrelation problem can not be rejected (Table 6).

As a guide to dynamic model fitting, testing down procedure proceeds identifying lag distribution. Insignificant terms are omitted, subject to the constraint of a random, residual correlogram. In the modified equation, pt-1 is omitted and r t-1 is constrained to '0'. Detailed results of the restricted model are provided in TableA12 in the appendix.

From TableA12, electricity price variable, ptd is inferred to be highly significant at 0.01 level of significance. Lagged dependent variable, xt-1, have a t-ratio near the critical value at 0.05 level of significance. Coefficients of the restricted model are provided in Table A5.

Table 5. Coefficients of restricted model of residential demand

Lag	Coefficients	
i	w_1^d	r^d
0	-1	-1.01328
1	0.23390	0
Σ	-0.7661	-1.01328

Value of R^2 being 0.671, is nearly the same in relation to unrestricted model (Table A11).Variables being co-integrated , R2 of 0.671 imply the presence of a meaningful relationship between the variables, in the absence of a spurious relationship.

DW statistics improves marginally and is fairly close to 2. However, DW value is not very useful in the presence of a lagged dependent variable xt-1 , as an explanatory variable in the equation in Table A 12.

Estimated LM statistics for first-order autocorrelation, is 0.6529 (Table 6). Given critical value of χ 2 (with 1 d.f.) at 0.05 percent level as 3.84, there is no problem of autocorrelation in the residuals. The LM statistics is also an indication to the effect that there is no dynamic specification error in modified model, as explained earlier.

Analogous to industrial model, diagnostic statistic relating to equation in Table A11 and Table 5 are appraised with the help of Table 6 which summarizes the statistics, to identify the equation that would be valid data and model coherent specification.

Table 6. Diagnostic statistics of residential demand model

Equation	Test Type	
	S	LM
Unrestricted model	0.1169	4.342 (1) 29.0965 (4)
Restricted model	0.1158	0.6529

LM statistics indicate autocorrelation problem of first and fourth-order in the unrestricted equation (TableA11). In restricted equation (TableA12), LM improves, implying that randomness of residual correlogram can not be rejected in the restricted model, following omission of pt-1. Standard error(S) declines from 0.1169 in unrestricted model to 0.1158 in the restricted equation. R^2 of unrestricted equation is 0.6738; it is marginally reduced to 0.6717 in the nested version of the equation in Table A12.

Preceding analysis of results of the dynamic model fitting methodology and testing down procedure indicates that equation of restricted model (Table A12) is preferred model , compared to unrestricted model (Table A11).Diagnostic statistics indicate that equation in Table A12 is valid and data acceptable. LM test imply no autocorrelation problem; it also indicates that there is no dynamic specification error in the equation. The specifications in the equation are valid due, also, to the reason that S (standard error) is lower compared to the unrestricted model.

Analogous to industrial model steady state or long-run parameters from preferred model in Table A12 are given by

$$\alpha^d = -\frac{\alpha_2}{-1+w_1} = -\frac{4.999223}{-1+0.233901} = -\frac{4.999223}{-0.766099} = 6.52555$$

$$\beta^{d} = -\frac{r_0}{-1+w_1} = -\frac{-1.013289}{-1+0.233901} = -\frac{-1.013289}{-0.766099} = -1.322660$$

$$\delta^{d} = -\frac{0.00207}{-0.766099} = 0.0027$$

The long term residential demand for electricity is given by:

$$l_n X^{d}{}_{t} = 6.52555 - 1.322660 l_n P_t^{d} + 0.0027t \tag{30}$$

It can be inferred from the diagnostic statistics that equation in TableA12 is the valid data and model coherent specification. There is, thus, a significant negative relationship between price and residential demand for electricity. Price elasticity value of -1.32 implies that for a 1% increase in electricity price, consumption of electricity by residential unit would be reduced by 1.32 % . It indicates that electricity purchase of household are very responsive to the changes in electricity price, on an average.

The time trend‘t’ influenced the statistical properties of the residential demand model, to a certain extent. It has a ‘t’ value which is greater than 1, in equation in TableA12. Variable ‘t’ can, therefore, be retained in the model (Thomas, 1992). Sign of ‘t’ is positive but not high , implying that growth in income and other factors expressed in the form of function of time has low but positive effect on residential demand for electricity in the model equation.

Comparative estimates of price elasticity, available mainly for western economies, are provided in table 7.

Table 7. Price Elasticities-residential demand for electricity

Study	Price Elasticity	Period
Halvorsen	-1.044	1969
Mount, Chapman & Tyrell	-1.25	1946-1970
Wills	-0.27	1966,1975
Beauvais	-0.60	1958-1973

The long- run steady state demand relationship is:

$$X_t^{\,d} = 682.2\, P^{-(1.32266)}\ e^{0.0027t} \tag{31}$$

These estimates relating to industrial and residential demand for electricity are applied, after estimation of LRMC, toward empirical estimation of Ramsey optimum prices to be levied on residential and light industrial consumers of electricity of the distribution agency- DPDC.

4.3 Empirical result of LRMC distribution cost.

LRMC of distribution at 0.4 KV level is estimated by means of Average Incremental Cost (AIC) method (section 3.2).

Period of analysis is FY 2002-03. to FY 2008-09 in a simplified approach. In estimating capital expenditure, three projects of DPDC which add to capacity, implemented during the period, are taken into account. These are:

1) Greater Dhaka Power Distribution Project, Phase IV (DPDC)

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2) Rehabilitation of Dhanmondi 2* 50/75 and 132/33 KV substation

3) Development of Shaympur BSIC II KV Station to 33/II KV sub-centre. (M/O Planning 2005-6).

Following M/O Power (2002) and London Economics(1996) exercise, in Table 8 derivation of distribution cost at 0.4 kv level is provided. Unitized distribution capacity cost per kwh is estimated to be 0.90 taka per kwh. It is added to unitized O & M cost estimated by M/O Power, (2002) to obtain total distribution cost (estimated) at 0.4 kv level, which is 1.16 taka per kwh, with 2008-09 as reference year.

Table 8. Distribution cost at 0.4 kv – DPDC

NPV capital expenditure 15% discount rate(million taka)	NPV incremental peak demand (MW)	Distribution capacity cost (taka/kw)	Annuitised capacity cost (taka/kw/yr)	Unitised capacity cost (paisa/ kwh)	Unitised O&M cost (paisa/kw)	Total distribution cost (taka/kwh)
1899.16246	60.238926	31527.16	4764.57	90	26	1.16

Average per unit cost, by customer group, is provided in Table 9, as per unit cost to residential and light industrial customers. Average cost per kwh is estimated to be 5.23 taka for light industrial customers and 6.08 taka for residential customers, with 2008-09 as reference year (cf Appendix B1,B2,B3).

Table 9. Average Economics Cost (AEC) - DPDC 2008 (taka/kwh)

Group	AEC
Residential	6.08
Light Industrial	5.23

Following Kahn's approach (1988), total welfare gain-consumer and producer surplus - estimated is positive, which is about taka 329 per residential unit and taka 2144 per industrial unit per quarter. (cf equation 26).

4.4 Discussion

Existing price of DPDC to residential and light industrial customers and optimal prices, estimated by the model in accord with equation (25) are provided in Table 11.

Table 11. Ramsey optimal and DPDC Price and cost to customers - 2008 Q1 (taka/kwh)

	Model price	DPDC price	Marginal cost
Residential	5.74	3.07	6.08
Lt Industrial	4.29	3.79	5.23

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In 2008Q1, movement to optimal price derived in the model generally requires increase in residential prices as well as light industrial price. It is in accord with present DPDC pricing and cost pattern during the period, as indicated in the Table.

The model prices emphasizes an anomaly in present relative prices, with higher marginal cost and lower relative price levied on residential unit, compared to industrial unit mainly due to redistribution objective. With ascending block rate, model, prices would be applicable in case of lifeline slab, in regard to residential units, resolving the question of redistribution.

It may be added that the present pricing criteria being followed by BERC (2008,2003) provide for ad-hoc preferential rate in regard to few classes. With additional research on demand function of other customer groups, present model of the study would act as a comprehensive basis of arriving at the optimum differential rates relating to all types of customer class or group, with utility's revenue constraint and also act as a index of welfare.

5. Conclusions

The paper provides a model of optimal electricity pricing in regard in Dhaka city, Bangladesh, which is a developing economy. Model is comprehensive, incorporating Ramsey pricing principle of price differentiation, dynamic demand function and LRMC of individual distribution utility, with the objective of ascertaining optimum prices and maximizing welfare, i.e. sum of consumer & producer surplus, constrained by revenue requirement or break even profit of the utility.

Present pricing exercise outcome are not stable and are wanting as an index of welfare, with ad-hoc markup and down on cost. Customers' demand structure are not taken into account. Tariff adjustment process, as M/O Planning opine, is ad-hoc and non-transparent (BERC, 2013, M/O Planning 1998 and M/O Power, 2002).

Estimated dynamic demand function of electricity by the model suggest non-zero effect of price on electricity demand, which emphasizes the relevance of the present model derived from Ramsey principle. Adjustment of prices estimated by the model would augment welfare – improving producer and consumer surplus, i.e. transaction surplus, to a significant extent. The model would rationalize prices as Table 10 indicate, while welfare gain of taka 329 and 2144 per unit per quarter of residential and industrial unit respectively (cf. Table 11) emphasize the process of rationalization by the price change.

In view of welfare and development objectives, cost differential and relatively high cost with low income, departures from marginal cost persist in Bangladesh. These departures from marginal cost are to be systematic & transparent with a view to ascertaining optimum prices – a requirement which the model tend to fulfill, with cost and demand of distribution utility based on individual utility's franchise and capacity. Any aspect relating to redistribution objective and cross subsidization, which is widely prevalent in Bangladesh, can be resolved primarily within the framework of the model, with a revenue constraint.

The paper extend previous work on electricity pricing, most of these, however, being limited to advanced economies. It is an improvement of the Imperial college model in U.K., as it extends pricing exercise to all customer classes by incorporating Ramsey model (Berrie & Anari, 1986), and is unlike works of Kopsakangus et al (2003) and Nelson (1982), which are only aggregate assessment or evaluation of pricing policy. It remedies the complexity of marginal cost pricing which characterizes Nelson et al's (1987) study, by including LRMC in the model.

Model will ease volatility of frequent price changes by the commission. However, demand & elasticity estimates of the paper can be improved, augmenting applicability of the

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model, with greater assistance from DPDC or BERC, in regard to data. The question of demand – reduced demand of any customer group as a result of higher model price, for instance – is thereby likely to be resolved. Adding certain extent of flexibility to model price would also aid demand and supply management.

It may be added that the present pricing criteria being followed by BERC (2008, 2003) provide for ad-hoc preferential rate in regard to few classes With additional research on demand function of other customer groups, present model of the study would act as a comprehensive basis of arriving at the optimum differential rates relating to all types of customer class or group, with utility's revenue constraint and also act as an index of welfare.

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Appendix A. Demand estimation

Table A1. Co-integrating regression (Light industrial demand)
Dependent Variable: x_t
Method: Least Square

Sample: 1992:3 2004:4

$[x_t = \beta + r\, p_t]$

Variable	Coefficient	Std. Error	t-statistic	Prob.
X_t	8.774	0.443	197.945	0.000
p_t	-0.823	0.126	-6.529	0.000

R-squared	0.47390	Mean dependent var.	8.49877
Adj.R-squared	0.45935	S.D. dependent var.	0.12944
S.E. of regression	0.09518	D.W. stat	1.35267
Sum sq. residual	0.43485		

Table A2. ADF test for co-integration (Light industrial demand)[a]

ADF Statistic[b]	-4.265	5% Critical value (Mackinnon) 2.92282 (Engle & Granger) 3.29

Notes:
(a) Test is in level
(b) Number of lagged first difference terms is 1.

Table A3. Breusch – Godfrey (BG) Serial correlation LM test (light industrial demand)[a]

F-statstic	5.466 (1)	Prob 0.02 (1)
	2.886 (2)	Prob 0.065 (2)
	2.090 (3)	Prob 0.098 (4)
Obs* R-squared[b]	5.209 (1)	Prob 0.022 (1)
	5.576 (2)	Prob 0.061 (2)
	7.983 (3)	Prob 0.092 (4)

Note:
(a) Figures in parentheses are number of lags, to denote order of autocorrelation.
(b) Critical value of χ^2 with 1, 2 & 4 d.f. are 3.84, 5.99 and 9.49 at 0.05 level of significance.

TableA4. Co-integrating regression (Residential demand)

Dependent Variable: x_t^d
Method: Least Square
Sample: 1992:3 2004:4
$[x_t^d = \beta^d + r\, p_t^d]$

Variable	Coefficient	Std. Error	t-statistic	Prob.
x_t^d	6.579	0.021	308.004	0.000
p_t^d	-1.596	0.176	-9.023	0.000

R-squared	0.6.49	Mean dependent var.	8.5019
Adj. R-squared	0.641	S.D. dependent var.	0.197
S.E. of regression	0.118	D.W. stat	1.727
Sum sq. residual	0.614		

Table A5. ADF-test for Co-integration (Residential demand)[a]

ADF Statistic[b]	-6.829	5% Critical value (Mackinnon)2.9320 (Engle & Granger)3.29

Notes:
(a) Test is in level
(b) Number of lagged first difference terms is 1.

Table A6. BG Serial correlation LM Test (Residential demand)[a]

F-statstic	0.793 (1)	Prob	0.377 (1)
Obs* R-squared[b]	0.833 (1)	Prob	0.361 (1)

Note:
(a) Figures in Parentheses are number of lags, to denote order of auto correlation.
(b) Critical value of χ^2 with 1 d. f. is 3.84

Table A7. Unrestricted Model of Light Industrial Demand

Dependent Variable: x_t
Method : Least Squares
Sample (adjusted): 1992:4 2004:3
Included observations: 48 after adjusting endpoints
$x_t = \alpha_1 + r_o p_t + r_1 p_{t-1} + w_1 x_{t-1} + \delta t$

Variable	Coefficient	Std. Error	t-statistic	Prob.
α_1	6.165098	1.254071	4.916068	0.0000
r_o	-0.630451	0.290746	-2.168391	0.0357
r_1	0.373738	0.299513	1.247820	0.2188
w_1	0.276482	0.145487	1.900387	0.0641
δ	0.002672	0.001905	1.402586	0.1679
R-squared	0.508097	Mean dependant var		8.497841
Adj.R squared	0.462339	S.D. dependant var		0.126745
S.E. of regression	0.092937	Durbin-Watson stat		1.917499
Sum sq.residual.	0.371399			

Table: A8. Breusch -Godfrey Serial Correlation LM Test Unrestricted Model (Light Industrial Demand)

F-statistic	0814456	Probability	0.371953
Obs*R-squared	0.913100	Probability	0.339293

Table A9. Restricted Model of Light Industrial Demand
Dependent Variable: x_t
Method Least Squares
Sample (adjusted): 1992:4 2004:3
Included observations: 48 after adjusting endpoints
$x_t = \alpha_1 + r_o p_t + w_1 x_{t-1} + \delta t$

Variable	Coefficient	Std. Error	t- statistic	Prob.
α_1	6.615133	1.208670	5.473067	0.0000
r_o	-0.420888	0.238834	1.762266	0.0850
w_1	0.232515	0.142047	1.636892	0.1088
δ	0.001938	0.001824	1.062724	0.2937
R-squared	0.490285	Mean dependent var.		8.497841
Adj.R sq.	0.455532	S.D. dependent var.		0.126745
S.E.of regression	0.093523	Durbin-Watson stat.		1.874047
Sum sq. resid.	0.384848			

Table A10. Breusch-Godfrey Serial Correlation LM Test Restricted Model (Light Industrial Demand)

F-statistic	1.646757	Probability	0.206274
Obs*R-squared	1.770438	Probability	0.183328

Table A11. Unrestricted Model of Residential Demand
Dependent Variable: x_t^d
Method: Least Squares
Sample(adjusted):1992:4,2004:4
Included observations: 44
Excluded observations: 5 after adjusting endpoints
$x_t^d = \alpha_2 + r_o^d p_t^d + r_1^d p_{t-1} + w_1^d x_{t-1}^d + \delta^b t$

Variable	Coefficient	Std. Error	t- Statistic	Prob.
α_2	5.248767	1.108789	4.733785	0.0000
r_0^d	0.952327	0.327142	-2.911048	0.0059
r_1^d	-0.176430	0.349416	-0.504928	0.6165
w_1^d	0.196298	0.170177	1.153497	0.2557
δ^d	0.001870	0.001991	0.939191	0.3534
R-squared	0.673871	Mean dependent variable		6.699584
Adj. R-squared	0.640422	S.D dependent variable		0.195036
S.E. of regression	0.116953	Durbin-Watson stat		1.786382
Sum Sq. residual	0.533441			

TableA12. Restricted Model of Residential Demand

Dependent Variable: x_t^d
Method: Least Squares
Sample (adjusted): 1992:4, 2004:4
Included observations: 44
Excluded observations: 5 after adjusting endpoints
$x_t^d = \alpha_2 + r_o^d p_t^d + w_1^d x_{t-1}^d + \delta^d t$

Variable	Coefficient	Std. Error	t-Statistic	Prob.
α_2	4.999223	0.983267	5.084300	0.0000
r_0^d	-1.013289	0.301204	-3.364131	0.0017
w_1^d	0.233901	0.151585	1.543030	0.1307
δ^d	0.002077	0.001930	1.076561	0.2881
R-squared	0.671739	Mean dependent var.		6.699584
Adj. R squared	0.647119	S.D. dependent var.		0.195036
S.E. of regression	0.115859	Durbin-Watson stat		1.795829
Sum sq. residual	0.536929			

Appendix B. Cost estimation

Table B1. Distribution cost at 0.4 kv level

(taka/kwh)

(1) Level[a]	(2) Average	(3) Peak	(4) Off peak
0.4 kv[b]	1.16	2.71	0.43

Note:
(a) Peak & off peak breakup is approximated from M/O power (2002).
(b) 2008-09 price

Table B2. Cost at voltage levela,b

(taka/kwh)

Level[c,d]	Average	Peak	Off Peak
Generation & Transmission	2.66	4.56	2.31
Plus 33 & II kv	3.75	7.06	2.76
Plus 0.4 kv	4.91	9.77	3.19

Source: M/O Power (2002), London Economics (1996). Farooque (2010).

Note:
(a)Cost has been adjusted by PPI
(b)Peak, off peak break up as per LE (1996).
(c) Cost estimates are without demand charge
(d) 2008-09 price

Table B3. Average economic cost (AEC) by customer group.

(taka/kwh)

Customer Group	Cost			Approx. Consumption Pattern (%)		AEC
	average	peak	off peak	peak	off peak	
Residential	4.91	9.77	3.19	44	56	6.08
Lt. Industrial	4.91	9.77	3.19	31	69	5.23

Source: M/O Power (2002), Farooque (2010).