ELECTRICITY DEMAND AND ELECTRICITY VALUE

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1. DEMAND FOR ELECTRICITY

The estimation of the demand for electricity is important in power project appraisal because it often affects the benefits of the projects. For projects that involve a decision about the timing of investment – when to install new capacity to meet the demand – the precision of the electricity demand forecast can be critical. For others, when electric tariff policy is involved, it is essential to relate the demand for electricity with tariffs through the use of a electricity demand model or demand elasticities.

In this paper, we shall discuss a commonly used demand for electricity model and demonstrate its use in our analysis.

1.1 ELECTRICITY DEMAND AND CAPITAL STOCK

Electricity is not consumed directly; it is consumed through the use of equipment and electrical appliances. While it is possible to adjust the amount of electricity consumed through actions such as turning off the light, turning down the thermostat, taking shorter showers, going to bed earlier and so on, the amount of electricity consumption is nevertheless affected by the size and number of electrical appliances in the long run. The size of houses, the size and number of air-conditioners, television sets, refrigerators, hot-water heaters are the capital stock that will affect household and commercial consumption. The capacity and type of machinery and equipment being installed will affect the power consumption of the industry and some commercial customers. Furthermore, electricity consumption is also influenced by consumers' habits and expected income. Both of which change only slowly. In short, electricity demand is strongly influenced by the existing capital stock of electrical appliances and machinery, past incomes and old habits.

1.2 THE LAG-ADJUSTMENT MODEL OF THE DEMAND FOR ELECTRICITY

The demand for electricity depends essentially on income or production level, prices and existing electrical capital stock[1]. It is also affected by other localized and transient secondary factors such as weather conditions, power failure rate, new customer connections. The demand model used here is based on models commonly used in the estimation and forecasting of electricity demand[2].

It is customary to use a lag-adjustment model to capture the lagged adjustment of electric capital stock to income and price changes. The lag-adjustment model or partial-adjustment model[3] postulates that the increase in capital stock in year t is a function of the desired level of capital stock (K_t*) and the actual level of capital stock (K_{t-1}) which can be written in the following form[4]:

$$K_t - K_{t-1} = \phi (K_t^* - K_{t-1}) \qquad (1)$$

[1] Lim (1979), Taylor (1975), Westley (1992).
[2] World Bank (1991).
[3] Westley (1992).

where $0 \leq \phi \leq 1$ is the adjustment factor. Equation (1) can be rewritten as

$$K_t = (1-\phi)K_{t-1} + K_t^* \tag{2}$$

The desired level of capital (K_t*) is a function of income, price of electricity, price of appliance, alternative fuel cost and others. Under the assumption that the utilization factor (or load factor) of the capital stock is constant or at least stable, equation (2) can be rewritten as

$$Z_t = (1-\phi)Z_{t-1} + f(P_t, Y_t, C_t, O_t \ldots) \tag{3}$$

where Z is the demand for electricity, $f(\,)$ is a function, P is real price of electricity, Y is real income or output, C is cost of capital, O are alternative fuel cost and other variables. Equation (3) is the most common estimation form of the lag-adjustment model.

For the convenience of demand elasticity estimation, it is further postulated that the demand for electricity and the lag-adjustment assume a log-linear demand function which can be written as

$$Z_t^* = \alpha Y_t^{\beta} P_t^{\gamma} \tag{4}$$

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[4] **Lim (1979), p.141; Westley (1992), p.241.**

where Z_t* is the demand based on the desired level of capital stock; α , β and γ are parameters that can be estimated; and

$$\frac{\partial Z^*}{ZY} \succ 0 \text{ and } \frac{\partial Z^*}{\partial P} \prec 0.$$

The relationship between the desired and actual levels of demand in periods t and t-1 is assumed to have the following log-linear form:

$$\frac{Z_t}{Z_{t-1}} = \left[\frac{Z_t^*}{Z_{t-1}}\right]^{1-\phi} \qquad (5)$$

Substituting equation (4) into (5), we get

$$Z_t^* = \alpha Y_t^{\beta(1-\phi)} P_t^{\gamma(1-\phi)} Z_{t-1}^{\phi} \qquad (6)$$

where β and γ are the long run income and price elasticities of demand respectively. Short run income and price elasticities are given by $\beta(1-\phi)$ and $\gamma(1-\phi)$. In a log-linear form, equation (6) can be written as

$$\ln Z_t^* = \alpha + \beta(1-\phi)\ln Y_t + \gamma(1-\phi)\ln P_t + \phi \ln Z_{t-1} \qquad (7)$$

When this equation is estimated, the coefficients of the equation will be the short run elasticities. The long run elasticities are equal to the short run elasticities divided by $(1-\phi)$.

The typical income and price elasticity estimates used in the electricity demand model are given in Table 1.[5]

Table 1: Income and Price Elasticities

	Short Run Income Elasticity	Long Run Income Elasticity	Short Run Price Elasticity	Long Run Price Elasticity	Adjustment Rate
Residential	0.75	1.07	-0.11	0.15	0.300
Industrial	0.70	1.16	-0.11	0.18	0.400
Commercial	0.60	1.00	-0.02	0.03	0.400
Rural	0.80	1.14	-0.01	.014	0.300
Services	0.70	0.82	-0.02	.023	0.148

2. ECONOMIC VALUE OF ELECTRICITY

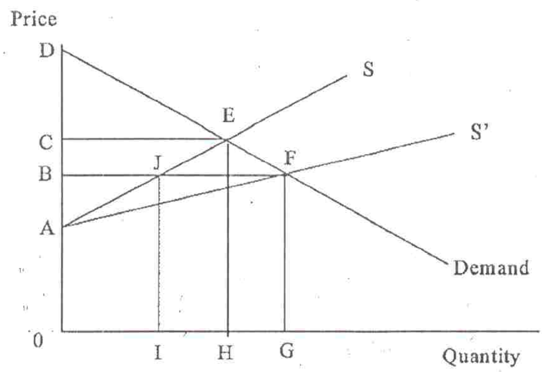
The measurement of the economic value of the output of a project differs markedly between a competitive industry and a regulated industry. A few countries have deregulated and introduced competition in their power industry. However, in most countries where the power industry remains regulated, a power project is typically the investment of a regulated power company within a regulated industry. In the following discussion, it is assumed that the power company concerned is such a regulated utility.

[5] **Based on Lim (1979), p.141; Taylor (1975), Westley (1992), and the World Bank (1991) and modified by the authors.**

2.1 ECONOMIC VALUE OF ELECTRICITY IN A COMPETITIVE INDUSTRY

In a competitive market, when a project increases the industry's supply of electricity (supply curve AS shifts to AS' in Figure 1), the price of electricity falls, the quantity of electricity demanded rises. The production of existing producers decreases. The increase in consumer welfare or willingness to pay is equal to the area HEFG. The resources released by the reduction of production of the existing firms is given by the area IJEH. The economic value of the project's output is the sum of these two areas.

Figure 1 The Impact Of A New Project In A Competitive Industry



IJEH = Saving in resources due to the production cut back of existing firms
HEFG = The incremental consumer welfare (willingness to pay) due to increase in demand

In the case of a *regulated* electric utility, the increase in supply from one of its new projects does not cause the price to change as it is regulated. A regulated utility typically plans the expansion of its supply to meet the forecasted increase in demand at a given price. The value of the electricity supplied by a regulated utility is considered below.

2.2 VALUE OF ELECTRICITY WITH POWER SHORTAGES

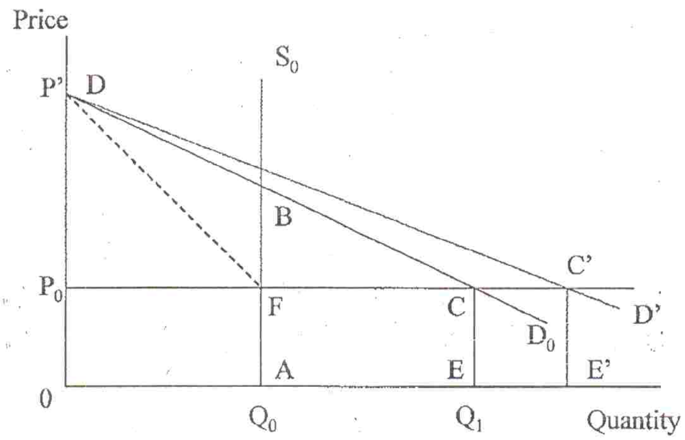
When a power shortage situation arises and persists for some time, some firms and residential customers may decide to install their own generators. Some would decide to conduct their business without electricity while others may simply cut back some of their activities that require electricity. Furthermore, some firms which otherwise would have located in the country or state may decide not to come. We shall refer to the potential demand for electricity in the state discouraged by the power shortages as the "deterred demand".

A power project providing electricity to customers during power shortages or to customers without a connection to power supply will have a direct impact on the consumers directly affected by the power shortages and an indirect impact on the economy by eliminating the deterrence to potential domestic and foreign investment in the state.

The direct benefits of providing electricity to the customers are measured by their willingness to pay for the power. In addition to the direct benefits accruing as a result of elimination of power shortages to those affected customers, there will be the added benefits due to reduction in the deterred demand.

In Figure 2, the supply of power by the existing system is fixed at the level Q_0 in year 0, represented by the vertical supply curve, Q_0S_0. Based on the demand curve DD_0, the demand for power would have been Q_1 at the prevailing tariff of P_0 at year 0. But because of the fixed supply at Q_0, a power shortage of AE persists. The valuation of electricity currently provided is given by the area 0DFA. The valuation of the entire demand (served and unserved), Q_1, is given by the area ODCE. If the power shortage is *evenly distributed among all customers* through a rotating blackout, the valuation of the "unserved energy" or shortage power is given by the area AFDCE. After the deterred demand is added, the new demand curve is represented by the line DC'D'.

Figure 2 **Demand and Valuation of Electricity with Rotation Of Power Shortages**



The highest value a customer is willing to pay can be estimated by the cost of the alternative power supply available to this customer, which usually means own-generation with a small gasoline or diesel electricity generator. For a rural farmer, the fuel cost of running a diesel water pump may provide an estimate of the highest level of willingness to pay. For rural residential usage, the cost of using a kerosene stove may be used.[6]

For the own-generated power to have the same degree of reliability as the power obtained from the electric utility, the own-generation will have to be backed up by another generator. The maximum willingness to pay for the shortage energy (P') with "similar to the utility" reliability can thus be estimated by the cost of own-generation plus the cost of maintaining a

[6] For example see World Bank, 1996.

reserve generator. P_0 is the gross of tax price of electricity in year 0 when the maximum willingness to pay for alternative power is estimated.

Let the quantity of the shortage energy (AE) be S (kWhs), the gross of tax price of electricity ($0P_0$ or AF) be P_0 in year 0.

We have

$$\text{Area } 0DFA = (P_0 + P')*Q_0/2 \text{ and} \tag{8}$$

$$\text{Area } 0DCE = (P_0 + P')*(Q_0+S)/2 . \tag{9}$$

The valuation of the "unserved energy" is given by the area

$$AFDCE = 0DCE - 0DFA = (P_0 + P')*S/2. \tag{10}$$

Equation (10) can be rewritten as

$$WTP*S = S*(P_0+P')/2, \tag{11}$$

where WTP is the average willingness to pay per unit of shortage power, S is the quantity of shortage power.

From equation (11), the average willingness to pay per unit of shortage power is given by

$$WTP = = (P_0+P')/2 \tag{12}$$

that is, the maximum willingness to pay plus the prevailing tariff in year t divided by 2.

An example of the calculation of the average willingness to pay is given in Table 2.

Table 2: Own-Generation Costs. Average Tariff and Willingness To Pay in Mexico (1990 Prices)[7]

Own-generation Cost ($/kWh)	0.210
Average Power Price in Mexico (Gross of Tax, 1990, M, Pesos/MWH))	0.114
Average Power Price in Mexico (Gross of Tax1990, $/kWh))	0.037
k (Capacity cost as a share of total own-generation cost)	0.403
Maximum Willingness To Pay (1990 $/kWh)	0.294
Maximum Willingness To Pay (1990 Millions Pesos/MWH)	0.904
Average Willingness To Pay (1990 $/kWh)	0.166
Average Willingness To Pay (1990 Millions Pesos/MWH)	0.509

It is important to note that the maximum willingness to pay will not be affected by the changes in electricity tariffs over time. Once the average willingness to pay in real prices is calculated, it will remain the same for the entire project.

2.3 DETERRED DEMAND

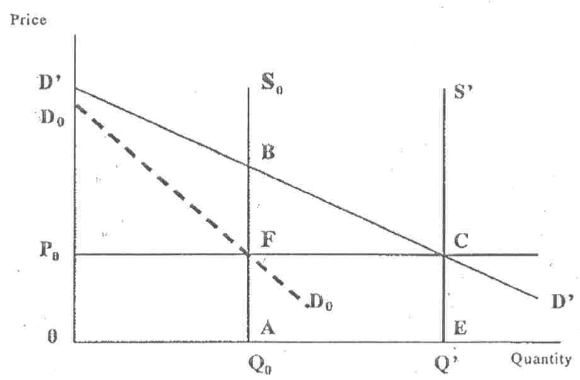
If a country or region's power shortages persist, there will be some potential businesses, investors and even residents being discouraged from settling in the region. We refer to this portion of the potential demand for electricity as the "deterred" demand. As long as the assumption that the deterred customers are of the types similar to the existing customers holds, the willingness to pay for the deterred demand can be represented by the area ECDC'E'. Equation (12) can be used to calculate the economic benefits per kWh when the deterred demand is considered in the study.

[7] **Annex 15a.**

2.4 VALUE OF ELECTRICITY WITH BALANCED SUPPLY

With balanced power supply, there will be no potential demand discouraged. There will be no deterred demand. In Figure 3, the growth in potential electricity demand, due to population and income growth, represented by the shift of the demand curve D_0D_0 to D'D' was expected by the utility. The new power project is built to meet this potential demand. The initial supply of power, represented by Q_0S_0 will be shifted to Q'S'. The value of the additional power supplied by the project is thus represented by the area $AFD_0D'CE$.

Figure 3: Demand and Valuation of Electricity with Balanced Power Supply



If the difference between the maximum willingness to pay 0D' and $0D_0$ is small and negligible, equations (11) can be used to calculate the total willingness to pay for the newly supplied electricity.[8]

2.5 NON-TECHNICAL LOSS - PILFERED ELECTRICITY

There will always be some electricity being pilfered in any power system. We shall refer to the portion of demand that should be metered, but is not, as pilfered demand or pilfered electricity. For pilfered electricity, consumers are likely to consume the electricity until the marginal utility for their electricity consumption becomes zero. The willingness to pay for the electricity consumed by these consumers is given by the entire triangular area under the demand curve (Figure 4). When meters are installed, these consumers will behave like any other electric consumers. Two things will happen. First, these newly metered consumers will continue to consume electricity but only to the point where the power price is equal to the marginal willingness to pay. To the utility, this will mean new "paid" customers and increased sales at no added costs, except for the meters and metering costs. Assuming that the pilferage behavior is evenly distributed among all groups of consumers, the reasoning and the estimation of the economic value of electricity for this portion of electricity demand is identical to the shortage case. Since the consumers already consumed this portion of pilfered electricity prior to the installation of new meters, this portion of "retained" pilfered electricity consumption adds no economic benefits to the consumers. What has occurred is the transfer of monetary payment from the consumers to the utility.

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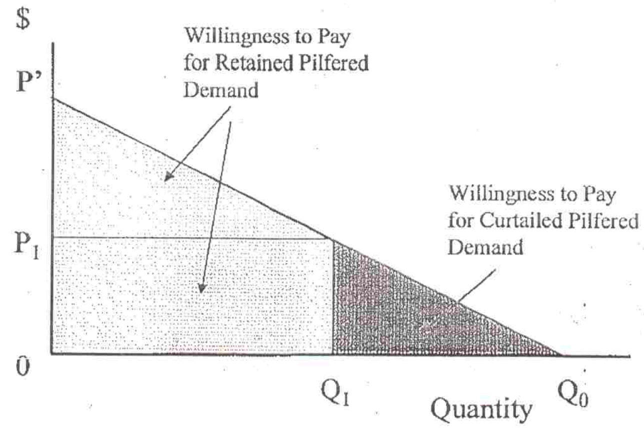
[8] **The new maximum willingness to pay 0D' is likely to be greater than the initial maximum willingness to pay $0D_0$ as consumers' income level increases.**

Figure 4 Pilfered Electricity, New Meters Installation and Curtailed Demand



P_1: Price of Electricity
Q_0: Demanded before metered = Pilfered Demand
Q_1 : Demand after metered = Retained Pilfered Demand

Second, because the newly metered customers must now pay for the electricity they consume, the portion of electricity which they previously consumed but valued at less than the price will no longer be consumed. The newly metered consumers will lose the value of this portion of power previously available to them at no cost. The average value or willingness to pay for this "curtailed" pilfered electricity, assuming a straight-line demand curve which intersects the horizontal axis, is equal to one half the electricity tariff now charged.

When new meters are installed for those previously unmetered electricity consumers, the quantity of the retained demand or consumption is estimated as the number of new meters installed times the average consumption per customer (Q_1 in Figure 4).

We shall assume the second portion or the curtailed portion of the pilfered electricity to be A% of the retained consumption (the first portion of the pilfered electricity, Q_1) [9]. The total willingness to pay for the curtailed portion of the pilfered demand (WTP_{CPD}) should therefore be

$$WTP_{CPD} = AQ_1(0.5P_1) = 0.5AP_1Q_1 \qquad (1)$$

where P_1 is the price of electricity. Since the utility no longer has to generate the curtailed portion of the previously pilfered demand, it will mean a fuel and capacity saving to the utility.

[9] Let Q_0 be the quantity of electricity pilfered before the project and let Q_1 be the quantity of electricity consumed and paid by the consumers who previously pilfered electricity. Let P' and P_1 be the maximum willingness to pay and the tariff respectively. Assume a linear demand curve, the following equation holds: $A = P_1/(P' - P_1) = 24.04\%$ where P'= 0.652 Million Pesos/Mwh, and P_1 =0.126 Million Pesos/Mwh in 1990.

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