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A New Slant on Slopes

Measuring the Benefits of Increased Electricity Access in Developing Countries

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Table of Contents

List of Tables

List of Figures

A New Slant on Slopes
Measuring the Benefits of Increased Electricity Access in Developing Countries

Executive Summary

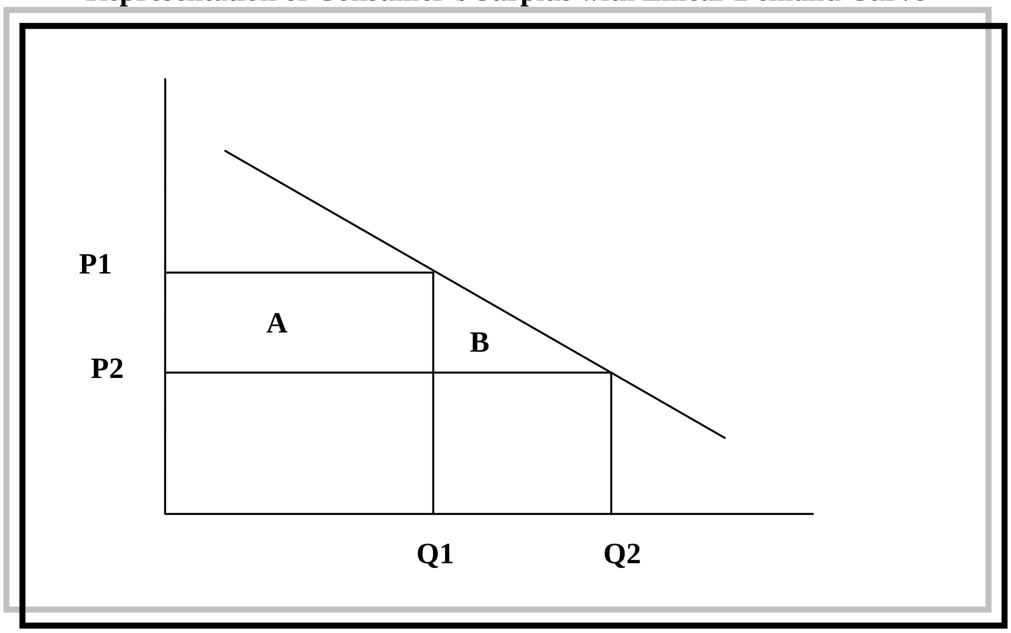
The objective of this paper is to shed some additional light on the benefits of improved access to electricity supply, specifically the benefits referred to as "consumer's surplus", which is the difference between what customers are willing to pay for the utilities associated with electricity access and the price that they actually pay. Measuring consumer's surplus has presented an ongoing challenge because it requires that the analyst construct a consumer demand curve, generally with very little in the way of actual data. In particular, there has been considerable uncertainty – even argument – about the shape that the curve might take between the known points. This paper outlines the concept of consumer's surplus, its derivation as a measurable benefit of electrification projects, the data challenges associated with deriving reliable estimates of its value, and the findings derived from recent research into the shape of consumer demand curves and hence "consumer's surplus" values.

Early analyses of the benefits of electrification focused on determining whether the chosen method of delivering electricity supply was the lowest cost alternative for meeting the projected demand for electricity. However, simply establishing that an investment was least cost did not answer the question of whether its benefits exceeded its costs. Accordingly the focus shifted from the cost side to the revenue side of the equation. Incremental revenues from tariffs represented a tangible benefit to the investor which could be compared with the associated investment and operating costs to determine the IRR. They also provided an observable indication of the value (benefit) that the consumer assigned to electricity access. This method became problematic, however, for two reasons. First, in many countries, electricity tariffs – especially for households - were set at historic cost or even at heavily subsidized levels. Hence, measuring the benefit of an investment in terms of the incremental tariff revenues would inevitably yield a negative rate of return. Second, measuring all benefits at the equivalent of the marginal willingness to pay ignored the fact that many customers would have been willing to pay a higher price for lesser quantities of electricity. This was evidenced by the behavior of households in non-electrified areas, who would pay significant amounts of money for a few kWh equivalents of kerosene lighting or dry cell radio operations or a small generator to operate a motor or pump. The tariff based measure of benefits therefore ignored a substantial benefit associated with the avoided cost of substitutes. In addition, it ignored possible benefits associated with customer access to electric fans, refrigerators, televisions, and other applications that were either infeasible or prohibitively costly without electricity supply. These benefits could be represented by the area under the customer demand curve for electricity between what he was willing to pay for these services and what he actually had to pay. If this area increased as a result of a proposed investment project, the customer would experience a gain in welfare that could be expressed in terms of an increase in consumer's surplus.

The figure below illustrates the concept. If P1 and Q1 represent the price and consumption of electricity without the investment and P2 and Q2 represent price and consumption of electricity with the project, then the increase in consumer's surplus resulting from the project is represented

by the area A plus B. Area A is sometimes referred to as the increase in surplus associated with substitution, while Area B is referred to as the increase in surplus associated with new demand induced by increased accessibility of electricity (either in the form of physical access or lower prices).

Representation of Consumer's Surplus with Linear Demand Curve



The idea of using consumer's surplus as a component of the benefits of electricity consumption was first introduced into World Bank lending in the mid 1980s. At times it caused considerable controversy because the analysis frequently yielded measures of "willingness to pay" that far exceeded the obvious "ability to pay" of customers. However, in 1998, the Bank formally approved the concept in its Handbook on Economic Analysis of Investment Operations[1].

The main problem with applying the concept, however, was that the results were highly dependent on the assumed shape of the demand curve. A straight line demand curve would produce a much higher increase in consumer's surplus than one that was highly concave. Unfortunately, analysts typically only had two or three observable points on the curve, which were insufficient to provide a reliable basis for deducing its full shape. These points might include the price and quantity of substitutes for electric lighting (kerosene and LPG lamps, candles), substitutes for electric radios and TV's (dry cell and car batteries), and diesel powered pumps and motors and the corresponding prices and quantities of electricity used by consumers with electricity supply.

Recently, however, a comprehensive household survey was carried out in Yemen directed towards patterns of energy supply, consumption and expenditure. The results of this survey provided an extremely rich database related to the energy consumption of households and the

[1] Belli, P., Anderson, J., Barnum, H., Dixon, J., Tan, J.-P., Handbook On Economic Analysis Of Investment Operations, World Bank, January 26, 1998

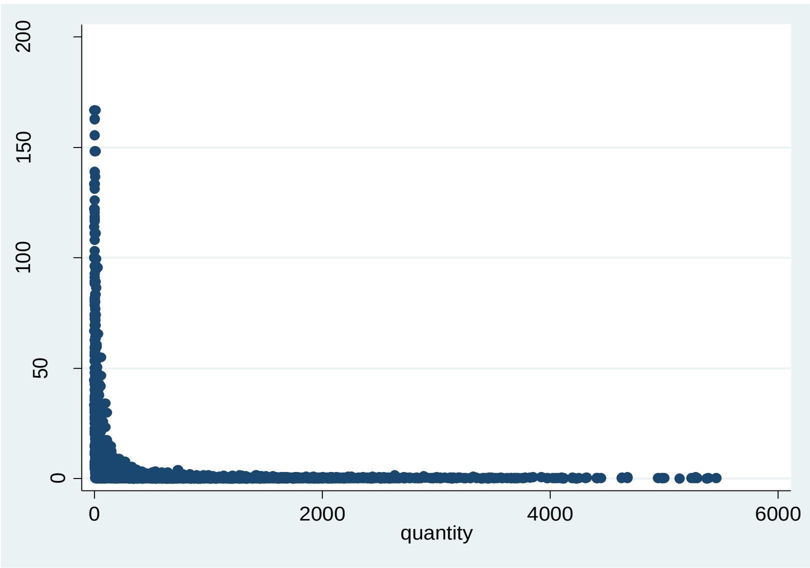
prices paid. The survey sample included households with and without access to electricity, and among those having access, included a number of different sources of electricity supply each of which had a different associated cost per kWh. Using survey data with respect specifically to household consumption of electricity and electricity substitutes for selected end uses, the present study was able to cast some new light on the vexing issues of how consumption of different utilities associated with electricity varies with price, how price-quantity relationships vary between urban and rural communities and how they vary among different income groups.

The study focused on household consumption of two main utilities – lighting and information/entertainment – and the relationship between the level of consumption and the prices paid. Not only were these used by virtually all survey respondents, but in most cases, households used both electric and non-electric sources of energy supply, which provided a wider range of price/consumption information. In addition, however, the study also looked at a selection of other applications which were largely limited to households with access to electricity and hence were only used by a part of the sample.

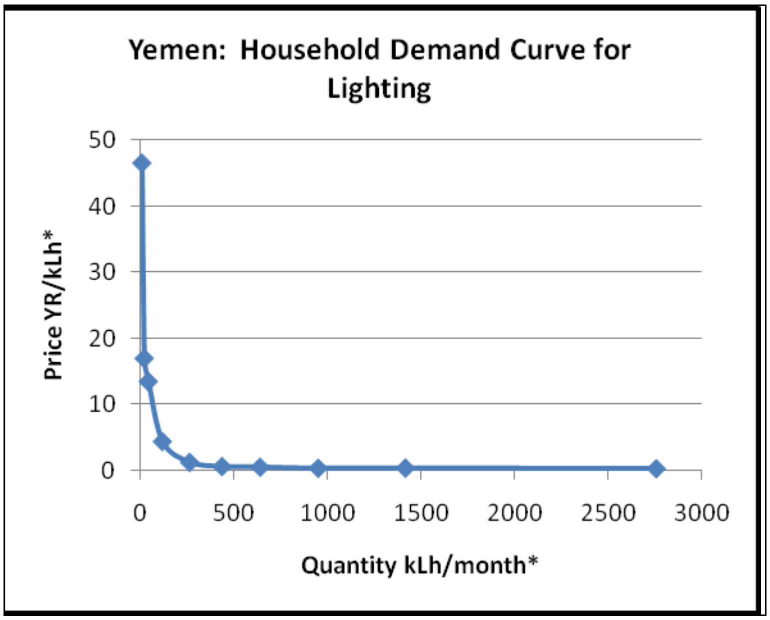
Lighting

Consumption of lighting derived from the various sources described above was measured in klumen.hrs in order to capture the differences in lighting quality relative to the amount of energy consumed for different types of lamps and bulbs. A pressurized hurricane lamp, for example, consumes energy at a rate of 200 watt.hrs per lamp hour. However, it generates light equivalent to only 0.15 lumens/watt, or 30 lumen.hrs per lamp hour. A 100 watt incandescent bulb, by contrast, generates light equivalent to 14 lumens per watt, or 1,400 lumen.hrs per lamp hour.

The team calculated for each of over 3,000 households the total klumen.hrs of lighting consumed per month (both electric and non-electric), the total expenditure on lighting, and the average price per klumen.hr, to create a set of price-quantity (P:Q) pairs. The results are shown in the scatter diagram below. The x-axis units are klumen.hrs per month and the y-axis units are YR/klumen.hr.



Individual results were then weighted using the weighting factors associated with the survey sample so as to provide nationally representative data. The resultant derived household demand curve is shown in the figure below.



*** Weighted average = 501 klumen.hrs/month at YR12.5/klumen.hr**

The parabolic shape of the derived demand curve is typical of a function based on a constant price elasticity, i.e. a curve with the following functional form:

$$\ln Q = A' + e * \ln P$$

Regression analysis was used with this model and the data points to determine the extent to which variations in quantity consumed could be explained by variations in price. The results of the regression analysis with a single variable are summarized in the table below:

Lighting – Price Elasticity of Demand – Single Variable Regression

Dependent variable: Lighting quantity (ln)		
	Coefficient	
Lighting price (ln)	-0.8183	***
Constant	5.5111	
Adj.R-sq 0.7530		
# of obs : 3216		

*** Significant at the 1% level

The co-efficient of the natural log of lighting price in the above results, -0.8183, is the price elasticity of demand by households for lighting in Yemen, which indicates that a 1 percent increase in the price of lighting would lead to a 0.82 percent decrease in the quantity of lighting consumed. The adjusted R square of 0.7530 means that the model explains over 75 percent of the changes in lighting quantity. The formula also provides a means of determining, through integration, the increase in consumer's surplus associated with moving from one P:Q point on the demand curve to another.

A regression analysis with multiple variables ("multivariate analysis") was also carried out to assess the relationship between price and quantity while controlling for the potential effect of other variables such as income, household size, locality and hours of electricity service. The results are shown below.

Lighting – Price Elasticity of Demand – Multivariate Regression

Dependent variable: lighting quantity (ln)			
	Coefficient		**Std.err.**
Lighting price (ln)	-0.7093	***	0.0124
Income per capita (ln)	0.1161	***	0.0226
Household size	0.0633	***	0.0045
Urban	0.1556	***	0.0372
Electricity service hours	0.0179	***	0.0022
Constant	3.7478	***	0.2023
Adj.R-sq: 0.7744			
# of obs : 3216			

Note: *** indicates significant at 1% level.

The multivariate regression analysis indicates that income, household size, locality and hours of electricity service in addition to price, have a statistically significant impact on demand quantity[2]. The multi-variable model explains 77 percent of the changes in quantity of lighting consumed – slightly higher than that explained by the single regression. Despite the greater accuracy of the multi-variable model, however, the additional data requirements would make it more difficult to use than the single variable model as a means of calculating the consumer's surplus (or area under the demand curve) between two observable points.

In terms of general observations, at the lower end of the demand curve, even very large changes in price will have little impact on the quantities consumed. At higher levels of consumption, even a small change in price will have a significant impact on quantities. This is not, however, simply the juxtaposition of two linear demand curves, although the shape is heavily influenced by the prevalence in the population of households who either have no access to electricity or who have access to the fairly reliable and extremely low cost national grid. As the scatter diagram shows, there are many observations of households that are paying above the grid price for energy, but are clearly not in the category of having no access to electricity. These households, which include those with access to isolated or cooperative grids, tended to have more of a balance between the use of electricity (albeit relatively costly supply) and electricity substitutes. A plot of their demand curves, however, displayed the same concavity as the composite national curve.

[2] The modest coefficient for income may be explained at least in part by the wide variance in prices and hence the dominance of price in determining the shape of the curve. In addition, high income households in areas without grid access are likely curtailing their consumption as a result of high prices as compared with low income households in areas with access to the grid.

The survey findings indicate that the benefits from increased consumer's surplus associated with moving from no access or partial access to full access to electricity supply (i.e. the substitution benefits) can be substantial on a per-unit basis. At the margin, household consumers pay an average price of only YR0.3[3] per klumen.hr for lighting. At the high end of the price range, customers pay on average YR46.6 per klumen.hr or more than 100 times the marginal price. In total, forty percent of households are paying more than 10 times the price associated with grid supply. Nevertheless, while households in the lowest consumption group are paying a very high unit price for lighting, they are consuming on average only 8 klumen.hrs per month. Even households in the fourth consumption decile, who are paying YR4.4 per klumen.hr, are consuming approximately 117 klumen.hrs per month. Thus, while benefits per klumen.hr may be high, the total substitution impact will be limited by the low number of units consumed.

The extreme concavity of the curve also means that the consumer's surplus attached to new or induced demand associated with moving from non-electric to electric lighting or from expensive to less costly electricity supply is much less than would accrue under a more gently sloping curve. At the lower levels of demand there is very little additional consumption induced by lower prices and hence the consumer's surplus benefits primarily accrue through an income effect that arises from an increase in the consumer's purchasing power with a price reduction, rather than from the substitution benefits of a price reduction. At the higher levels of demand there are significant increases in consumption induced by access to lower cost supply. However the price reductions are very small and the area attributable to induced consumption under this section of the demand curve will also be small.

The analysis of the impact of location (urban vs rural) and income per capita concluded that there was little difference between urban and rural households in terms of price elasticity. However, the proportion of rural households consuming small amounts of high-cost lighting greatly exceeded the corresponding proportion of urban households, and potential substitution benefits were correspondingly higher. While this is undoubtedly a function of differences in access to lower-cost grid electricity (which is much higher in urban areas), it highlights the importance of understanding the target market for a particular investment project before trying to establish the shape of the demand curve.

To examine the impact of income on demand curves for lighting, households were divided into four quartiles based on household income per capita. The demand curves for all income quartiles displayed a similar high degree of concavity. Price elasticity was found to decrease as income increased, but was still very high in all income groups. Price also explained more of the variations in consumption in the lower income quartiles. The results of the regressions are shown below:

Price Elasticities for Lighting by Income Quartile

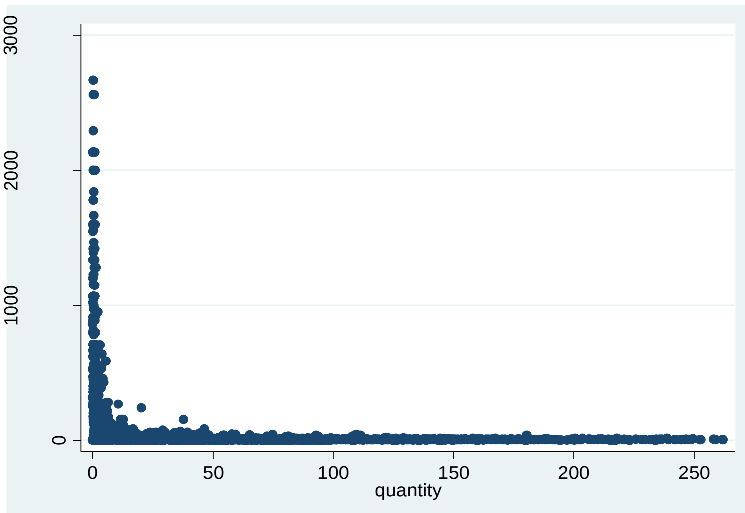
	Coefficient		R-Squared	Constant	Observations
Quartile 1	-0.8493	***	0.8021	5.5709	771
Quartile 2	-0.8292	***	0.7759	5.5037	801
Quartile 3	-0.8049	***	0.7228	5.4474	836
Quartile 4	-0.7620	***	0.5934	5.5924	808

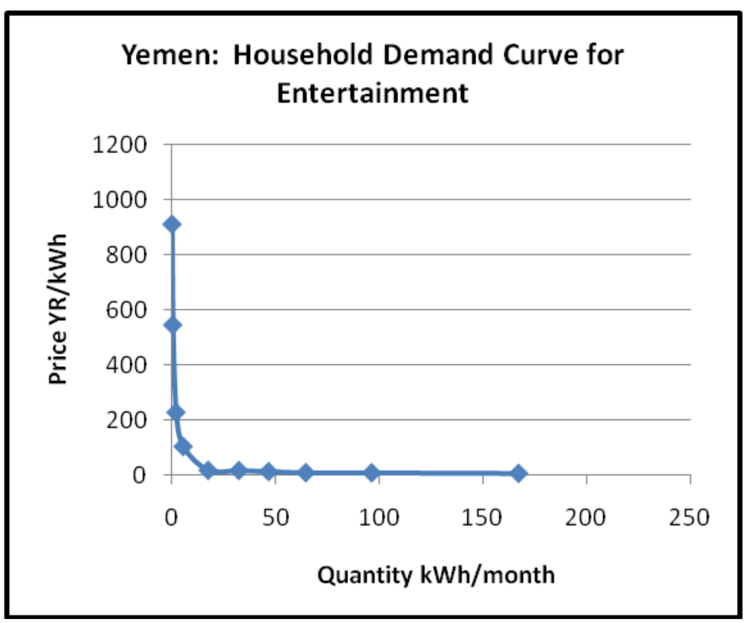
[3] The household tariff in Yemen is heavily subsidized.

Note*** Significant at the 1% level

Entertainment

The estimated consumption of electricity for "entertainment" by survey households was taken as the sum of consumption electricity used to power radios and televisions, both black and white and colour. These were powered by three different energy sources: dry cell batteries, car batteries and AC power.[4] The same general methodology as for lighting was used to generate the scatter diagram and derived demand curve shown below.





As with lighting, the demand curve is highly concave. The results of the single regression analysis to estimate price elasticity are summarized below. According to the model, a 1 percent

[4] Colour televisions were only powered by car batteries and AC power.

increase in the price of electricity used for entertainment will lead to a 0.91 percent decrease in the quantity of electricity consumed for this purpose.

Entertainment – Price Elasticity of Demand – Single Variable Regression

Dependent variable: Entertainment quantity (ln)		
	Coefficient	
Entertainment price (ln)	-0.916	***
Constant	5.5629	
Adj.R-squared - 0.7101		
# of obs : 2819		

A multivariate regression analysis was also carried out to assess the relationship between price and quantity while controlling for the potential effect of other variables such as income, household size, locality and hours of electricity service. The results are shown below. .

Entertainment – Price Elasticity of Demand –Multivariate Regression

Dependent variable: entertainment quantity (ln)			
	Coefficient		**Std.err.**
Entertainment price (ln)	-0.7745	***	0.0147
Income per capita (ln)	0.2392	***	0.0287
Household size	0.0757	***	0.0055
Urban	0.4469	***	0.0468
Electricity service hours	0.0168	***	0.0026
Constant	2.0658	***	0.2683
Adj.R-sq: 0.7456			
# of obs : 2819			

Note: *** indicates significant at 1% level.

The multivariate regression analysis indicates that household size, income per capita, locality and hours of electricity service, in addition to price, all have a statistically significant impact on demand. According to this model, the impact of price is lessened; when price increases by 1 percent, the quantity of entertainment consumption will decrease by 0.77 percent. The Adjusted R square indicates that the model explains 75 percent of the changes in quantity of entertainment consumed which is a modest improvement over the single variable regression. As with lighting, however, the additional data requirements of the multivariate model would make it more difficult to use than the single variable model as a means of calculating the consumer's surplus (or area under the demand curve) between two observable points.

Analysis of the differences between the demand curves of urban and rural households indicated that both had a similar – and very high negative - level of price elasticity. The main distinction between the two groups of customers is that approximately 60 percent of rural customers are consuming in the vertical segment of the range as compared with 10 to 20 percent of the urban customers. In addition, the average observed willingness to pay of rural customers for electricity to provide basic access to entertainment is much higher than that of urban customers.[5] Thus as a general principle in Yemen, investments in improving electricity supply to rural households will yield higher substitution benefits from lower-cost access to entertainment.

Differentiation among income levels showed little variation in the shape of the demand curves. Somewhat surprisingly, the P:Q coefficients of the lowest consumption decile are very similar in all four income groups. Clearly a significant portion of households in each income class choose or are forced on occasion to use extremely costly energy to meet some of their entertainment demand. All income groups displayed a high negative price elasticity of demand, although generally this elasticity declined as income levels increased.

Other Applications

In the hope of extracting additional useful information on price:quantity relationships from the Yemen data-base, a number of additional data sets were examined. Cooking seemed particularly promising since households reported using a variety of fuels with varying unit prices. However, there was also a possibility of identifying demand curves for other, solely electric appliances given the range of unit electricity prices reported by the survey. These included electric fans, vacuums, mixers, refrigerators, air conditioners, computers, audio and video players, and satellite dishes.

Unlike lighting and entertainment, which were reported as used by all survey respondents, ownership and use of these latter appliances were restricted to households with some form of electricity supply. Refrigerators, satellite receivers, electric fans, and mixers were the most commonly reported. Almost 60 percent reported using refrigerators, 44 percent used fans, 43 percent used satellite receivers, and 38 percent used mixers. Ownership and use of the other electric appliances was limited, generally to than 10 percent of the electrified households surveyed.

The analysis of other applications for electric energy provided some interesting lessons with respect to the factors affecting electricity consumption. In the case of cooking, it was found that notwithstanding the fact that electricity was the lowest cost method, kerosene was the dominant fuel in both urban and rural households. Tradition and style of cooking may be factors, as might availability of kerosene vs electric stoves. Electric stoves may also carry a high up-front cost that hinders their purchase even if their use would be less costly in the longer term.

Other entertainment devices, refrigerators, and electric mixers were owned predominantly by urban survey respondents. Use of electric fans, however, was more commonly reported by rural than by urban households. The average monthly consumption of urban households for the various applications was approximately double that of rural households, and the average price paid was approximately 40 percent lower.

[5] This is not to suggest that urban customers assign a lower value to entertainment; it may merely mean that they are more likely to have access to lower-cost sources of energy supply, and hence the amount that they are "observed" as willing to pay is lower.

In all instances, consumption took place within a relatively narrow band of prices, and the national demand curves showed relatively little correlation between the quantities consumed and the prices paid or between quantities consumed and household income. In the case of fans and refrigerators, regression analysis suggested that consumption increased with rising prices and decreased with rising income – a counter-intuitive finding. However, one of the main factors causing the upward sloping demand curves for fans and refrigerators is the inverted block tariff structure. The higher end of the consumption scale for these two appliances falls into the range of the higher tariff blocks for both urban and rural households. Hence, as consumption increases, average prices rise.

Regrettably it is difficult to draw broadly relevant conclusions regarding demand curves for the use of electric appliances. Because ownership was limited and heavily biased towards urban households, the prices charged for electricity fell within the narrow range of the PEC national grid tariff, as compared with the much broader range of prices observable for lighting and entertainment. The inverted block structure of the tariff further complicated the analysis for appliances such as fans and refrigerators. Consumption by households in the higher consumption deciles for these appliances often reached the range at which second or third block tariffs would apply; hence, the demand curve suggested that consumption increased as prices rose. The main conclusion that can be drawn is that there is in fact a logical relationship between price and quantity as evidenced by the differences in the consumption patterns of urban and rural households. Average prices paid by former are approximately 40 percent lower than those paid by the latter, and average consumption is approximately double.

Conclusions

The following are the key conclusions of the study.

1. The demand curves for lighting and basic information/entertainment derived from the Yemen Household Energy Survey are downward sloping and highly concave. The shape is consistent with a demand function based on a constant and high level of price elasticity, i.e. a function of the form $\ln(Q) = A + e^*\ln(P)$. The coefficient that represents the price elasticity of demand for lighting is estimated at -0.81 and for entertainment is estimated at -0.92. The implications for the benefits associated with new or improved access to electricity are twofold. First, while the unit value of savings as a result of avoided use of non-electric substitutes may be high, the number of units replaced by access to electricity is small. Hence the amount of consumer's surplus associated with substitution is limited. Second, the amount of consumer's surplus associated with additional demand induced by access to electricity for these two applications is also limited. Because the curve quickly approaches and parallels the x-axis, the area between the curve and the rectangle that represents the amount actually paid for the electricity is very small.

This has significant implications for the analysis of electrification projects. The high price elasticity observed for residential consumers in the Yemen survey, and the consequent low level of consumer surplus, means that the average household willingness to pay for electricity supply (traditionally used as a measure of the benefit of increased supply) may be closer to the prices actually paid than has generally been assumed. Estimates of average willingness to pay that are significantly higher than electricity tariffs cannot be justified given the evidence of this analysis.

Either tariffs will need to be sufficient to justify the investments or other benefits will need to be demonstrated to justify projects where the tariffs are not compensatory.

2. Price is a major determinant of quantity consumed for both lighting and entertainment. As noted above, in single variable regression models, price accounts for approximately 75 percent of the variations in the quantity of lighting consumed and 71 percent of variations in entertainment consumption. In a multivariate regression model, household size and daily hours of electricity service, income per capita and locality (urban vs rural) are also significant at the 1 percent level.

3. Locality (urban versus rural) has little effect on price elasticity of demand for electricity although it has a definite impact on the quantities consumed, doubtless owing to the lower prices prevailing in urban areas. For both lighting and entertainment, price elasticity declines with rising incomes. The estimated income elasticity of demand was 0.12 for lighting and 0.24 for entertainment. However, the wide variation in price, as well as the limited correlation between income and the price faced by consumers, may help to explain the limited impact of income on the quantities consumed.

4. The curve of electricity demand for cooking derived from survey data showed virtually no correlation between fuel price and consumption. Even though electricity and LPG are the lowest-prices fuels, they are the least used. Instead, cooking is dominated by kerosene. Ownership and use of other household appliances which are fully dependent on access to electricity is primarily an urban phenomenon. Because ownership was limited and heavily biased towards urban households, the prices charged for electricity fell within the narrow range of the PEC national grid tariff, as compared with the much broader range of prices observable for lighting and entertainment. The inverted block structure of the tariff further complicated the analysis for appliances such as fans and refrigerators. Consumption by households in the higher consumption deciles for these appliances often reached the range at which second or third block tariffs would apply; hence, the demand curve suggested that consumption increased as prices rose. There was, however, a logical relationship between price and quantity in that average prices paid by urban households are approximately 40 percent lower than those paid by the rural households, and their average consumption is approximately twice as high.

5. The Yemen survey data provides empiric evidence of the shape of the demand curves for lighting and entertainment, as well as the magnitude of the price elasticities. These can provide a guide to analysts who are studying the potential consumer's surplus benefits of new or improved access to electricity. However, while the shapes and elasticities may be transferrable, the prices of electricity and electricity substitutes and the quantities consumed are not. Some basic research needs to be done with respect to the consumption patterns of both electrified and non-electrified households, and of total spending and unit prices paid. This need not be a national survey. A small purpose-built survey focused on the project target area would probably provide sufficient guidance, although of course greater scope and detail would provide greater reliability of the findings.

6. The Yemen Household Energy Survey was originally designed to give a comprehensive picture of the supply and use of household energy, including diesel, kerosene, biomass, LPG, gasoline and fuel oil. In addition to satisfying its original purpose, the survey has provided the

detailed data that was needed to carry on this more extensive study of relationships between electricity prices and consumption. Doubtless there is also sufficient data to carry out many more in depth studies into other areas of interest. Insofar as energy – and its interaction with poverty – continues to be a focus of Bank lending, there is a strong argument in favor of additional surveys of this nature, so that a household energy database can be established that provides both time series data sets and also data sets covering a range of socio-economic and geographic groupings.

1 A Brief History of Economic Analysis

1.1 Benefit-Cost Analysis

The concept of benefit-cost analysis is an inherent part of the principles of 'economic man'. People make decisions or choices in order to maximize their utility. In order to make such decisions, individuals or groups take into account both the positive (benefit) and negative (cost) utility associated with the outcome. Where more than one action is possible, this assessment is applied to all of the alternatives and the outcomes compared on an equivalent basis[6].

Often, the flows of benefits and costs associated with an action or with alternative actions will be spread over an extended period of time. Accounting for time differences in the flow of benefits and costs requires consideration of the time value of money. If one deposits money in an interest-earning security, the amount of money available would grow and additional goods could be acquired in the future. One must decide whether the value of those future goods outweighs the cost of forgoing the immediate use of the funds. Similarly, one can spend money now that one does not have by borrowing and paying interest for the use of the funds. The question then becomes whether having the use of the money now generates greater benefit than the cost of borrowing. In order to make these assessments, it is necessary to compare the cost and benefit streams at a common point in time. If the time value of money is known, the future streams of costs and benefits can be discounted at this rate and the results compared either as a benefit-cost (BC) ratio or a Net Present Value (NPV). Provided the resultant finding is positive, the investment meets the minimum criteria for acceptability. In some instances, a third alternative is used – the interest rate at which the discounted values of the cost and benefit streams were equal. This is referred to as the Internal Rate of Return (IRR). If the IRR exceeds the threshold requirement for return on investment, then the investment meets the criteria for acceptability.

Individuals, groups and corporations commonly apply this weighing of benefits and costs of an action or set of alternative actions to financial activities – decisions regarding which investment or investments will yield the highest financial return, or whether a particular investment will satisfy some criteria for minimum return. This usually forms a part of what is referred to as "financial analysis" of an investment or project.

There are other situations, however, where the benefits and costs may not match up directly, for example when a government needs to choose among investments aimed at improving the living standard of the population, or when an NGO needs to decide where its interventions might have the greatest positive impact. These assessments can be more complex. It may be difficult to predict the type of impacts that might arise as a result of the investment (the bilharzia outbreak which followed construction of the Aswan High Dam being a well-known example), and even when the full range of effects can be predicted, it may be difficult in many cases to value them in

[6] Cost-benefit analysis is a neoclassical way of evaluating projects from an economic perspective. However, this is not the only method of project evaluation and the assumptions behind this approach do not represent a consensus of everyone. There are well-argued questions or doubts about the utility maximizing behaviour of consumers.

a common numeraire. Staying with the electricity example, it is a challenge to bring to a common base the value of reduced indoor pollution through the elimination of kerosene lamps, better educated children as a result of better study opportunities, reduced childhood mortality as a result of access to local health posts, and the entertainment value of access to colour TV. Notwithstanding the challenges, this type of analysis is the core of what is commonly referred to as the "economic analysis" of an investment or project.

As a purveyor exclusively of government guaranteed loans, the World Bank has been a leader in researching and defining the principles for the economic evaluation of investment projects. In the interest of ensuring that its loans are used in the best interest of the borrowing country, it engaged in a program of setting and improving guidelines for the measurement of both the benefits and the costs of government investments. Works by authors such as Squire and van der Tak[7], or Gittinger[8] still form the basis for increasingly complex assessments of benefits and costs which must now take into account not only national impacts of investment projects but also global impacts in terms of the environmental effects of carbon emissions.

Projects relating to enhancement of electricity supply have always presented a particular challenge in Bank lending. Such projects are exceedingly popular among borrowing countries. The beneficiaries enjoy an immediate and tangible improvement in their day-to-day quality of life, and credit normally goes to the current government for having delivered these benefits – a factor that may prove influential at election time. Yet in many instances the revenues that flow to the investor/government are insufficient to cover the economic opportunity cost of capital, making it difficult to establish that the investments are economically viable. Nevertheless, the benefits of increased access to low-cost electricity supply are not trivial, even though many of them may be difficult to measure. The risk lies in focusing on the benefits that can be measured for analysis whilst overlooking the other less tangible positive attributes.

The objective of the present paper is to shed some additional light on the benefits of improved access to electricity supply, specifically the benefits referred to as "consumer's surplus". The paper outlines the concept of consumer's surplus, its derivation as a measurable benefit of electrification projects, the data challenges associated with deriving reliable estimates of its value, and the findings derived from recent research into the shape of consumer demand curves and hence "consumer's surplus" values.

1.2 Benefits of Electrification

Early analyses of the benefits of electrification focused on determining whether the chosen method of delivering electricity supply was the lowest cost alternative for meeting the demand for electricity. Thus, for example, supply from the central grid would be compared with the cost of isolated grids, and development of isolated grids would be compared with the cost of a number of local diesel plants. This least cost analysis continues to be a fundamental principle of the economic analysis of electrification projects. If there are alternative investments available that would yield the same outcomes but at a lower cost, then the proposed investment is not maximizing the return to the investor.

[7] Squire, L, van der Tak, H. G., Economic Analysis of Projects, Johns Hopkins University Press, Baltimore, 1975
[8] Gittinger, J. Price, Economic Analysis of Agricultural Projects, Johns Hopkins University Press, Baltimore, 1982

However, simply establishing that an investment was least cost did not answer the question of whether its benefits exceeded its costs. Measuring benefits solely in terms of cost saving presumed that the outputs without question yielded a return in excess of the investor's minimum requirement. Accordingly the focus shifted from the cost side to the revenue side of the equation. Incremental revenues from tariffs represented a tangible benefit to the investor which could be compared with the associated investment and operating costs to determine the IRR. Provided that tariffs were set at the long run marginal cost (LRMC) faced by the investor, the investment would yield a return at least equivalent to the investor's cost of capital. This method had the added advantage of providing a measure of the benefit to the electricity consumers; the fact that they were willing to pay the LRMC tariff for electricity supply implied that their benefits were at least equal to the cost.

This method became problematic, however, for two reasons. First, in many countries, electricity tariffs – especially for households - were not set at LRMC but rather at lower levels such as historic cost or even at heavily subsidized levels. Hence, measuring the benefit of an investment in terms of the incremental tariff revenues would inevitably yield a negative rate of return. Second, measuring all benefits at the equivalent of the marginal willingness to pay ignored the fact that many customers would have been willing to pay a higher price for lesser quantities of electricity – e.g. enough to light one or two rooms of his house or operate a radio or a fan in the case of households, or a small diesel or petrol generator in the case of commercial and small industrial customers. This willingness to pay higher prices was evident from the behavior of households in non-electrified areas, who would pay significant amounts of money for a few kWh equivalents of kerosene lighting or dry cell radio operations or a small generator to operate a motor or pump. The tariff based measure of benefits therefore ignored a substantial welfare benefit associated with the avoided cost of substitutes. In addition, it ignored potential welfare benefits associated with customer access to electric fans, refrigerators, televisions, and other applications that were either infeasible or prohibitively costly without access to electricity supply.

1.3 Consumer's Surplus

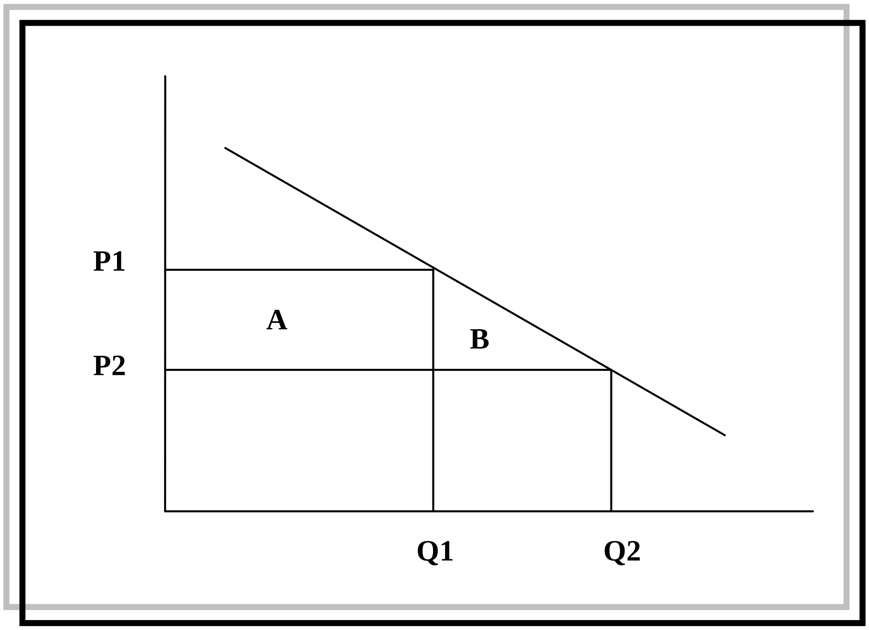
The idea of using consumer's surplus as a component of the benefits of electricity supply was first introduced in Bank lending in the mid 1980s. At times it caused considerable controversy because the analysis frequently yielded measures of "willingness to pay" that far exceeded the evident "ability to pay" of customers. However, in 1998, the Bank formally approved the concept in its Handbook on Economic Analysis of Investment Operations[9]. According to the Handbook, "When a project lowers the price of the project's output, more consumers have access to the same product and the old customers pay a lower price for the same product. Valuing the benefits at the new lower price understates the project's contribution to society's welfare. If the benefits of the project are equated with the new quantities valued at the new price, the estimate of benefits ignores consumer's surplus: the difference between what consumers are prepared to pay for a product and what they actually pay. In principle, this increase in consumer's surplus

[9] Belli, P., Anderson, J., Barnum, H., Dixon, J., Tan, J.-P., Handbook On Economic Analysis Of Investment Operations, World Bank, January 26, 1998

should be treated as part of the benefits of the project." The Handbook also notes that "There may also be a gain in consumer's surplus without any decline in price. If supply is rationed at a price below what consumers would be willing to pay, an increase in supply at the same controlled price involves a gain in consumer's surplus over and above what consumers actually pay for the increase."

The Handbook goes on to say that "measuring consumer's surplus is straightforward under certain simplifying assumptions". The graph below illustrates their suggested method.

Figure 1-1 Representation of Consumer Surplus with Linear Demand Curve



If P1 and Q1 represent the price and consumption without the investment under the project, and P2 and Q2 represent price and consumption with the investment under the project, then the consumer's surplus is represented by the area A plus B. Their representation of the demand curve as a straight line simplified the computation of consumer's surplus as the combined areas of a rectangle and a triangle[10].

A straight line demand curve implies a constantly changing price elasticity of demand as price and quantity change. Price elasticity of demand is defined as the percentage change in quantity of a good demanded relative to the percentage change in price. The graph below demonstrates how this changes in a straight line demand curve depending on the starting and ending point chosen.

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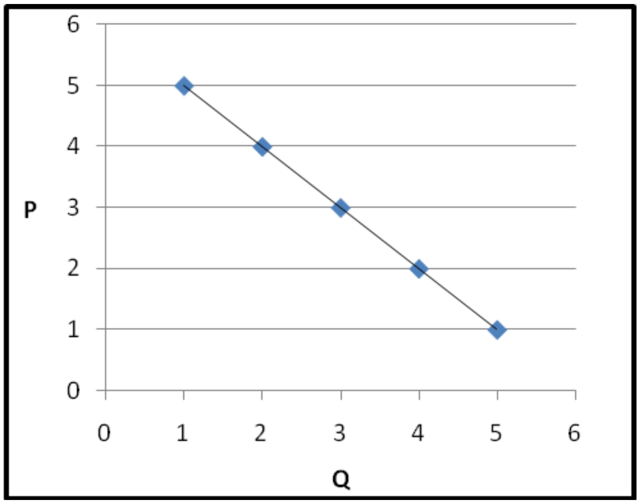
[10] Had the Handbook been more precise, it would have noted that what is actually being measured is the **increase** in consumer's surplus as a result of the investment. **Total** consumer's surplus (i.e. the difference between what customers would be willing to pay for the product versus what they actually pay) is actually represented by the total area under the demand curve minus the rectangle bounded by P2 and Q2.

Figure 1-2 Price Elasticity and Linear Demand Curves



Price	Quantity	% Δ P	% Δ Q	Elast.
5	1			
4	2	-20%	100%	(5.00)
3	3	-25%	50%	(2.00)
2	4	-33%	33%	(1.00)
1	5	-50%	25%	(0.50)

At this stage the distinction between *arc elasticity* and *point elasticity* needs to be introduced. As its name implies, arc elasticity covers a discrete change in the values of P and Q along the demand curve..[11] A point elasticity refers to a point for P and Q on the demand curve.[12] In a demand curve with a constant price elasticity, the point elasticity would be constant and hence by definition would equal the arc elasticity, which would also be constant. Otherwise, the values of these elasticities generally differ. References to price elasticity of demand generally mean point elasticities at the point on the demand curve that represents actual consumption at the prevailing price of electricity (or other good or service). The example shown in the Handbook, however, refers to arc elasticity. Thus, it might more properly be represented by Figure 1.3 shown below. The increase in consumer's surplus is still represented by the area A plus B. However, the total value of the increase is clearly less than in the example given.[13]

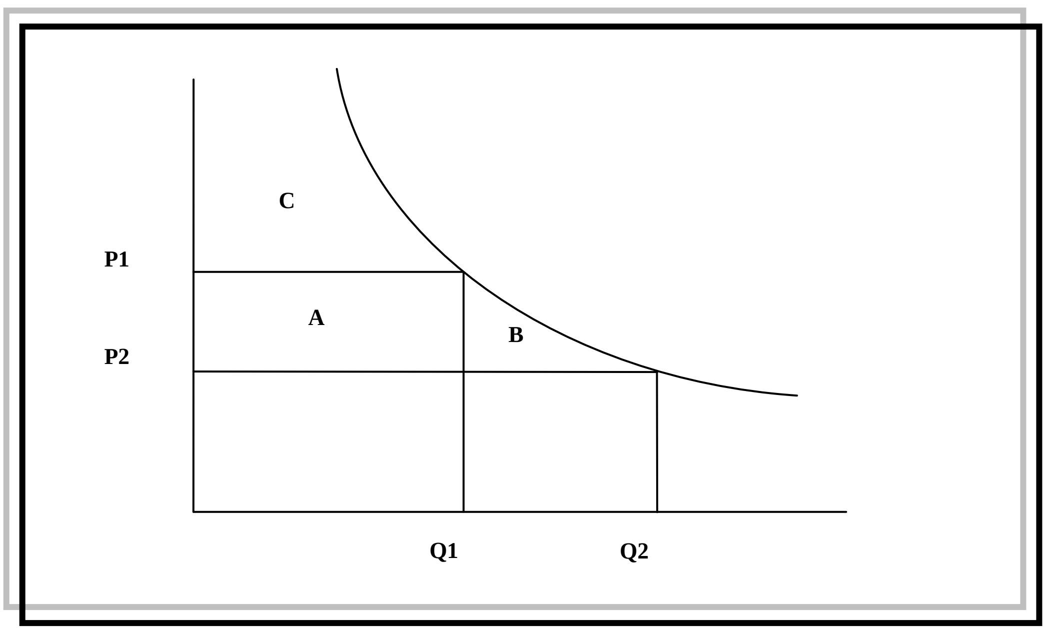
[11] The formula for calculating the arc price elasticity of demand is e = (Change in quantity/Average quantity) / (Change in price/Average price) or e = ((Q1 - Q2) / (Q1 + Q2)/2)) / ((P1 - P2)/((P1 + P2)/2)). The formula for a demand curve with a constant price elasticity is Q = AP^e where A is a constant and e is the price elasticity of demand.

[12] The formula for point elasticity is the standard definition, viz e = [δQ/Q]/[δP/P], where δ represents an infinitesimally small change. At the limit of δ, the expression becomes the ratio of the differentials, namely [dQ/Q]/[dP/P], or [dQ/dP]*[P/Q]. Note that this expression is the product of the slope of the tangent at this point times the ratio of the values of P to Q at the point. The expression for elasticity is not merely the tangent. Understanding this feature is important for interpreting the shapes of the demand curves. For a curve with constant elasticity, a move along the curve changes the slope of the tangent that is offset by an equal and opposite change in the ratio P/Q.

[13] A further distinction that is sometimes overlooked is between *short-run elasticities* and *long-run elasticities*. Long run elasticities are relevant to demand forecasting, and short run elasticities are relevant to assessing immediate responses to changes in electricity prices. According to the theory of price determination, in the short run consumers keep the same end uses and appliances but modify usage levels of electric appliances. In the long run, consumers can implement a range of responses to a price change, covering change of appliance usage level, change of appliances for the same end uses, switch to another energy source that has become cheaper than electricity for a particular end use, and elimination of end uses by taking out of use some electric appliances. In the empirical

Why is the shape of the demand curve concave to the origin? Basically, this shape reflects the presence of a budget constraint on expenditures on electricity (or other good or service). This constraint arises from marginal utility considerations, under which a household, for example, is expected to allocate the amount of money available for expenditure on all goods and services in a way that produces equal marginal utility from each good and service, and thus maximize the total amount of utility derived from this amount of expenditure. In simple terms, the constraint shows how much a household can afford to spend on electricity. Although in theory this approach is an elegant explanation of household consumption behavior, in practice it probably provides a rough match to actual behavior because households rarely analyse their marginal preferences to the degree implied by this theory. This is one reason that demand curves based on this approach only approximately reflect real consumption patterns.

Figure 1-3 Representation of Consumer Surplus with Exponential Demand Curve



Unfortunately, while many analysts recognized that the demand curve for electricity was likely to be concave, they typically only had two or three observable points on the curve, which were insufficient to provide a reliable basis for deducing its full shape. These points might include the price and quantity of substitutes for electric lighting (kerosene and LPG lamps, candles), substitutes for electric radios and TV's (dry cell and car batteries), and diesel powered pumps and motors and the corresponding prices and quantities of electricity used by consumers with electricity supply. Analysts had considerable discretion about interpolating the shape of the demand curve between these points.

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literature, short run is often used to mean a short, fixed period of time that is usually one year, and the length of the long run is usually put at about 4 – 7 years from a change in electricity price, income or other variables, meaning that by then consumers will have made all (or nearly all) of the modifications they intend to make.

The responses to the data limitations varied. In some instances, the project was fortunate to have tariffs that were high enough that customer willingness to pay as represented by the tariffs was sufficient to provide a satisfactory IRR for the investments, and the analysts were able to ignore consumer's surplus. In other instances, the consumption and prices of substitutes was so high that the savings generated by switching existing energy consumption to electricity (i.e. area A) were sufficient without the need for estimating the value of surplus associated with induced consumption (area B). In other instances, the analysts assumed that all electricity consumption could be valued at the avoided cost of substitutes, ignoring the downward sloping nature of the demand curve and grossly overstating the project's benefits. Some analysts tended to choose the linear shape as a default option, partly because this option offered the easiest computation of benefits. In yet other cases, a generally unsubstantiated "cost of un-met demand" was used to value the benefits of incremental electricity supply without relating the implied willingness to pay for this amount of electricity to the consumers' budget constraint. In other words, the implied expenditure on electricity in the with-project case would often exceed the amount that households could afford at this cost, and so much of the claimed benefit was not real.

In those cases which followed the recommended Bank practices by recognizing consumer's surplus as a project benefit, one approach was to assume, absent observable information to the contrary, that the shape of the demand curve was in fact a straight line (Laos 2006, Philippines 2002). Another was to recognize that a straight line demand curve might overstate benefits and to count a proportion of the area under the curve as surplus by applying an "adjustment factor" of less than unity to the computed surplus (Bolivia 2003). The value of this factor was usually based on a conventional number such as 0.80 that had gained credibility from time-honoured and repeated use, rather than from rigorous empirical analysis. The remaining approaches assumed either a constant price elasticity (Peru 2006), or a constant price elasticity with income compensation (Ghana 2007, Uganda 2007).

The lack of clear guidelines in terms of approach, particularly with respect to electrification projects, is well illustrated by an IEG Impact Evaluation carried out in 2008.[14] The Evaluation reviewed the economic analysis carried out in 23 SAR's, PAD's and ICR's for rural electrification projects financed by the Bank Group between 1990 and 2003. Three of the projects used avoided cost as a measure of project benefits. Two used a dual approach to measure the willingness to pay, namely the sum of the cost for avoided use of electricity substitutes and the prevailing tariff for induced consumption (i.e. no benefit was included for an increase in consumer's surplus). One valued the benefits at the tariff. Five measured consumer's surplus as the area under a linear demand curve. One measured it as one quarter of the area under a linear demand curve, and four measured it as the area under a semi-log demand curve. Six of the reports either provided no estimate of the project's EIRR or no information on the way in which the EIRR was calculated.

[14] World Bank Independent Evaluation Group, "The Welfare Impact of Rural Electrification: A Reassessment of the Costs and Benefits", World Bank, 2008

1.4 Demand curves

Measuring consumer's surplus is complicated by the fact that demand curves for electricity, as well as price elasticities of electricity demand, differ depending on the class of consumer (household, commercial, industrial). Household consumers may exhibit a relatively elastic demand because budget constraints on electricity consumption are linked to income level. These constraints are thus stronger for households – especially low income households – than for commercial and industrial establishments and high income households. Hence demand curves for low income households are more concave than the curves for these other consumers, especially under a tight budget constraint on household expenditure. When the price of energy declines, their tendency will be to consume more. Conversely, when the price rises, their consumption will drop.[15] The sensitivity to electricity price is likely to be less for the electricity demands of commercial and industrial customers than for household electricity demand. Commercial and industrial customers require a certain amount of electricity in order to carry out their business. If prices fall, they are unlikely to use more – at least in the short term.[16] If prices rise, they can generally pass the increased cost on to customers or introduce energy efficiency measures in order to maintain competitiveness.

Classes of electricity consumers are differentiated by their uses for electricity as well as by their budget constraints. Electricity is not a good or service that is desired in its own right. Rather, demand for electricity is a derived demand; that is, it is a function of demand for a variety of other services such as lighting, heating, cooling, entertainment, motor drives, etc. Hence, a user's demand curve for electricity is a composite of a number of other demand curves each relating to the demand for a particular utility for which electricity is an input. The relative contributions of these uses to overall electricity demand is an important consideration for formulating the demand curve for electricity and hence for assessing the consumer's surplus.

Differences in the composition of uses for electricity among user classes complicate attempts to formulate a generalized demand curve for electricity for all societies, especially a curve based on a universal value for price elasticity of demand. The shape of the curve is specific to the nature and priorities of the society and group of customers being investigated. Nevertheless, analysis of electricity demand can be advanced by establishing general shapes of demand curves related to different utilities or outputs from electricity consumption. These shapes could then be applied to different combinations of electricity demand weighted according to end use to derive consolidated electricity demand curves for different situations.

Electricity demand curves are thus specific to groups of electricity users. This means that household electricity demand functions and elasticities vary according to the economic and

[15], As prices of commercial energies rise, households may also revert to traditional energies (fuelwood, biomass, agricultural waste) which are procured without any monetary transaction. These energies are not without cost, however, as they require both time and effort to collect, transport and store. The difficulties inherent in determining their cost, as well as their quality relative to commercial fuels, means that they are generally ignored in developing derived demand curves for energy utilities.

[16] The inelasticity of consumption in the short term reflects the fact that the level of consumption for many customers depends on their stock of electricity-consuming equipment. Responses to lower electricity prices will only fully develop once these customers have had the time to integrate the new prices into their long term capital expansion plans.

social factors that are specific to a group of household electricity users during the period under analysis. Consequently, it would be futile to seek a universal value for price elasticity or income elasticity, even in the sense of an *ex-ante* value that might be applied in a model economic environment. This view is supported by the findings of a review of empirically derived econometric functions for residential electricity demand that is presented in Annex 1.

Given the amount of data needed to properly deduce the demand curve for electricity in a particular country, region or project area, it is perhaps not surprising that a simplified consumer's surplus approach to benefits analysis has often been used in the analysis of Bank supported electrification projects, without using rigorously formulated demand curves. The required data for formulating electricity demand curves has not been collected even in detailed household surveys carried out in borrower countries, since these surveys focused on the study of household living standards and poverty levels. While all surveys included some questions on energy use and expenditure, the collected data were seldom sufficiently detailed to allow deep analysis of energy consumption and spending patterns.[17]

Recently, however, a comprehensive household survey was carried out in Yemen directed exclusively towards patterns of energy supply, consumption and expenditure. The results of this survey provided an extremely rich database related to household energy use, and selected findings with respect to supply, consumption and expenditure were presented in a report published in 2005.[18] As a cross-sectional survey undertaken at a particular point in time, the study includes data on energy appliance ownership, which is essential for understanding consumer responses to changes in energy prices. This study uses the survey data to derive household demand functions for various services derived from electricity consumption by analysing household consumption of electricity and electricity substitutes for selected end uses. The study specifically determines how consumption of lighting and entertainment services varies with price of electricity,[19] how price:quantity relationships vary between urban and rural communities, and how these relationships vary among different income groups. The findings of this analysis are interpreted in the context of the findings of the empirical review of demand functions presented in Annex 1.

[17] See O'Sullivan, Kyran and Douglas F. Barnes. "Energy Policies and Multitopic Household Surveys. Guidelines for Questionnaire Design in Living Standards Measurement Studies". World Bank Energy and Mining Sector Board Discussion Paper No. 17. April 2006.
[18] World Bank, "Household Energy Use and Supply in Yemen", Report No. ESM 315/05, December 2005
[19] Note that demand curves were derived for lighting obtained from various energy sources, but that demand curves were derived for electricity, albeit not always AC electricity, used for entertainment.

2 Database and Methodology

2.1 The Yemen Household Survey

In 2003/2004 ESMAP funded a major household energy survey in Yemen (Report ESM315/5). Yemen is a low income country that is highly dependent on declining oil resources for revenue. Petroleum accounts for roughly 25% of GDP and 70% of government revenue. An estimated 35 percent of the 22 million people live in poverty[20], with a higher concentration in rural areas (where 73 percent of Yemenis and 84 percent of the poor live). The lives of the rural people are characterized by lack of access to basic infrastructure facilities like energy, education, health, water supply and sanitation. Households consume about 80% of all energy.

For readers unfamiliar with Yemen, the table below which provides comparative figures with other countries for some key indicators might be of assistance.

Table 2-1 Comparative Key Indicators, Yemen vs. Countries in Other Regions

	Population million	GNI US$/ Capita	GDP Growth %	Agriculture % of GDP	Electricity Use kWh/capita	Energy Use kg.oe/capita
Yemen, Rep.	22.38	2,440	3.3	16.3	189.8	326.4
Pakistan	162.48	2,540	6.0	20.6	480.1	498.7
Philippines	88.72	3,660	7.1	14.2	572.3	493.4
Vietnam	85.15	2,530	8.5	20.3	597.7	621.5
Bangladesh	157.75	1,340	6.4	19.2	146.4	161.1
Nepal	28.11	1,060	3.3	33.5	79.7	340.3
Armenia	3.07	5,740	13.7	20.3	1,580.9	842.8
Egypt, Arab Rep.	80.06	5,090	7.1	14.1	1,303.7	795.2
Ghana	22.87	1,350	6.1	34.0	311.9	424.4
Kenya	37.53	1,550	7.0	26.1	145.3	491.0
Bolivia	9.52	3,960	(0.0)	12.9	484.6	625.3
Low income	952.65	1,332	6.9	25.2	316.3	428.3
Note: Figures are for 2007 except for electricity and energy use which are 2006						

The Yemen Household Survey involved interviews with a nationally representative sample of 3,625 households and addressed in detail household supply and consumption of electricity and other energy forms. Interviews were also carried out with 135 village heads in rural areas to obtain additional village level data. The sample design was based on a stratified random sampling technique with the population first divided between urban and rural areas, where urban areas included Sana'a and Aden plus the main cities in each governorate. Rural areas were subdivided into 5 geographic regions. The sampling rate for urban households in each geographic region was proportional to the number of households with the exception of Sana'a and Aden where higher rates were used in order to capture the potential diversity within the

[20] World Bank, *Yemen Poverty Assessment*, November 2007

urban areas. The sampling rate for the rural areas was designed to capture an approximately equal number of villages and households in each geographic region. Hence, the sampling rates varied quite significantly among the regions. In total, the sample consisted of 1,585 urban households and 2,040 rural households. Interviews were carried out between December 7 and 22, 2003.

The survey addressed household consumption of electricity and electricity substitutes for a wide range of appliances serving a number of end uses or utilities. The table below provides an indication of the types of appliances covered, grouped broadly according to the typical application or utility provided.

Table 2-2 Household Appliances Surveyed

Appliances	**Utility**
Incandescent bulbs (by wattage), fluorescent bulbs (by wattage and type), kerosene wick lamps, hurricane lamps, candles, pressurized kerosene lamps, LPG lamps	Lighting
Radio, B&W TV, color TV, satellite dish, computer, video player, audio player	Information/ Entertainment
Kerosene stoves, charcoal stoves, electric stoves, traditional stoves	Cooking
Electric fans, refrigerators, vacuums, electric water pumps, mixers, air conditioners	Other

Detailed data were collected both on ownership and on average daily hours of use of each of these appliances.

In addition, because electricity supply in Yemen is provided by a number of different public and private agencies, the survey encompassed households facing a number of distinct prices for electricity. Tariffs ranged from a low of approximately YR4/kWh (US$0.02 per kWh) from the national grid to a high of YR30 /kWh (US$0.15 per kWh) for supply from a private grid. Prices in terms of the cost of supply from small electricity generation units that serve individual households or villages and are not connected to a public power network ("gensets") were even higher in most instances. The table below shows the classifications used and the number of households sampled. The survey also included households that had no access to electricity, and were obliged to use other energy sources to meet their demands for various utilities that might generally be met with electricity.

Table 2-3 Sources of Electricity Supply

Electricity Supply	No of Households	% of Total
PEC grid	1857	52.5%
PEC isolated network	100	2.8%
Cooperative grid	128	3.6%
Private grid	11	0.3%
Village genset	221	6.2%
Neighbor genset	42	1.2%
Family genset	54	1.5%
None or Other	1127	31.8%
Totals	3,540	100%

Since each electricity supply source carried a different cost per kWh, the number of price:quantity (P:Q) pairs available for analysis was greatly expanded. Thus, unlike many surveys which are only able to provide a single price point for electricity and a second average point for electricity substitutes, the Yemen survey was able to provide a number of intermediate points on the demand curve, providing an indication of the shape of the curve both in total and for different applications.

2.2 Study Scope and Methodology

The objective of the current study was to use the Yemen database to fill in additional data points on the household demand curves for a selection of the utilities provided by access to electricity, with the ultimate objective of being able to better estimate the associated consumer's surplus benefits. While not necessarily providing a guide for all cases, the results of this work would at least provide one empirical example of the shape of the household demand curves and of the price elasticities of demand. Because it has been observed that, when households are first given access to electricity, their priorities are to install electric lights and purchase a radio and/or TV set, lighting and TV/radio use were chosen as the main utilities for study. It was also helpful that households without access to electricity supply also made extensive use of substitutes (other fuels, batteries, etc.) for both lighting and entertainment (TV/radio), thereby providing additional points on the demand curves for each. However, the study also looked at the relationships between price and quantity for a range of other utilities including cooking and a selection of household electric appliances, although with the proviso that the range of price data and in some cases the incidence of use was narrower than for lighting or entertainment.

Using the STATA data management and statistical software package (http://www.stata.com), the general methodology for each utility was to determine for each household its consumption of a particular application as well as the average price paid. In actual fact, as will be discussed in the following sections, the calculations were much more complex, requiring the conversion of both outputs and inputs to a common base for comparison. In the case of electrified households, it was also necessary to adjust total computed consumption of electricity (based on number of appliances, wattage and usage) in order to reconcile it with the actual monthly consumption noted on their electricity bills, since in most instances the computed consumption exceeded the actual.

The sample data were then weighted to generate nationally representative results based on the weightings provided in the survey for the different geographic areas. The P:Q relationships were converted to a set of points on a curve by dividing households into deciles based on their monthly consumption of different types of lighting, entertainment, etc. The average price and average consumption of each decile was used as the representative point on the average household demand curve. Having established the household demand curve for a particular utility, further testing was done to see whether household location (urban versus rural) or household income had a significant impact on the shape of the demand curves.

Finally, single and multiple variable regression analysis was used to approximate the price elasticities of the demand curves, together with the goodness of fit, and also to examine the degree to which independent variables other than price helped to explain the changes in quantities consumed.

3 Demand Curves for Lighting

The use of energy for lighting is almost universal. Sources range from candles and rags stuffed into tin cans filled with kerosene to more sophisticated kerosene and LPG lamps, incandescent and fluorescent bulbs and most recently LED lights. Access to higher quality, low cost lighting is also often cited as one of the primary benefits of electrification. It is seen not only as a desired utility in its own right but also as a contributing factor to better education, and safety and security. The focus of the lighting analysis was to first establish a generalized function for the relationship between lighting consumption and price, with a view to establishing a demand function which could be used to calculate the associated area under the demand curve and hence benefits of improved access. The secondary objective was to further deconstruct the demand function to investigate the impact of location (urban vs rural) and household income on the coefficients of the curve, and thereby the impacts on consumer's surplus benefits of access.

3.1 Consumption

The quality of lighting provided by different lighting sources varies – particularly compared to the amount of energy that goes into producing the light. A 25 watt fluorescent bulb may produce as much light as a 100 watt incandescent bulb. Both will produce much more light than a candle that is rated at 50 – 100 watts. Thus, to compare household consumption of lighting in terms of lamp hours or even in terms of equivalent kilowatt-hours would distort the results.

The method that has been generally adopted to measure the consumption of different types lighting on a common basis is to convert the lighting output into lumens or kilolumens (klumen) and the consumption into klumen.hrs. The literature contains numerous estimates of the lumen output of various types of electric and fuel-based lamps. While the figures vary (sometimes significantly) among sources, the estimates in the table below are representative and were used in this study.

Table 3-1 Lumen Output by Type of Lamp

Type of lighting	Watts	Lumens/watt	Lumen.hrs/Lamp hour
Incandescent bulbs	All	14	14 *x* watts
Fluorescent bulbs	All	50	50 *x* watts
Candle	90	0.22	20
Kerosene Wick Lamp	200	0.05	10
Hurricane Lamps	200	0.15	30
Pressurized Kerosene Lamps	560	0.54	300
LPG Lamps	350	0.86	300

The survey asked respondents to provide information on the number and types of lighting appliances that they owned, and the number of hours of daily use. The "types of lighting" covered included those listed in the above table, as well as a wide range of wattages for both incandescent and fluorescent bulbs, and a range of fluorescent bulbs including tubes, circular tubes, and CFBs. Unfortunately, the survey did not specify whether all or only some of the bulbs/lamps of a particular type were used for the reported number of hours, and there was approximately a four-fold difference between the extremes of assuming that only one lamp of each type was in use and assuming that all lamps were in use for the reported number of hours. Initial calculations assuming that only one lamp of each type was in use provided very low figures for total monthly consumption of electric lighting – ranging from a minimum of 4 kWh to a maximum of 40 kWh, and also showed very little differentiation in consumption between low and high income consumers.

It was therefore decided that, unless a household had only one lamp/bulb, all lamps/bulbs would be assumed to be in use for half of the reported number of hours[21]. Thus, for each type of electric bulb, monthly consumption in watt.hrs was estimated as number of bulbs *x* number of daily hours *x* watts per bulb *x* 0.5 *x* 30 days. Watt.hrs were converted to lumen.hrs using the above ratios of lumens per watt. As noted earlier, the total kWh of electricity consumption that was computed based on a household's use of all electric appliances (including lighting) was compared with the actual total monthly consumption of electricity according to the household's utility bill[22]. In order to reconcile the two, the computed consumption of electric lighting was adjusted (generally downwards) by the ratio of total actual to total computed monthly use of electricity.

For non-electric lighting, monthly use in lumen.hrs was estimated for each type of lamp as number of lamps *x* number of daily hours *x* lumen.hrs per lamp-hour *x* 0.5 *x* 30 days. The combination of these two data sets were used to provide a profile, for each household, of the total monthly consumption of lighting (both electric and non-electric) measured in klumen.hrs.[23]

3.2 Unit Prices and Monthly Lighting Expenditure

Electricity

Electricity purchased from a third party is billed in different ways. All four categories of grid/network customers (PEC grid, PEC Isolated Grid, Cooperative Grid and Private Grid) are billed based on kWh consumed. Customers supplied by a village genset were also uniformly charged on a kWh basis. For each of these customers, total monthly expenditure on electricity was divided by the total number of kWh consumed to give the unit price per kWh. This in turn was multiplied by the kWh of electric lighting consumption to give monthly expenditure on electric lighting.

Households using a neighbor's genset were charged in one of 3 different ways: a flat monthly fee, a charge based on number of appliances and a charge per kWh. Unfortunately, not all of the households using a neighbor's genset provided detailed information on the amount that they paid for electricity. In order to not lose these responses, the average electricity cost per kWh (based on use of all appliances) for households in this category who had provided complete responses

[21] If the household had only one lamp/bulb, it was assumed to be in use for the full number of reported hours.
[22] In some instances, the household was unable to provide the electricity bill but could recall the total amount paid. Total kWh used were estimated by dividing total payment by the tariff. Where neither kWh nor payment was reported, the household was excluded from the current analysis.
[23] A second calculation was also done assuming that only one lamp of each type was in use for the full number of hours reported. The resultant scatter diagram of price-quantity relationships did not differ significantly in shape.

was applied to those who had not provided cost data. Again, this was multiplied by the kWh of electric lighting consumption to give monthly expenditure on electric lighting.

Finally, for households using a family genset, the survey provided good data on capital and operating costs. The only gap was the expected life of the equipment. Responses to the question regarding the number of years that the equipment had been owned ranged from 1 year to 23 years, with an average of 5 years. To account for the capital cost of the equipment, the average purchase price per kW was amortized over a 5 year period and the result was added to each customer's monthly cost of electricity supply from their own genset. This together with the monthly fuel cost was divided by the monthly kWh consumed by the household (including use of other appliances) to give a cost per kWh, which in turn was multiplied by the kWh of lighting consumption to give total monthly expenditure.

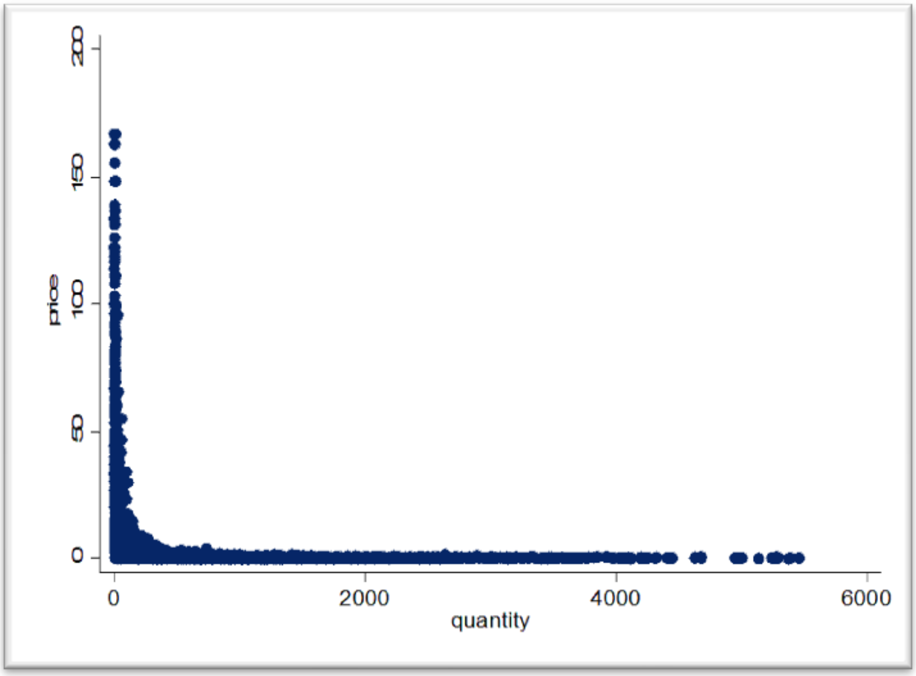
Other Lighting Fuels

The other fuels reported to be used for lighting included kerosene, LPG and candles. For candles, the survey posed specific questions on the number of candles purchased per week and per month, and the weekly and monthly spending for candles. These expenditures were assumed to be fully for purposes of lighting. For kerosene, the survey requested information on the amount of kerosene used per week and per month by the household, the spending per week and per month, the price per liter, and the percentage of kerosene used for lighting, cooking and other uses. The percentage reported for kerosene multiplied by the monthly kerosene expenditure provided an estimate of the monthly spending on kerosene lighting. For LPG, the survey collected the same set of data as for kerosene – viz weekly and monthly consumption and expenditure, unit price, and percentage used in different applications. The same process was used to estimate the monthly spending on LPG lighting.

3.3 Demand Curve

As was noted in the initial report on the Yemen Household survey, most households with access to electricity also used non-electric lamps on occasion as a source of lighting, regardless of their primary source of electricity supply. Calculating a household's price per klumen.hr therefore involved factoring in a number of different consumption quantities and unit prices to determine the household's total monthly spending on lighting and from there, its weighted average price. The sum of each household's monthly expenditure on lighting both from electric and non-electric sources was divided by the total lighting consumption in klumen hrs to give a price per klumen.hr and a corresponding monthly consumption – that is, a P:Q pair. The scatter diagram below shows the resultant picture of price:quantity relationships according to the survey. Prices are in YR per klumen.hr and quantities are in klumen.hrs of lighting per month.

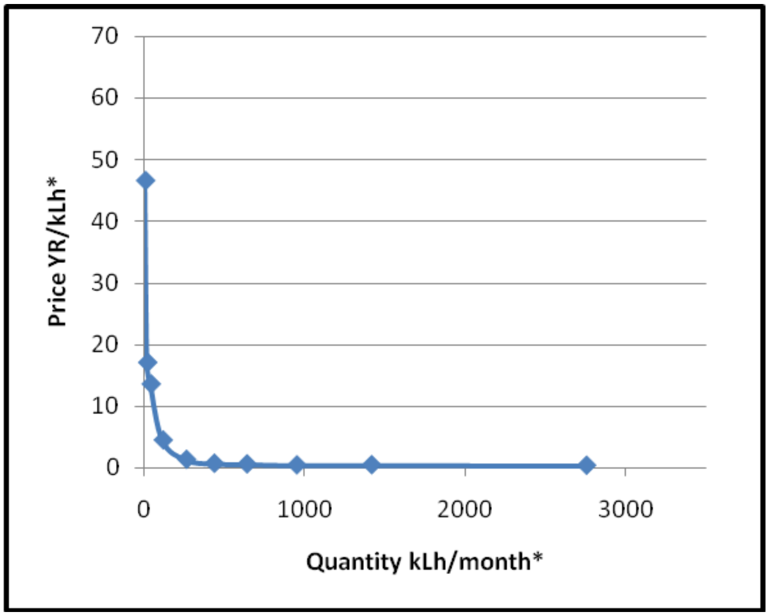
Figure 3-1 Scatter Diagram of Price:Quantity Relationships - Total Lighting



The previous chapter described how the survey sample was stratified with different weights applied to rural and urban households and different weights to each rural region. The results for individual respondents were then weighted so as to provide nationally representative data using the weighting factors associated with the survey sample. The resultant weighted profile of household demand is shown in the figure below[24]. Note that with incandescent lighting, 14 klumen.hr is equivalent to electricity consumption of approximately 1 kWh, while with fluorescent lighting, 50 klumen.hr is equivalent to electricity consumption of approximately 1 kWh. Among the survey sample, the household average was approximately 25 klumen.hrs per kWh, so the weighted average consumption figure of 501 klumen.hrs is equivalent to approximately 20 kWh per month. This figure would not apply across the full spectrum. The low consumption households in particular are likely to be heavily weighted towards non-electric lighting sources which will have a very low ratio of klumen.hrs per kWh.

[24] The curve shows the P and Q means of consumption deciles where households were ranked according to consumption and then divided into 10 groups with equal numbers of households in each group.

Figure 3-2 Yemen – Household Demand Curve for Lighting



Note* Weighted average = 501 klumen.hrs/month at YR12.5/klumen.hr**

3.4 Functional Representation of Demand Curve

The parabolic shape of the derived demand curve that is shown in Figures 3-1 and 3-2 is typical of a function based on a constant price elasticity, i.e. a curve with the following functional form:

$$\ln Q = A' + e * \ln P$$

In order to evaluate the goodness of fit of such a model to the data points, regression analysis was used to determine the extent to which variations in quantity consumed could be explained by variations in price.

The results of the single regression analysis are summarized in the table below:

Table 3-2 Lighting – Price Elasticity of Demand – Single Variable Regression

Dependent variable: Lighting quantity (ln)		
	Coefficient	
Lighting price (ln)	-0.8183	***
Constant	5.5111	
Adj.R-sq 0.7530		
# of obs : 3216		

*** Significant at the 1% level

The adjusted R square of 0.7530 means that the model based on constant price elasticity explains over 75 percent of the changes in lighting quantity. The co-efficient of the natural log of lighting price in the above results, -0.8183, is the price elasticity of lighting demand by households in

Yemen. A 1 percent increase in the price of lighting would lead to a 0.82 percent decrease in the quantity consumed. The formula also provides a means of determining, through integration, the increase in consumer's surplus associated with moving from one P:Q point on the demand curve to another.

A multivariate regression analysis was also carried out to assess the relationship between price and quantity while controlling for the potential effect of other variables such as income, household size, locality and hours of electricity service. The results are shown below.

Table 3-3 Lighting – Price Elasticity of Demand – Multivariate Regression

Dependent variable: lighting quantity (ln)			
	Coefficient		Std.err.
Lighting price (ln)	-0.7093	***	0.0124
Income per capita (ln)	0.1161	***	0.0226
Household size	0.0633	***	0.0045
Urban	0.1556	***	0.0372
Electricity service hours	0.0179	***	0.0022
Constant	3.7478	***	0.2023
Adj.R-sq: 0.7744			
# of obs : 3216			

Note: *** indicates significant at 1% level.

The multivariate regression analysis indicates that income, household size, locality and hours of electricity service, in addition to price, have a statistically significant impact on consumption quantity.[25] According to this model, the impact of price is lessened as compared with the single regression; when price increases by 1 percent, the quantity of lighting consumption will decrease by 0.71 percent. The Adjusted R squared indicates that the model explains 77 percent of the changes in quantity of lighting consumed –slightly higher than that explained by the single regression. Despite the greater accuracy of the multi-variable model, however, the additional data requirements, as well as the complexity of the function, would make it more difficult to use than the single variable model as a means of calculating the change in consumer's surplus (or area under the demand curve between the old and new prices) associated with a shift from one observable consumption point to another.

3.5 Implications of Findings

In terms of general observations, the profile of the demand curve for lighting is highly concave. At lower levels of consumption, even very large changes in price will have little impact on the quantities consumed, while at higher levels of consumption, even a small change in price will have a significant impact on quantities consumed. This is not, however, simply the juxtaposition of two linear demand curves, although the shape is heavily influenced by the prevalence in the

[25] The modest coefficient for income may be explained at least in part by the wide variance in prices and hence the dominance of price in determining the shape of the curve. In addition, high income households in areas without grid access are likely curtailing their consumption as a result of high prices as compared with low income households in areas with access to the grid.

population of households who either have no access to electricity or who have access to the fairly reliable and extremely low cost national grid. As the scatter diagram shows, there are many observations of households that are paying above the grid price for energy, but are clearly not in the category of having no access to electricity. These households, which include those with access to isolated or cooperative grids, tended to have more of a balance between the use of electricity (albeit relatively costly supply) and electricity substitutes. A plot of their demand curves displays the same concavity as the composite national curve.

The survey findings indicate that the consumer's surplus benefits associated with moving from no access or partial access to full access to electricity supply (i.e. the substitution benefits) can be substantial on a per-unit basis. At the margin, households with grid supply are paying an average price of only YR0.3 per klumen.hr for lighting. At the high end of the price range, however, customers are paying on average YR46.6 per klumen.hr or more than 100 times the marginal price. In total, forty percent of households are paying more than 10 times the price associated with grid supply. At the same time, it is important not to exaggerate the total value of this benefit. For example, while households in lowest consumption decile may be paying YR46.6 per klumen.hr for lighting, they are consuming on average only 8 klumen.hrs per month. Households in the fourth consumption decile, who are paying YR4.4 per klumen.hr, are consuming approximately 117 klumen.hrs per month. Thus, while benefits per klumen.hr may be high, the total substitution impact will be limited by the low number of units consumed.

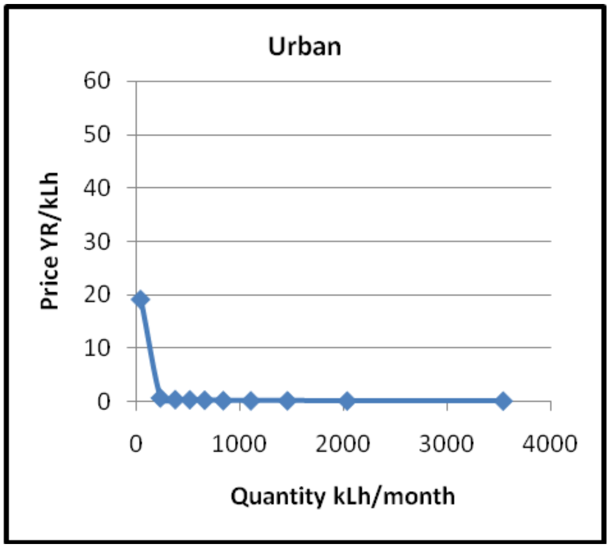
The extreme concavity of the curve also means that the consumer's surplus attached to new or induced demand associated with moving from non-electric to electric lighting or from expensive to less costly electricity supply is much less than would accrue under a more gently sloping curve. At the lower levels of consumption the demand curve is almost vertical. There is very little additional demand induced by lower prices and hence the consumer's surplus benefits primarily accrue through substitution benefits of a price reduction. At the higher levels of consumption, the demand curve is almost flat. Within this segment of the curve, there are significant increases in consumption induced by access to lower cost supply. However the price reductions are very small and the area attributable to induced consumption under this section of the demand curve will also be small.

The low levels of lighting consumption at the higher price levels (one-third of a kWh per month), and also the weighted average lighting consumption (501 klumen.hrs or approximately 20 kWh per month) are generally contrary to what has been assumed in many analyses, which suggests that the lighting benefits of improved access to electricity may have been overstated in the past, even in those studies that assumed a concave demand curve. Unfortunately, comprehensive survey data has typically been directed towards considerations other than energy, and hence the questions have generally not been sufficiently detailed to determine the prices and consumption levels. However, while the analysis presented here helps to provide some guidance on the shape of the demand curve for lighting, if consumer's surplus benefits are to be properly assessed, it is important to have at least some representative survey data that focuses on these fundamental questions of energy consumption and price. These surveys can either be integrated into poverty or living standards surveys, carried out as part of sector work, or done on an as-needed basis as part of project preparation.

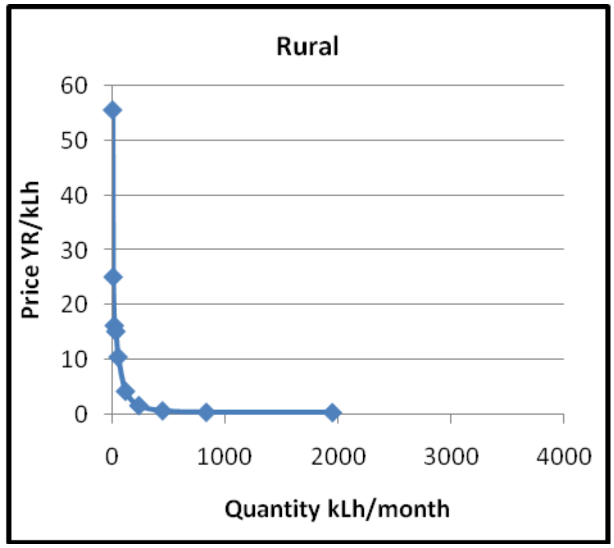
3.6 Impact of Location

The study also examined whether there were any significant differences in the shape of the demand curve displayed by urban and rural residents. Not surprisingly, there were, especially at the lower end of the quantity range. Urban households were more likely to have access to grid electricity, and hence, on a weighted average basis, were less likely to incur the high unit costs associated with non-electric lighting. In addition, urban households on average consumed approximately three times as much lighting during the course of a month as compared with their rural counterparts.

Figure 3-3 Demand Curves for Lighting – Urban and Rural Households



Average 1,020 klumen.hrs at YR2.46/klumen.hr



Average 340 klumen.hrs at YR15.6/klumen.hr

The table below shows the results of the regression analysis and the computed price elasticities for the urban and rural demand curves. Both models separately show a lower price elasticity than the national model. Neither model is quite as good at explaining the variances in quantity as the national model (.578 R-Squared in the case of Urban households and .724 R-Squared in the case of Rural as compared with .753 R-Squared for the national model).

Table 3-4 Price Elasticities for Lighting by Urban/Rural Locality

	Coefficient		R-Squared	Constant	Observations
Urban	-0.7780	***	0.5783	5.6400	1407
Rural	-0.7956	***	0.7263	5.4185	1809

Note*** Significant at the 1% level

Given the shape of the demand curves, investments to reduce the cost of lighting to rural households would, at least in the case of Yemen, yield higher benefits than investments to reduce the cost to urban households. The table below gives the values associated with the above charts. Assuming that the minimum price shown for each class of customer (i.e. urban and rural) could be achieved for all customers through investments, urban customers in Yemen would enjoy an average benefit from substitution of YR0.15/klumen.hr. Rural customer would enjoy an average benefit of 0.80/klumen.hr.[26]

Table 3-5 Lighting Benefits to Urban and Rural Households from Improved Access to Electricity

	Urban households			Rural households		
Consumption Decile	**Quantity Klumen.hr/mo**	**Price YR/klumen.hr**	**Benefit YR/month**	**Quantity Klumen.hr/mo**	**Price YR/klumen.hr**	**Benefit YR/month**
1	47	19.25	884.8	6	55.63	342.3
2	237	0.82	140.2	11	25.20	274.2
3	381	0.51	107.2	21	16.33	328.7
4	522	0.47	128.4	34	15.27	504.3
5	664	0.38	103.2	55	10.61	553.7
6	844	0.31	74.9	121	4.35	468.5
7	1108	0.28	62.1	238	1.76	304.2
8	1462	0.28	73.2	447	0.80	144.0
9	2037	0.25	50.3	833	0.53	41.6
10	3540	0.23	0.0	1947	0.48	0.0
Total	10842		1624.3	3713		2961.5
Average			0.15			0.80

This may not be the case in other countries/markets, but obviously there is a likelihood that urban and rural households may display demand curves for lighting that are both different in shape and different in terms of their limits for prices and quantities. Any benefit analysis should therefore ensure that the characteristics of the target market are known and that surveys relating to pricing and consumption of lighting are focused on populations with characteristics similar to those of the populations who are the intended beneficiaries of the project.

3.7 Impact of Household Income

Measuring household income based on survey data is always a challenge. Cash income tends to be under-reported, income in-kind is seldom included, remittances may be overlooked (especially if they do not occur on a monthly basis), and the value of bartered goods and services also tends to be omitted. Expenditure tends to be a better measure of wealth, but needs to be adjusted to account for home produced food, bartered goods and services, and the imputed rent associated with owning one's home. Notwithstanding these drawbacks, the income figures reported in the Yemen household survey were used as a measure of relative, if not absolute well-being. In other words, it was assumed that the biases noted above were similar across all income levels.

Household incomes were first weighted according to the number of persons in the household and households were then divided into four income quartiles, with Quartile 1 being the lowest and Quartile 4 the highest. The table below shows the relative average values of per capita income

[26] The table below is a broad approximation of the increase in consumer's surplus associated with improved access to electric lighting. A more accurate calculation would involve integrating under the demand curve between the x-axis coefficients for consumption deciles 1 through 10.

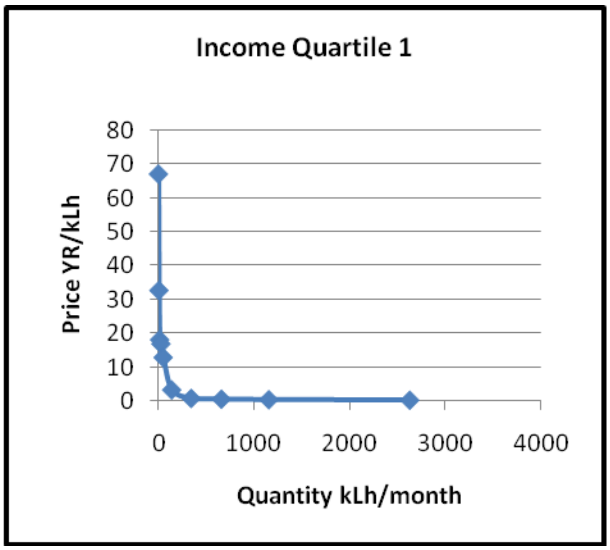
and per capita expenditure in each of the income quartiles. It shows that income is a good proxy for expenditure particularly for quartiles 1, 2 and 3.

Table 3-6 Average Income and Expenditure by Quartile

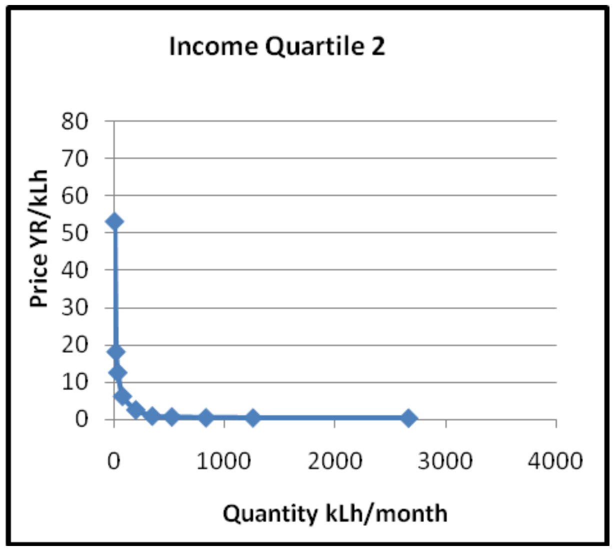
Quartile	Per capita income (YR/month)	Per capita expenditure (YR/month)
1	1,595	1,904
2	3,129	3,123
3	4,971	4,671
4	11,516	8,682
Average	**4,738**	**4,205**

The resultant demand curves for lighting are shown below.

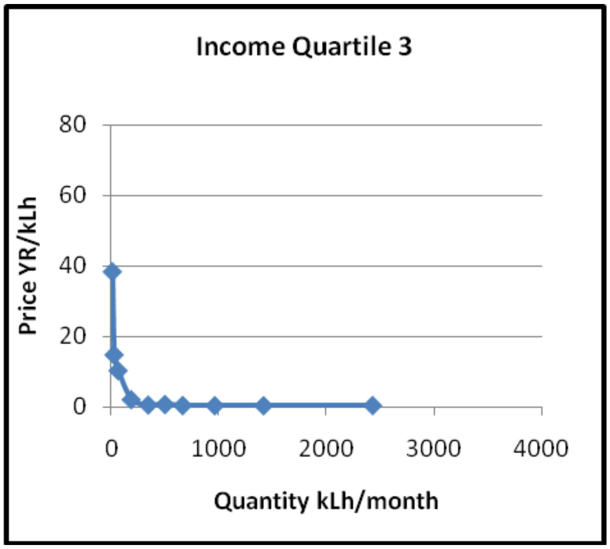
Figure 3-4 Demand Curves for Lighting by Income Quartile



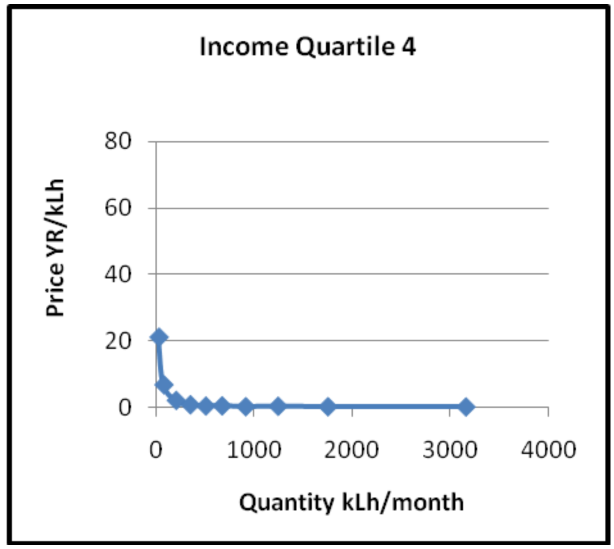
Average 372 klumen.hrs at YR20.2/klumen.hr



Average 534 klumen.hrs at YR12.5/klumen.hr



Average 485 klumen.hrs at YR9.2/klumen.hr



Average 660 klumen.hrs at YR5.1/klumen.hr

Again, although the initial and marginal P:Q pairs differ, all four demand curves display a high degree of concavity. The table below shows the findings of the single regression analysis of price elasticities.

Table 3-7 Price Elasticities for Lighting by Income Quartile

	Coefficient		R-Squared	Constant	Observations
Quartile 1	-0.8493	***	0.8021	5.5709	771
Quartile 2	-0.8292	***	0.7759	5.5037	801
Quartile 3	-0.8049	***	0.7228	5.4474	836
Quartile 4	-0.7620	***	0.5934	5.5924	808

Note*** Significant at the 1% level

The regression models for income Quartiles 1 and 2 (Q1 and Q2) show price elasticities that are greater than that of the national model, and also a better goodness of fit (R-Squared). The regression for Quartile 3 (Q3) is also very good at explaining the changes in the consumption of lighting. The models also suggest that as income level increases, the price elasticity drops. This was perhaps predictable; consumption of the higher income customers is also at the higher end of the quantity scale. As income increases, more of the customers' basic lighting needs have been met, and they might thus be less inclined to purchase additional lighting if prices decline. In the highest income quartile (Q4), this is even more pronounced. Price elasticity drops even further, and price now explains only a little over half of the variances in quantity consumed.

The earlier multivariate regression analysis of lighting consumption (Table 3-2) also provides an indication of the effect of income on household lighting demand. The regression coefficient for income of 0.116 indicates that a 1 percent increase in income per capita leads to a 0.116 percent increase in lighting consumption. The relatively small impact of income on lighting consumption can be explained in part by the very high level of prices faced by some households owing to their lack of grid access and their inability to change this regardless of their income when they live in an area that does not have access to grid supply. It is possible that the income elasticity of demand would be higher if this constraint on access to cheaper lighting options were less pronounced among the sample.

Nevertheless, a comparison of the average monthly lighting consumption of each income quartile does show that the differences between income groups in terms of total consumption is much less than, for example, the difference between urban and rural households. Households in the lowest income quartile consume on average 372 klumen.hrs per month whereas household in the highest quartile consume 660 klumen.hrs per month or approximately 77 percent more. The average per capita income of households in the highest quartile, however, is more than 7 times that of the lowest quartile. This would suggest that, while increases in income and electricity consumption may be closely correlated at lower levels of consumption, there is a point at which an increasingly smaller portion of incremental income is directed towards the purchase of additional electricity.

3.8 Summary

The above sections hopefully dispel at least some of the mystery surrounding the shape of the demand curves for lighting. It would appear to be indisputable that the curve is not a straight line. The main question would appear to be the degree of concavity, and the extent to which it should be adjusted for different target markets.

The Yemen survey, which at present provides the only known empirical data covering a broad spectrum of lighting prices, suggests that the price elasticity of demand for lighting is very high. It also shows that households are willing to pay prices that are many times higher than their average cost for a minimum amount of lighting. Once this demand has been met, however, willingness to pay for additional units declines dramatically. Furthermore, the number of kWh equivalents of lighting considered "essential" is very low – less than 1 kWh per month for households with no access to electricity, and approximately 5 kWh per month for households with access. The average monthly consumption per household for lighting is approximately 20 kWh equivalent per month, while households in the highest consumption group are consuming just over 100 kWh equivalent per month. Under these circumstances, while there may be substantial substitution benefits associated with reductions in the price of lighting, the number of kWh involved is small, and consumer's surplus from induced consumption is unlikely to be significant.

The table below summarizes the calculated price elasticities of different groups of consumers. Price is a major determinant of consumption, explaining more than 70 percent of the variances in quantity consumed at the national level among rural customers and among all income classes except the highest. Price elasticity is slightly higher in rural areas than in urban areas. Elasticity declines as income increases.

Table 3-8 Lighting Demand Curves - Summary of Regression Coefficients

	Coefficient		R-Squared	Observations
National	-0.8183	***	0.7535	3216
Quartile 1	-0.8493	***	0.8021	771
Quartile 2	-0.8292	***	0.7759	801

Quartile 3	-0.8049	***	0.7228	836
Quartile 4	-0.7620	***	0.5934	808
Urban	-0.7780	***	0.5783	1407
Rural	-0.7956	***	0.7263	1809

Note*** Significant at the 1% level

The often significant differences in price elasticity among different customer groups highlight the importance of understanding the market for the investments being evaluated. A largely rural, low income market is likely to have a higher price elasticity of demand, and hence a more dramatically concave demand curve than a market that consists mainly of high income urban residents.

Finally, while the data presented in this chapter provides guidance on the likely shapes of lighting demand curves, it will still be essential to carry out some basic survey work as part of assessing the benefits of improvements in electricity supply. The shapes of the curves displayed by Yemeni households may be transferrable to other jurisdictions; the prices and quantities are not. At a minimum, a limited household survey will be needed to provide guidance on the initial and terminal points on the lighting demand curve.

4 Demand Curves for Information/Entertainment

After lighting, the second most common utility provided by electricity is the increased use of radio and television. Many travelers have been surprised on first driving into a poor rural village to see the skyline filled with television antennae and satellite dishes. Yet the importance of television, as well as radio, as a source of information and entertainment seems to be almost as universal as the importance of better lighting.

4.1 Consumption

The Yemen survey included a number of questions on the use of a range of appliances that would provide either information and/or entertainment, including radios, black and white and colour televisions, computers, satellite dishes, and audio and video players. The most widely and intensively used were radios and televisions, and these were therefore the focus of the demand analysis. Specifically, the appliances included were:

- Dry cell radio
- Radio operated by car battery
- Radio plugged into electrical outlet
- Dry cell black and white television
- Black and white television operated by car battery
- Black and white television plugged into electrical outlet
- Colour television operated by car battery
- Colour television plugged into electrical outlet

The common base chosen for measuring the consumption of entertainment was the kWh. While radios and televisions come in a wide range of sizes and therefore consume different levels of watts per hour of use, the analysis assumed the following:

- Radio: 5 watts
- Black and white television: 30 watts
- Color television: 300 watts

Survey respondents indicated, for each type of appliance the number of appliances owned and the hours of monthly usage. The product of number owned, hours of use and the assumed watts gave the household's monthly consumption of each entertainment appliance in kWh. There were a number of instances where households reported owning more than one radio or television set – particularly when these were powered by electricity. However, the distortion was much less than in the case of lighting, and it was therefore assumed that each appliance was used for the number of hours reported. As with lighting, an adjustment factor was applied to the use of electric appliances to reconcile the computed household consumption of electricity with the reported monthly consumption.

4.2 Unit Prices

Electricity: The calculation of unit prices of electricity for households with different sources of electricity supply was described in the previous chapter, and is not repeated in detail here. Briefly, for grid/network customers as well as customers supplied by a village genset who are charged on a kWh basis, total monthly expenditure was divided by total kWh consumed to give the average unit price paid. For households that were using a neighbor's genset, an average cost per kWh was calculated for households who had provided complete responses and was applied to all households in the category. For households using a family genset, the unit cost was calculated based on the reported capital and operating costs of the generator (including fuel) divided by the estimated total monthly amount of electricity consumed by the household (for all electric appliances).

Car Batteries: The unit cost of energy supplied by car batteries was estimated based on survey data regarding battery voltage, amp-hour rating, battery cost, cost per recharge and recharge expenditure per month. The survey did not cover the life of the battery. However, the capital cost was small relative to the operating cost and since the amortization period would thus have little effect on the average cost per kWh, it was decided to amortize it over one year. On average, the unit cost of using a 12 volt, 50 amp-hr car battery was equivalent to YR440 per kWh, or approximately US$2.20 per kWh.

Dry cell Batteries: The survey collected a considerable amount of information on the use of dry cell batteries. Questions included whether they were used continuously, frequently, or not at all, how many were used per week and per month, and how much was spent per week and per month. There were some gaps in the database, though, that made it difficult to determine the actual expenditure on batteries used for entertainment. While households reported their total monthly expenditure on dry cell batteries, they only reported their hours of use for radios and black and white televisions. Without knowing the voltage and amp-hr ratings of the batteries purchased, one could not estimate what percentage of the batteries purchased were used for entertainment and what percentage for other applications. Since no other uses of dry cell batteries were addressed in the survey, the options were to either assign an arbitrary percentage of dry cell expenditures to entertainment or to assign all expenditures to entertainment. As a base case scenario, the latter was chosen, and was found to yield costs per kWh that were not out of line with empiric data on battery costs in other countries (i.e. an average of approximately $4.50/kWh).

4.3 Demand Curve

The total consumption of entertainment by each household was calculated in terms of kWh, as was their total spending on energy. Dividing the latter by the former provided a weighted average cost per kWh for household consumption of entertainment. The graph below is a scatter diagram showing the P:Q responses of the survey participants. Prices are expressed in YR/kWh while quantities are expressed in kWh.

As described in the chapter on lighting, the survey sample was stratified with different weights applied to rural and urban households and different weights to each rural region. To convert the survey findings to nationally representative figures, the data above were adjusted based on the weighting factors provided as part of the survey design The second figure below shows the findings.

Figure 4-1 Scatter Diagram of Price:Quantity Relationships – Entertainment

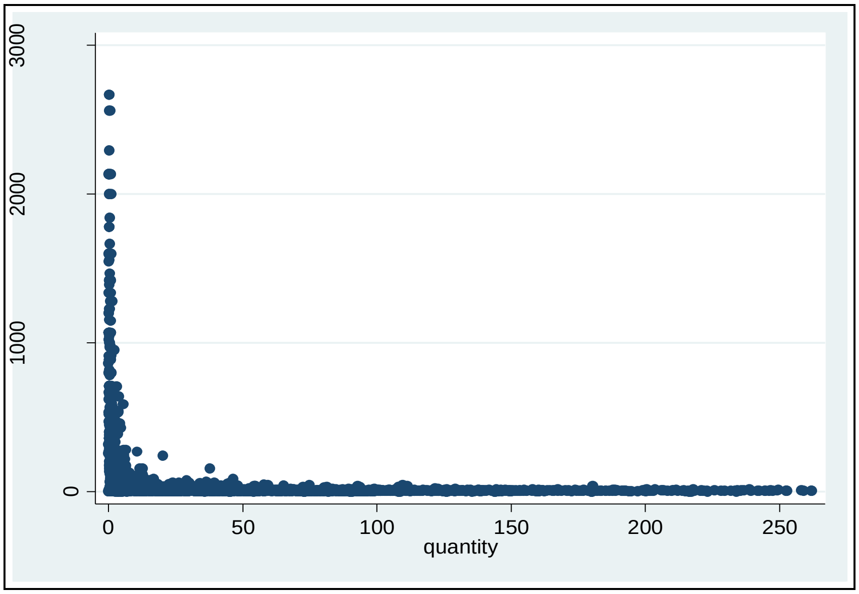
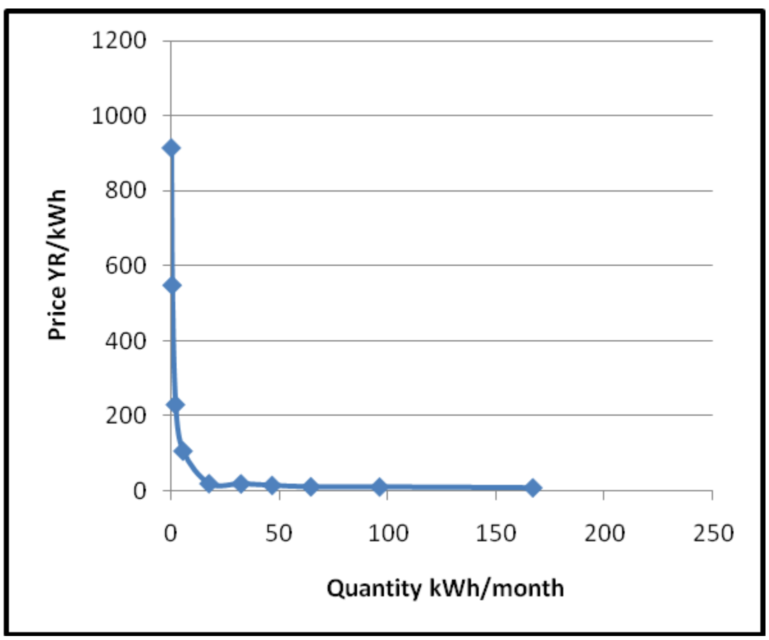


Figure 4-2 Yemen: Demand Curve for Entertainment



Average 32.3 kWh at YR246/kWh

4.4 Functional Representation of Demand Curve

As with the demand curve for lighting, the entertainment demand curve is typical of a curve with a constant price elasticity. In order to evaluate the goodness of fit of such a model to the data points, regression analysis was used to determine the extent to which variations in quantity consumed could be explained by variations in price. As with lighting, the regression analysis tested the fit of the data to the form

$$\ln Q = A + e * \ln P$$

The results of the single regression analysis are summarized in the table below:

Table 4-1 Entertainment – Price Elasticity of Demand – Single Variable Regression

Dependent variable: Entertainment quantity (ln)		
	Coefficient	
Entertainment price (ln)	-0.916	***
Constant	5.5629	
Adj.R-squared - 0.7101		
# of obs : 2819		

The co-efficient of the natural log of entertainment price in the above results, -0.916, is the price elasticity of entertainment consumption in Yemen. A 1 percent increase in the price of lighting would lead to a 0.916 percent decrease in the quantity consumed. The adjusted R square of 0.7101 means that the model explains approximately 71 percent of the changes in entertainment quantity.

A multivariate regression analysis was also carried out to assess the relationship between price and quantity while controlling for the potential effect of other variables such as income, household size, locality and hours of electricity service. The results are shown below.

Table 4-2 Entertainment – Price Elasticity of Demand – Multivariate Regression

Dependent variable: entertainment quantity (ln)			
	Coefficient		Std.err.
Entertainment price (ln)	-0.7745	***	0.0147
Income per capita (ln)	0.2392	***	0.0287
Household size	0.0757	***	0.0055
Urban	0.4469	***	0.0468
Electricity service hours	0.0168	***	0.0026
Constant	2.0658	***	0.2683
Adj.R-sq: 0.7456			
# of obs : 2819			

Note: *** indicates significant at 1% level.

The multivariate regression analysis indicates that household size, income per capita, locality and hours of electricity service, in addition to price, all have a statistically significant impact on consumption quantity. According to this model, the impact of price is lessened; when price increases by 1 percent, the quantity of entertainment consumption will decrease by 0.77 percent. The Adjusted R square indicates that the model explains 75 percent of the changes in quantity of entertainment consumed which is a modest improvement over the single variable regression. As with lighting, however, the additional data requirements of the multi-variable model, as well as the complexity of the function, would make it more difficult to use than the single variable model as a means of calculating the change in consumer's surplus (or area under the demand curve) associated with a shift from one observable consumption point to another.

4.5 Implications of the Findings

The profile of the demand curve for entertainment shows an even high degree of concavity than that for lighting. At lower levels of consumption, even very large changes in price will have little impact on the quantities consumed; at higher levels of consumption, however, even a small change in price will have a substantial impact. This also means, however, that the consumer's surplus attached to new or increased demand induced by having access to less costly electricity supply is much less than would accrue under a more gently sloping curve. At the lower levels of consumption the demand curve is almost vertical. There is very little additional demand induced by lower prices and hence the benefits primarily represent substitution benefits of a price reduction. At the higher levels of consumption, the demand curve is almost flat. Within this segment of the curve, significant increases in consumption are induced by access to lower cost supply; however the price savings are very small, and the area attributable to induced consumption under this section of the demand curve will also be small.

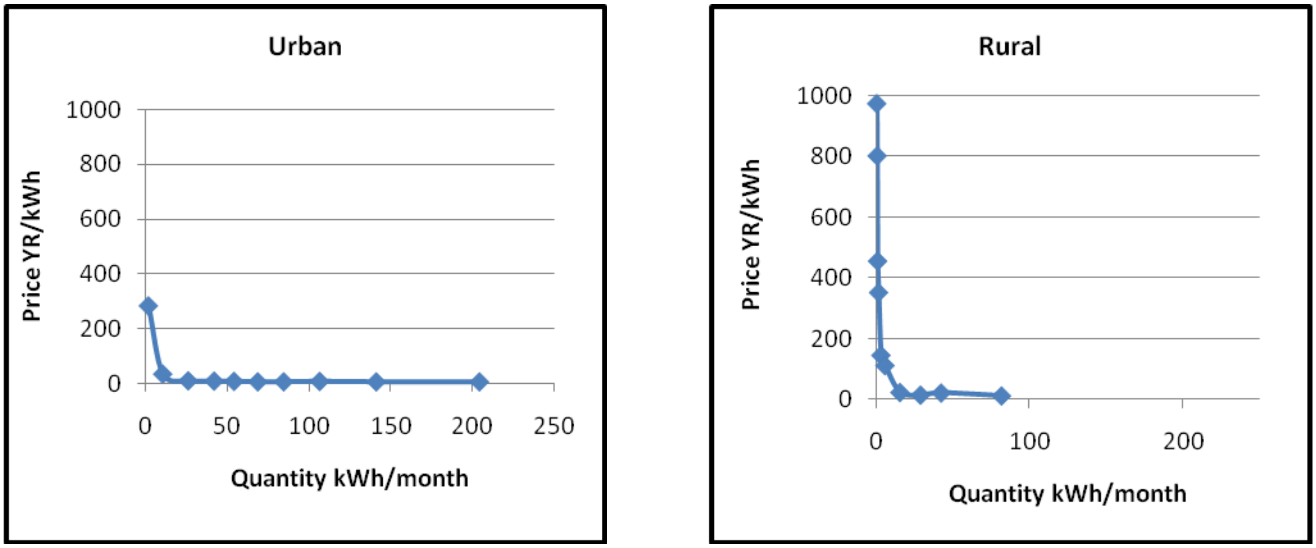
While the potential for consumer's surplus benefits associated with induced consumption may be limited, consumer's surplus associated with substitution can be significant in the lower ranges of consumption. Up to approximately 6 kWh per month equivalent of entertainment, households are willing to pay between YR100 and YR900/kWh (approximately US$0.50 to US$4.50/kWh) for entertainment. Moreover, nationally in Yemen, 40 percent of households are purchasing entertainment – albeit in small amounts – at these price levels.

Finally, while lighting is generally regarded as a primary requirement and hence also as a primary rationale for improving access to electricity, it is interesting to observe that in terms of total consumption of kWh by households, consumption for entertainment exceeds that of lighting. On average, households consumed 20 kWh of lighting per month as compared with 32 kWh of entertainment. Households in the highest consumption decile for lighting averaged 100 kWh per month of lighting consumption. Households in the highest consumption decile for entertainment consumed on average almost 190 kWh in a month.

4.6 Impact of Location

The differences in the shape of the demand curve for entertainment between urban and rural consumers are illustrated in the charts below. As with lighting, the demand of both urban and rural customers is insensitive to large absolute changes in price up to a certain minimum level of consumption – in this instance up to the equivalent of approximately 6 kWh per month - after which the demand curves flatten out and small changes in price can lead to large changes in consumption. Also as with lighting, there were significant differences at the lower end of the quantity range. Urban households were more likely to have access to grid electricity, and hence, on a weighted average basis, were less likely to incur the high unit costs associated with the use of batteries. This also helps to explain the differences in the average monthly consumption, where urban households are consuming at almost four times the level of rural households.

Figure 4-3 Entertainment Demand Curves by Urban/Rural Locality



Average 70.1 kWh at YR37 per kWh **Average 17.8 kWh at YR326 per kWh**

The table below shows the results of the single regressions of the urban and rural demand curves. Both curves show slightly lower price elasticities than the national model. The coefficients in both cases are very similar, suggesting that urban and rural residents have a similar consumption response to changes in price when entertainment is involved. However, the model explains only 45 percent of the variations in urban consumption, as compared with 71 percent of the variations in rural consumption.

Table 4-3 Price Elasticities for Entertainment – Urban and Rural Localities

	Coefficient		R-Squared	Constant	Observations
Urban	-0.8557	***	0.4472	5.6352	1323
Rural	-0.8410	***	0.7070	5.0658	1496

Note*** Significant at the 1% level

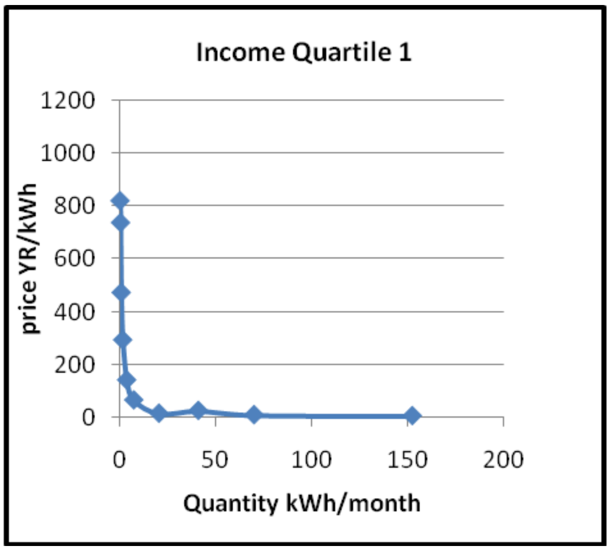
The main distinction between the two groups of customers is that approximately 60 percent of rural customers are consuming in the vertical segment of the range as compared with 10 to 20 percent of the urban customers. In addition, the average observed willingness to pay of rural customers for basic access to entertainment is much higher than that of urban customers.[27] Thus as a general principle in Yemen, investments in improving electricity supply to rural households will yield higher substitution benefits from lower-cost access to entertainment.

[27] This is not to suggest that urban customers assign a lower value to entertainment; it may merely mean that they are more likely to have access to lower-cost sources of energy supply, and hence the amount that they are "observed" as willing to pay is lower.

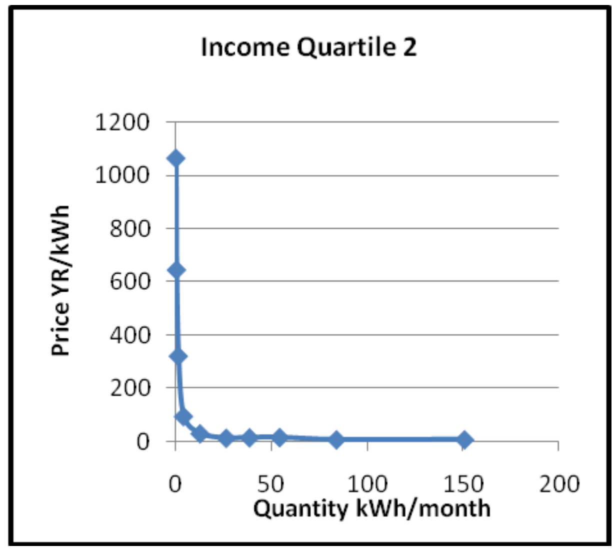
4.7 Impact of Income

Households responding to the survey were divided into 4 quartiles based on per-capita income, with Quartile 1 being the lowest income group and Quartile 4 being the highest. The entertainment demand curves for each of these groups are shown in the four charts below. As with lighting, the shapes of the curve are similar among all income groups.

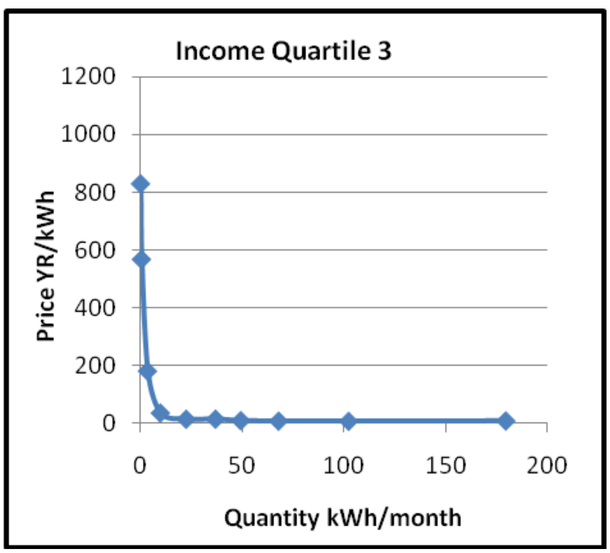
Figure 4-4 Entertainment Demand Curves by Income Quartile



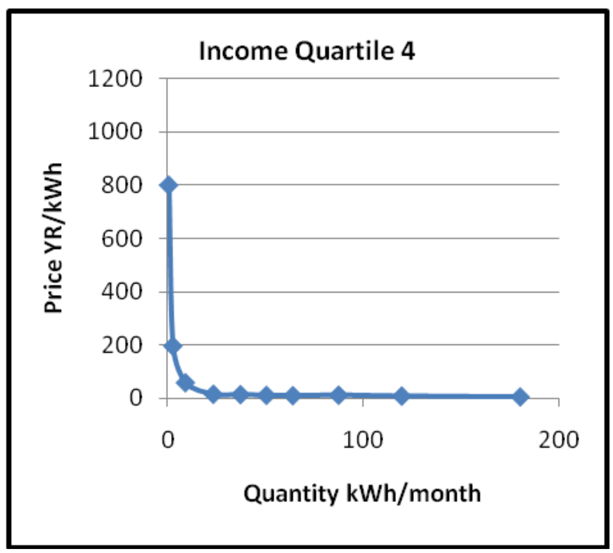
Average – 22 kWh at YR342/kWh



Average – 30 kWh at YR269/kwh



Average – 36 kWh at YR210/kWh



Average – 42 kWh at YR 158/kWh

The table below shows the findings of the regression analyses of the four demand curves. All income quartiles show a very high level of price elasticity, although the R-squared values decline as income increases. Except for Q1, price elasticities also decline as income levels increase.

Table 4-4 Price Elasticities for Entertainment by Income Quartile

	Coefficient		R-Squared	Constant	Observations
Quartile 1	-0.8977	***	0.7703	5.3828	596
Quartile 2	-0.9305	***	0.7606	5.5476	702
Quartile 3	-0.9017	***	0.6599	5.4826	757
Quartile 4	-0.8814	***	0.5852	5.6442	764

Note*** Significant at the 1% level

Somewhat surprisingly, the P:Q coefficients of lowest consumption decile are very similar in all four income groups. Clearly a significant portion of households in each income class choose or are forced on occasion to use extremely costly energy to meet some of their entertainment demand[28]. In the lower income groups, the level of consumption of the highest deciles is also surprising. Monthly consumption of 150 kWh for entertainment seems high for low income households – even if the price is only YR 7/kWh (3.5 US cents/kWh). Overall average consumption for each quartile, as shown below the charts, is in line with that found for lighting, however with households in the highest quartile consuming approximate twice the monthly kWh for entertainment as households in the lowest quartile.

The earlier multivariate regression analysis of entertainment consumption shown in Table 4-2 also provides an indication of the income elasticity of household entertainment demand. The regression coefficient for income of 0.2392 indicates that a 1 percent increase in income per capita leads to a 0.23 percent increase in entertainment consumption.

The results of a multivariate regression including only entertainment price and income per capita, also showed income to be a significant explanatory variable, although with a lower elasticity.

Table 4-5 Entertainment Regression Coefficients, Price and Income

Dependent variable: entertainment quantity (ln), include no-access					
	Coefficient		Std Error	R-squared	Obs.
Entertainment price (ln)	-0.9014	***	0.0113	0.7133	2819
Income per capita (ln)	0.1612	***	0.0286		
Constant	4.1656	***	0.2513		

Note: *** indicates significant at 1% level.

4.8 Summary

The above analysis of Yemeni households' behavior with respect to their consumption of entertainment and their responses to changes in price adds an additional dimension to the evaluation of the benefits of electrification projects. In addition to providing information on the P:Q coordinates of the demand curve at both the minimum and maximum levels of consumption, it provides strong evidence that the price elasticity between these points is very high. It establishes that all households are willing to pay a very high unit price for an initial quantity of

[28] The decision to assign all dry cell battery use to entertainment may have contributed to this finding. However, only a few other household appliances might be significant users of dry cell batteries. It seems unlikely that not accounting for their consumption would heavily bias the use of dry cells by radios and televisions.

entertainment (between US$4.00 and $5.00/kWh for the equivalent of less than 0.5 kWh per month). However, total consumption remains low until prices drop significantly. Consumption will reach or exceed 100 kWh per month when prices reach the YR 7 to 10 per kWh range (3.5 to 5.0 US cents/kWh). Thus, there may be significant substitution benefits (in terms of savings per kWh) as a result of access to low cost electricity. However, these benefits will be applicable to only a small number of units per household. Consumer's surplus benefits from induced consumption are likely to be so small as to be meaningless.

The table below brings together the calculated price elasticities of different groups of consumers. The results here are more consistent than for lighting. In all instances, price is a major determinant of consumption, explaining almost 90 percent of the variances in quantity consumed at the national level. It also explains more than 80 percent of the variances among both urban and rural customers and among all income classes. Price elasticity is virtually the same in rural areas and urban areas; as with lighting, elasticity declines as income increases.

Table 4-6 Summary of Price Elasticities - Entertainment

	Coefficient		R-Squared	Observations
National	-0.9162	***	0.7101	2819
Quartile 1	-0.8977	***	0.7703	596
Quartile 2	-0.9305	***	0.7606	702
Quartile 3	-0.9017	***	0.6599	757
Quartile 4	-0.8814	***	0.5852	764
Urban	-0.8557	***	0.4472	1323
Rural	-0.8410	***	0.7070	1496

Note*** Significant at the 1% level

Finally, while the data presented in this report provides guidance on the likely shapes of entertainment demand curves, it will still be essential to carry out some basic survey work as part of assessing the benefits of improvements in electricity supply. While the shapes of the curves displayed by Yemeni households may be transferrable to other jurisdictions, the prices and quantities are not. At a minimum, a limited household survey will be needed to provide guidance on the initial and terminal points on the demand curve.

5 Demand Curves for Other Applications

In the hope of extracting additional useful information on price:quantity relationships from the Yemen data-base, a number of additional data sets were examined. Cooking seemed particularly promising since households reported using a variety of fuels with varying unit prices. However, there was also a possibility of identifying demand curves for other, solely electric appliances given the range of unit electricity prices reported by the survey. These included electric fans, vacuums, mixers, refrigerators, air conditioners, computers, audio and video players, and satellite dishes.

Unlike lighting and entertainment, which were reported as used by all survey respondents, ownership and use of these latter appliances were restricted to households with some form of electricity supply. Refrigerators, satellite receivers, electric fans, and mixers were the most commonly reported. Almost 60 percent reported using refrigerators, 44 percent used fans, 43 percent used satellite receivers, and 38 percent used mixers. Ownership and use of the other electric appliances was limited, generally to than 10 percent of the electrified households surveyed. The following sections discuss the findings with respect to price:quantity relationships for these remaining applications.

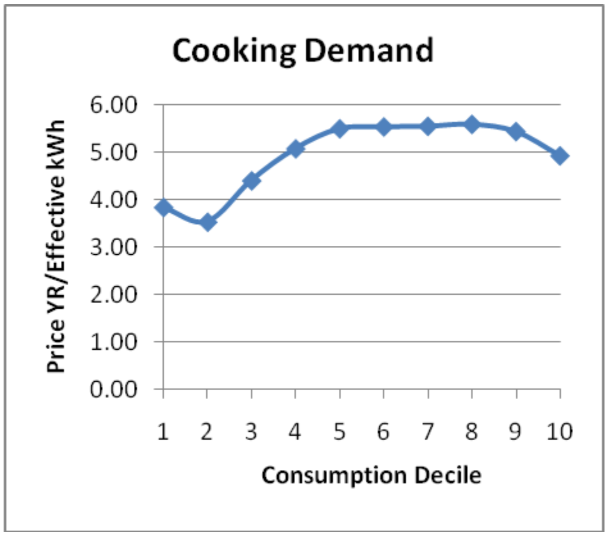
5.1 Cooking

Arguably, improved access to electricity could yield considerable benefits in the form of savings in the cost of cooking. Cooking with an open flame such as that generated by most non-electric stoves is generally considered to be inefficient in terms of the conversion of energy to useful heat. Electric cooking is also cleaner, leading to less indoor pollution and therefore fewer health problems. As part of this study, it was therefore decided to test whether the data from the Yemen survey indicated any appreciable benefit and consumer’s surplus from the use of electricity for cooking.

The fuels used for cooking in Yemen include the following: crop residue, fuelwood, kerosene, LPG, and electricity. Much of the cost of crop residue and fuelwood was a social cost – i.e. the time spent in collecting and storing the fuel. In addition, data on the energy content of these fuels per unit of volume varied widely according to the type of material – information that was not available from the survey. The study therefore focused on the three “commercial” fuels: kerosene, LPG and electricity. Reported hours of use for cooking were converted into effective kWh equivalents of cooking energy (based on the energy content of the fuel and the efficiency of the cooking appliances), while reported expenditures were converted into unit costs per effective kWh.

Sadly from the analytical point of view, the expected downward sloping demand curve did not materialize. Kerosene proved to be the overwhelmingly dominant cooking fuel in Yemen. Use of electricity and LPG were so limited that, even though they were the lowest priced fuels, they represented the least-used fuels for cooking. The chart below shows the aggregated demand curve for cooking. The table shows how the high levels of kerosene consumption result in an upward sloping demand curve.

Figure 5-1 Demand Curve for Cooking



	Kerosene	LPG	Electricity
1	4.7%	78.0%	17.3%
2	14.0%	85.1%	0.9%
3	30.8%	68.9%	0.3%
4	69.4%	29.7%	0.9%
5	94.0%	5.6%	0.4%
6	98.3%	1.7%	0.0%
7	99.5%	0.5%	0.0%
8	99.0%	1.0%	0.0%
9	99.3%	0.7%	0.0%
10	99.8%	0.2%	0.0%

Clearly factors other than price are affecting the demand for cooking energy in Yemen. It cannot solely be access to electricity because otherwise lighting and entertainment would have displayed a similar profile. Possibly tradition or the type of cooking favors an open kerosene stove. Possibly the electric stoves available to households are prohibitively expensive. Possibly institutional factors are preventing the wide-spread distribution of LPG (which should clearly be favored on economic grounds). The answer to this question is not the subject of the current study. The cooking curve does highlight, however, the fact that in some cases factors other than price can be the dominant factor in determining the shape of a demand curve.

5.2 Other Electrical Appliances

The household survey covered the usage and cost of an assortment of appliances that were used only when there was an AC power source available. These included various entertainment devices, cooling appliances, and household convenience items. The specific appliances covered, and the percentage of electrified households reporting owning and using them are listed in the table below:

Table 5-1 Other Appliances Used by Electrified Households

	Urban	% of HH Surveyed	Rural	% of HH Surveyed	Total	% of HH Surveyed
Fan	579	39.6%	495	51.7%	1,074	44.4%
Air Conditioner	181	12.4%	38	4.0%	219	9.0%
Refrigerator	989	67.6%	456	47.6%	1,445	59.7%
Vacuum	349	23.9%	77	8.0%	426	17.6%
Electric stove	49	3.4%	14	1.5%	63	2.6%
Mixer	614	42.0%	300	31.3%	914	37.8%
Video Player	82	5.6%	30	3.1%	112	4.6%
Audio Player	6	0.4%	14	1.5%	20	0.8%

Computer	144	9.8%	15	1.6%	159	6.6%
Satellite Receiver	691	47.3%	342	35.7%	1,033	42.7%
Water pump	231	15.8%	56	5.8%	287	11.9%
Total Surveyed	1,462		958		2,420	

A selection of the most commonly used appliances was chosen for further analysis to establish whether the price:quantity relationships established for lighting and entertainment also pertained for these applications.

5.2.1 Other Electrical Appliances

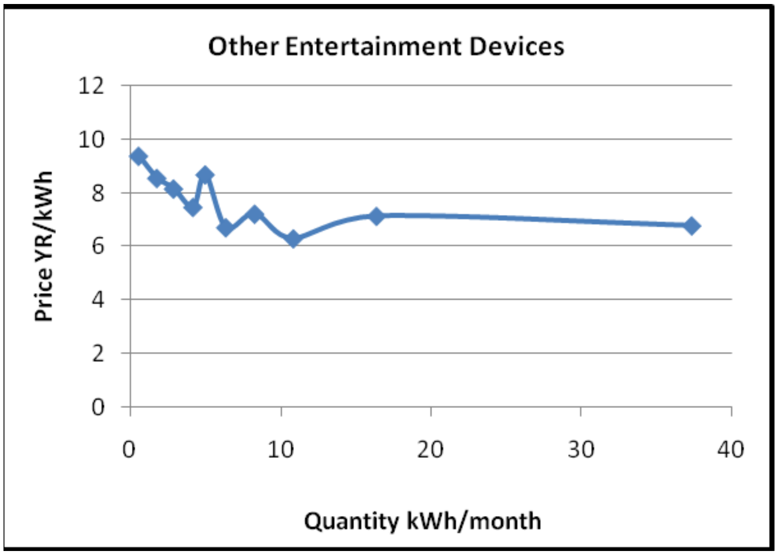
Usage of a number of other appliances that might be broadly classed as part of information/entertainment was also covered in the Yemen survey. Because the only source of energy for these appliances was electricity, they were not included in the main "entertainment" category. The appliances in question, as well as their assumed power consumption, are listed below. In total, 1,077 households or 44.5 percent of the electrified households surveyed reported ownership and use of one or more of these devices. However, 49 percent of urban households surveyed reported owning and using them as compared with only 37 percent of rural households.

Table 5-2 Other Entertainment Devices – Electricity Consumption

Appliance	Watts
Video Player	50
Audio Player	50
Computer	300
Satellite Receiver	30

Using survey responses, the same procedure was used as for entertainment to derive the associated demand curve. Number of appliances were multiplied by watts and by hours of usage to give watt-hrs or kWh consumption per month, which in turn was adjusted by the household ratio of actual to calculated consumption. Consumption was plotted against unit prices for electricity paid by the households. Mean prices and quantities were calculated for each consumption decile and used to create the national demand curve shown in the chart below.

Figure 5-2 Household Demand Curve – Other Entertainment Devices



Average 7.2 kWh/month at YR7.8/kWh

The demand curve for "other entertainment" displays none of the characteristics of the demand curves for lighting or entertainment. There is no dramatic curvature, and the maximum willingness to pay is in the order of YR9 per kWh (approximately US4.5 cents). Regression analysis computed a price elasticity of -0.659. However, in the logarithmic model, variations in price explained just over 4 percent of the variations in quantity consumed. A multivariate regression analysis indicated that the only location (urban) and hours of electricity service were significant at the 1 percent level. Price, income and household size were significant at the 5 percent level, although price elasticity was positive (i.e. in increase in price led to an increase in consumption). This model explained 38.7 percent of the variance in quantities consumed. The results of the multivariate regression are shown below.

Table 5-3 Multivariate Regression – Other Entertainment

Dependent variable: other entertainment quantity (ln), exclude no-access					
	Coefficient		Std. Error	R-Squared	Obs.
Price (ln)	0.2559	**	0.1022	0.3872	924
Income per capita (ln)	0.1093	**			
Household size	0.0231	**			
Urban	1.2771	***			
Electricity service hours	0.0491	***			
Constant					

*** Significant at the 1% level   ** Significant at the 5% level

A simple linear regression of quantity against price provided more logical results with a y-intercept of 8.14 and a slope of -0.05. However, this model still only explained 32 percent of the variances in consumption, making it a poor basis for calculating consumer's surplus benefits.

Demand curves for urban and rural households, and for households in each income quartile were also generated. In each case, single regressions against price provided a poor fit. The results of these regressions are shown in the table below.

Table 5-4 Other Single Variable Regression Results – Other Entertainment

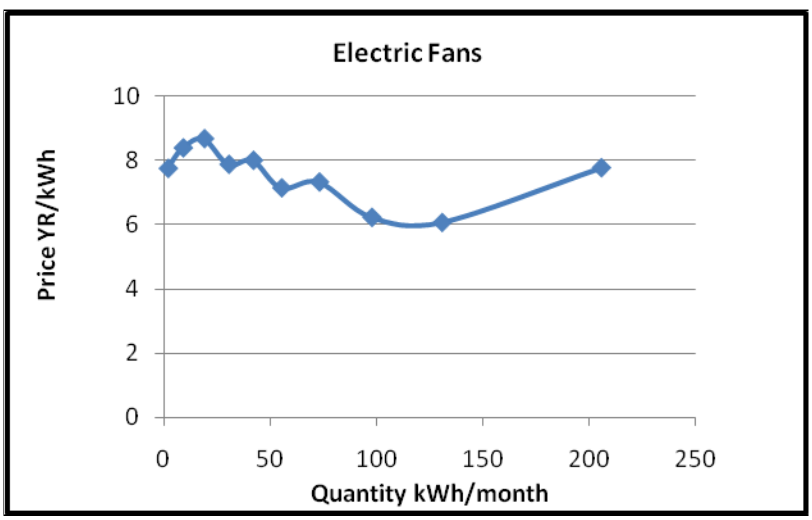
	Coefficient		R-squared.	# obs.
Q1	-0.74205	**	0.0636	86
Q2	-0.80539	***	0.0678	185
Q3	-0.68993	***	0.0436	286
Q4	-0.46874	***	0.0168	383
Urban	0.976914	***	0.0997	637
Rural	-0.09261		-0.0024	303

*Note** Significant at the 1% level ** Significant at the 5% level

5.2.2 Electric Fans

Approximately 44 percent of the households surveyed who had access to electricity supply reported owning and using electric fans. Percentage-wise, ownership was more common among rural than among urban households. Forty percent of urban households reported using electric fans as compared with 52 percent of rural households. While the rated wattage of these fans can vary widely, it was assumed that the average rating was 100 watts. Survey responses were used in the same manner as for other applications to derive the associated demand curve. Number of fans was multiplied by hours of usage and by watts to give watt-hrs or kWh consumption per month. These were plotted against unit prices for electricity paid by the households. Mean prices and quantities were calculated for each consumption decile and used to create the national demand curves shown in the charts below.

Figure 5-3 Household Demand Curve – Electric Fans



Average 58 kWh/month at YR7.6 per kWh

The graph showing the price:quantity relationships for electric fans also shows little similarity to those for lighting and entertainment. Willingness to pay is clustered between YR 6 and YR8.5/kWh. However, the highest consumption decile is also paying one of the highest prices. The calculated price elasticity was -0.370, but the single variable model explained less than 1 percent of the variation in quantity. A multivariate regression showed that income, urban location and hours of service were all significant variables at the 1 percent level. However, both the income and price coefficients had the wrong sign. The results are summarized in the table below.

Table 5-5 Multivariate Regression Results – Electric Fans

Dependent variable: fan quantity (ln), exclude no-access					
	Coef.		Std. Err.	adj.R-sq	Obs.
Price (ln)	0.1401		0.1326	0.2908	942
Income per capita (ln)	-0.1892	***	0.0657		
Household size	0.0022		0.0133		
Urban	0.8220	***	0.1081		
Electricity service hours	0.0807	***	0.0062		
Constant	2.7280	***	0.6215		

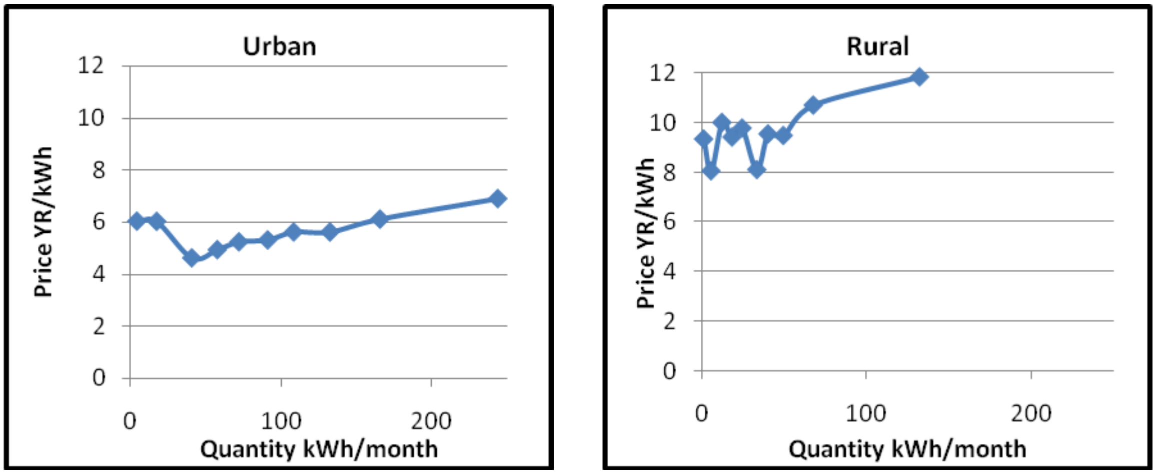
Note*** Significant at the 1% level ** Significant at the 5% level

Linear regression did not provide a significantly better result. The sign of the price coefficient was negative (-0.007) but the R squared was only .246.

The figures below show the separate demand curves for urban and rural households and help to explain some of the anomalies in the national demand curve and the regression model. First, households that are using fans extensively are moving into consumption levels where the tariff structure becomes a factor in determining the prices paid. In Yemen, households connected to the PEC national grid pay an inverted block tariff. The price breaks for urban households are 200, 350 and 700 kWh per month; for rural households the break is at 100 kWh per month[29]. Total monthly consumption of those households in the higher consumption deciles for fans is most likely in one of the higher tariff brackets. Second, average urban consumption of electricity for fans is more than double that for rural households. Hence, locality (urban vs rural) becomes a dominant factor in determining the shape of the national demand curve. The lower consumption level of rural households is also the primary price response that is observed from the analysis.

[29] Block tariffs for urban households are YR4, 7, 10 and 17 per kWh. For rural households they are YR7 and 17 per kWh

Figure 5-4 Electric Fan Demand – Urban vs Rural



Average 84kWh at YR5.6/kWh **Average 35kWh at YR9.5/kWh**

The data on consumption of electric fans was also used to test whether climate zones might be a major determinant of demand. The low-land areas along the Red Sea are significantly warmer and more humid than the central highlands, while the northern and eastern regions are hot and dry. To test whether this was a significant factor, surveyed households were assigned to one of three climatic zones based on governorate, coast, highlands, and eastern, and the regression was re-run. The results are shown below.

Table 5-6 Multivariate Regression Results – Electric Fans by Climate Zone

Dependent variable: fan quantity (ln), exclude no-access					
	Coef		Std Error	Adj. R Squared	Obs
Fan price (ln)	0.1730		0.1273	0.3568	942
Income per capita (ln)	-0.0715		0.0636		
Household size	0.0292	**	0.0130		
Urban	0.7542	***	0.1056		
Electricity service hours	0.0830	***	0.0065		
Coast	1.0478	***	0.1060		
Eastern	0.8057	***	0.1257		
Constant	0.6854		0.6371		

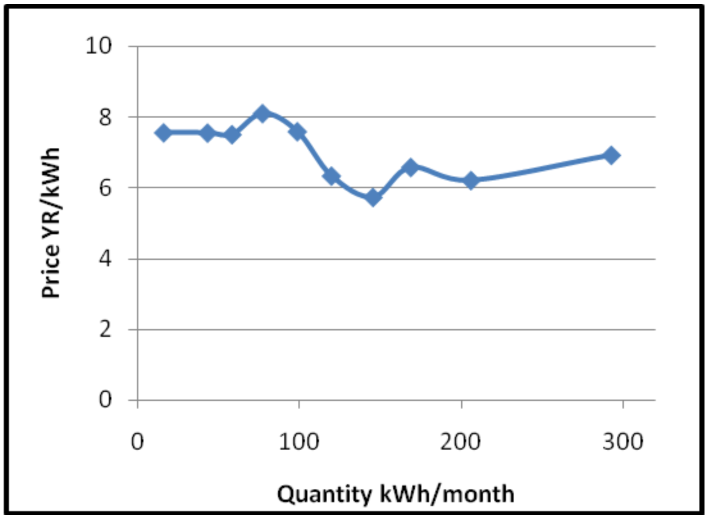
Note *** Significant at the 1% level ** Significant at the 5% level

The regression included dummy variables for Coast and Eastern zones in order to determine whether their consumption differed from that in the highlands. The results indicate that consumption in both zones is higher, which suggests that the warmer climates in the coastal and eastern interior zones is in fact a determinant of demand.

5.2.3 Refrigerators

Refrigerators were owned and used by almost 60 percent of the households surveyed. This was also a largely urban occurrence; 68 percent of urban households reported owning a refrigerator versus only 48 percent of rural households. The rated watts for refrigerators can range from 100 watts for a mini-fridge to several hundred watts for larger models. However, the appliance is only consuming electricity at this rate when the compressor is operating. Since survey respondents were unlikely to have distinguished between "on" and "compressor running" in response to the questions regarding hours of use, the average watts consumed per hour was assumed to be 250. Watts and hours of use were used to calculate monthly kWh of electricity consumption per household and the results divided into deciles to give the demand curve shown below.

Figure 5-5 Demand Curve – Refrigerators



Average 104 kWh/month at YR7.2 per kWh

The logarithmic single regression model for refrigerator demand shows a very limited correlation between the natural logs of price and quantity consumed. The coefficient for price of -0.1834 is significant only at the 5% level, and the R-squared is 0.0036.

The multivariate regression model, shown below, provides a better fit, with price, locality and hours of electricity service all significant at the 1 percent level, and income significant at the 5 percent level. However, both price and income have the "wrong" sign; consumption increases as price increases and declines as income increases. The significant factors with the correct sign are locality (urban vs rural) and electricity hours of service.

Table 5-7 Multivariate Regression Results – Refrigerators

Dependent variable: refrigerator quantity (ln), exclude no-access					
	Coef.		Std. Err.	adj.R-sq	obs.
Refrigerator price (ln)	0.6758	***	0.0696	0.5117	1296
Income per capita (ln)	-0.0695	**	0.0287		
Household size	0.0011		0.0059		
Urban	1.1691	***	0.0561		

Electricity service hours	0.0675	***	0.0036		
Constant	1.5714	***	0.2761		

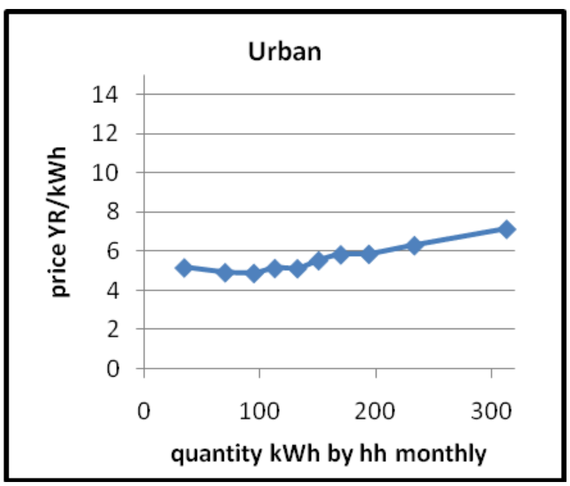
Note*** Significant at the 1% level ** Significant at the 5% level

Linear regression also provided a poor fit. The slope of the line was negative at -0.005 but the R squared was only .318.

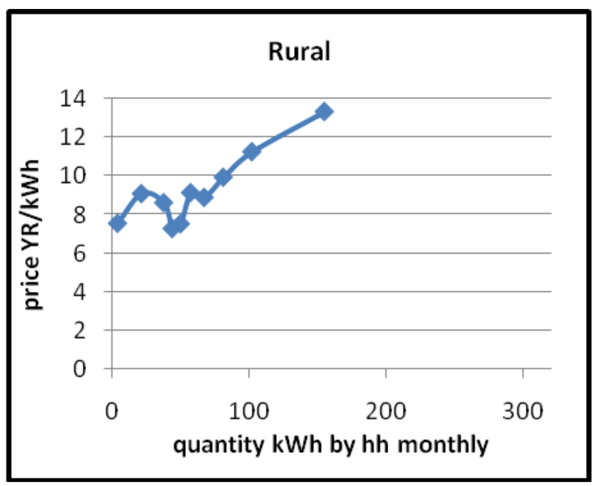
The charts below highlight the differences between urban and rural households in terms of their use of refrigerators and help to explain the significance of locality – and the reversed sign of the price coefficient in the model of the national demand curve. The over-riding determinant of the shape of the demand curve would appear to be the block tariff structure – especially the structure applicable to rural households where consumption in excess of 100 kWh per month is charged at YR17 per kWh as compared with YR7 for the initial block. The urban demand curve also seems to be affected by the block tariff structure, but the impact is less dramatic as the second block only starts at 200 kWh per month and the price only increases from YR4 to YR7 per kWh.

The primary price response that can be deduced from the analysis lies in the difference between the total consumption of urban and rural households. Rural households that own refrigerators use them much less than do urban households – averaging only 61 kWh per month as compared with 141 kWh for urban households. Unfortunately, given the greater prevalence of refrigerator ownership among urban households and the higher average level of consumption, these distinctions are lost when the two are combined into a national curve.

Figure 5-6 Refrigerator Demand – Urban vs Rural



Average 141 kWh at YR5.5/kWh

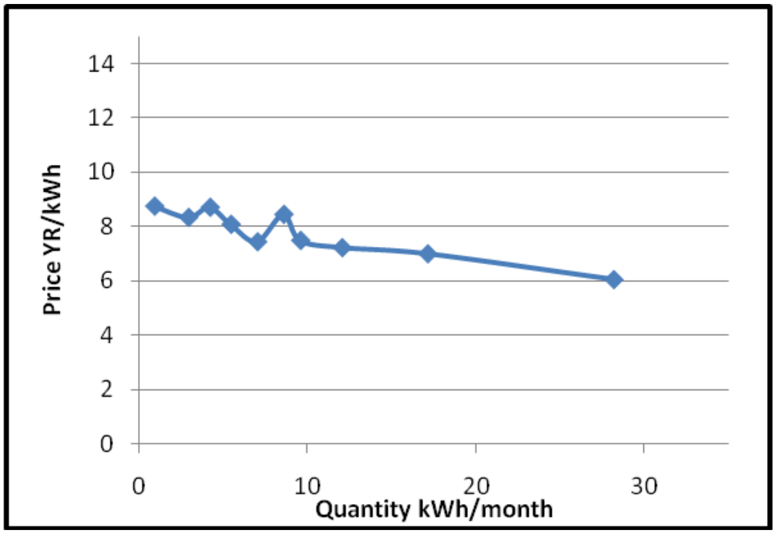


Average 61 kWh at YR9.2/kWh

5.2.4 Electric Mixers

Electric mixers were used by 37.8 percent of electrified survey respondents, and were assumed to consume 300 watts per hour of use. Again, urban users dominate, with 42 percent of urban households reporting using a mixer as compared with 31 percent of rural households. Watts and reported hours of use were used to calculate monthly kWh of electricity consumption per household and the results divided into deciles to give the demand curve shown below.

Figure 5-7 Demand Curve Electric Mixers



Average 7.4 kWh/month at YR8/kWh

The single variable elasticity model for mixers showed a price elasticity of -0.5990, but an R-squared of only 0.038. The multivariate regression model showed a better fit, but price and income were only significant at the 5 percent level, and as with refrigerators, both have the "wrong" sign.

Table 5-8 Multivariate Regression Results – Electric Mixers

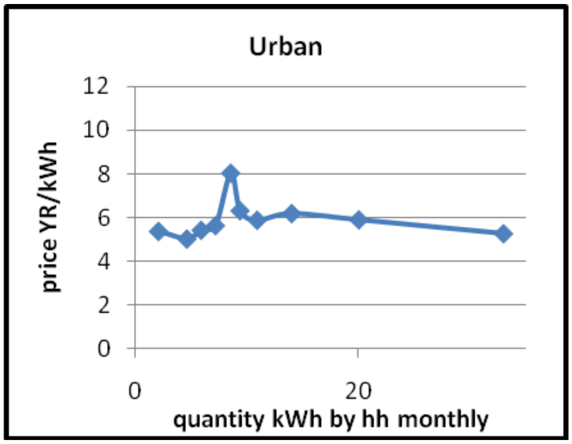
Dependent variable: mixer quantity (ln), exclude no-access					
	Coefficient		Std. Error	R Squared	Obs.
Mixer price (ln)	0.2949	**	0.1098	0.3802	764
Income per capita (ln)	-0.1234	**			
Household size	-0.0176	**			
Urban	0.8929	***			
Electricity service hours	0.0754	***			
Constant					

Note*** Significant at the 1% level ** Significant at the 5% level

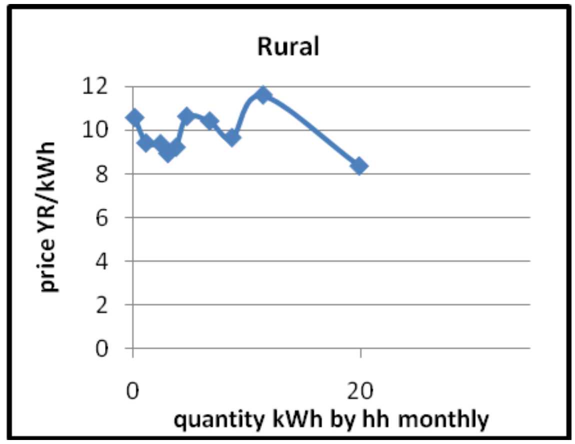
Linear regression provided a much better explanation of the variations in quantity. The linear curve had an R squared of 0.834, with a y-intercept of 8.72 and a slope of -0.10.

Again the comparison of urban and rural demand curves helps to explain some of the anomalies in the demand curve. Urban and rural households both consume within a relatively narrow band of prices. Average consumption of urban households is almost twice that of rural households, however, and the average price is 40 percent lower. As with refrigerators, it would appear that the primary price response that can be deduced from the analysis lies in the difference between the total consumption of urban and rural households. Unfortunately, given the greater prevalence of mixer ownership among urban households and the higher average consumption per household, these distinctions are lost when the two are combined into a national curve.

Figure 5-8 Mixer Demand – Urban vs Rural



Average 10.0 kWh at YR5.9/kWh



Average 5.1 kWh at YR9.9/kWh

5.3 Summary

The study of other applications for electric energy, including cooking and other electric appliances, provides some interesting lessons with respect to the factors affecting electricity consumption. In the case of cooking, it was found that notwithstanding the fact that electricity was the lowest cost method, kerosene was the dominant fuel in both urban and rural households. Tradition and style of cooking may be factors, as might availability of kerosene vs electric stoves. Electric stoves may also carry a high up-front cost that hinders their purchase even if their use would be less costly in the longer term.

The other electric appliances that were studied were owned and used by only a segment of the surveyed households, and were powered exclusively with AC outlets. Other entertainment devices, refrigerators, and electric mixers were owned predominantly by urban survey respondents. Use of electric fans, however, was more commonly reported by rural than by urban households. The average monthly consumption of urban households for the various applications was approximately double that of rural households, and the average price paid was approximately 40 percent lower.

In all instances, consumption took place within a relatively narrow band of prices, and the national demand curves showed relatively little correlation between the quantities consumed and the prices paid or between quantities consumed and household income. In the case of fans and refrigerators, regression analysis suggested that consumption increased with rising prices and decreased with rising income – a counter-intuitive finding.

One of the main factors causing the upward sloping demand curves for fans and refrigerators is the inverted block tariff structure. The higher end of the consumption scale for these two appliances falls into the range of the higher tariff blocks for both urban and rural households. Hence, as consumption increases, average prices rise.

Regrettably it is difficult to draw broadly relevant conclusions regarding demand curves for the use of electric appliances. Because ownership was limited and heavily biased towards urban households, the prices charged for electricity fell within the narrow range of the PEC national grid tariff, as compared with the much broader range of prices observable for lighting and entertainment. The inverted block structure of the tariff further complicated the analysis for appliances such as fans and refrigerators. Consumption by households in the higher consumption deciles for these appliances often reached the range at which second or third block tariffs would apply; hence, the demand curve suggested that consumption increased as prices rose. The main conclusion that can be drawn is that there is in fact a logical relationship between price and quantity as evidenced by the differences in the consumption patterns of urban and rural households. Average prices paid by former are approximately 40 percent lower than those paid by the latter, and average consumption is approximately double.

6 Postscript

The complexity of the analysis presented in this study inevitably leaves a number of "loose ends" among the conclusions in the sense of not rigorously resolving every analytical question that arises from the analysis. This postscript addresses qualitatively some of the significant questions.

6.1 Composite Demand Curves for Electricity

The earlier chapters talked about price: demand relationships for a selection of utilities that could be provided by electricity. In principle, one could combine these price:demand functions to form an overall composite demand curve for all uses of electricity by Yemeni households, under the implication that these curves are also a proxy for a demand curve for electricity. But is it possible in practice to integrate the above curves to create overall composite demand curve for all uses of electricity? The answer is most likely not. Consumption of lighting and entertainment was reported by virtually 100 percent of the sample households. The demand curves were based on a wide range of observed prices and consumption, and are probably representative of the total population. Demand curves for the remaining applications, however, were based on much lower participation rates, with the highest being 60 percent for refrigerators. As such, they cannot simply be added on to the lighting and entrainment curves to create a total figure. There were other biases in the data as well. For example, almost all of the households owning refrigerators were connected to the national grid and hence paid the same tariff for electricity.

Nevertheless, calculating the benefits of new electricity connections will often rely heavily on the benefits associated with lower cost lighting, radios and televisions. The findings of this study with respect to the shape of those demand curves are highly relevant to that exercise and the estimation of consumer's surplus benefits arising from both substitution and induced demand. For other applications, the analysis indicates that there is little consumption induced simply by having access to electricity. Most of the consumption of other applications took place at price levels that were close to the lowest price available, and would yield almost nothing by way of additional consumer's surplus.

Demand curves are also combined in the different context of urban and rural households, or more precisely, households from a broad range of household incomes in each group where incomes for the urban group are substantially higher than for the rural group.[30] The study presents combined demand curves for all households as well as separate curves for urban households and rural households, and also for income quartiles. In principle, this practice would be acceptable provided that the equation parameters have similar values for these consumer groups. In practice, the study found similar values for price elasticities - for example in the case of lighting minus 0.778 for urban households and minus 0.795 for rural households - and for equation constants – 5.6400 for urban households and 5.4185 for rural households (table 3.4). Likewise,

[30] Note that the lowest income urban households are at similar levels to to rural household incomes, indicating that this population lives on the margin of urban areas.

similar values for price elasticities and for equation constants were found among income quartiles for lighting demand (table 3-7). This finding indicates that the practice of combining the constant elasticity demand functions for these users is acceptable.

6.2 The place of Yemeni elasticities in the universe of elasticities.

The price and income elasticities computed for Yemeni household electricity demand lie towards the extremes of the range of elasticities reported in Annex 1 from published empirical studies. The Yemeni elasticities from multivariate regressions should be used for this comparison,[31] because the empirical studies are based on multivariate regressions. In summary, the estimated price elasticity for Yemeni household demand is minus 0.71 for lighting and minus 0.77 for entertainment, whereas the long-run price elasticity of electricity demand for the group of household demand functions reviewed in Annex 1 averages minus 0.40. Likewise, the estimated per capita income elasticity for Yemeni household demand is plus 0.116 (table 3-3) for lighting and plus 0.24 for entertainment (table 4-2), whereas the income elasticity of electricity demand for the group of household demand functions reviewed in Annex 1 averages plus 0.75.

Yemeni household demand for electricity thus appears to be substantially more price elastic and substantially less income elastic than household demands in the countries covered by the review in Annex 1. The logical reaction to these significant differences is to find valid explanations, rather than to discredit the findings of one or both reviews. One explanation that is surely valid is that **the Yemeni elasticities are for single uses derived from a variety of energy sources, whereas the elasticities for the other countries are for composite demands from a variety of uses derived only from electricity**. This finding is important for the proper understanding and usage of electricity demand elasticities, in the sense that the choice of elasticity values for analysis should specifically reflect the mix of electricity uses that make up the demand function in question.

6.3 Cross-Elasticities of Demand

The analysis of the price:quantity relationships did not specifically address cross-price elasticities of demand for alternative fuels, mainly because the focus was on electricity and at the prices prevailing at the time of the survey, it was without exception cheaper than alternative fuels for the utilities being examined. Moreover, the review of empirical household electricity demand in Annex 1 shows that reliable estimates of cross-price elasticities can only be obtained when substitute energy sources are readily available to consumers. One interesting point emerged from the Yemen survey with respect to cooking. While both electricity and LPG were less costly than kerosene for cooking, kerosene was nevertheless the fuel of choice for most households. In other words, for this particular application, the price of alternative fuels was irrelevant to the fuel choice within the range of prices being offered. A second interesting point related to lighting consumption in electrified households. A large percentage of these households owned and reported using kerosene and LPG lamps and candles in addition to electric bulbs, and the expenditure per households was highest among those households paying

[31] The price elasticity values from multivariate regressions are lower than the price elasticity values from single variable regressions. For example, see tables 3-2 and 3-3 in the case of lighting, and tables 4-1 and 4-2 in the case of entertainment.

the highest unit prices for electricity (e.g. family or neighbor genset, cooperative and private grids). While this is suggestive of some cross-price elasticity, these households also receive the lowest number of daily hours of service, and it would be difficult to separate the impacts of price and hours of electricity service on the consumption of non-electric lighting.

6.4 Seasonality of Demand

Seasonality was not considered to be a major determinant of electricity demand in Yemen. Variation in the number of hours of daylight is small as are seasonal variations in daily temperature. The annual range in average monthly temperatures is in the order of 10 degrees C. The main concern of the authors of the original report on the household survey was that by carrying out the survey in December, they may have underestimated the use of electric fans in the hot and humid coastal provinces.

Seasonality should not be ignored, however, in attempting to interpret survey results from other locations. Lighting demand could definitely be affected by large seasonal variations in the hours of daylight. Similarly, use of electric fans or (in wealthier environments) air conditioners would be affected by seasonal variations in temperature. The regression results that showed higher use of fans in the warmer coastal and eastern zones of the country are proof that this can be a significant factor. While heating is not commonly a cost effective application for electricity, demand would of course be affected by ambient temperatures.

6.5 Long Run vs Short Run Price Elasticities

The estimates of elasticities cited earlier in the report are based on data taken at a single point in time. Normally a time series set of data would be required to generate long run price elasticities - continuous observations which allowed the researcher to observe customer responses to a long term change in the price of a utility. Otherwise, the price elasticities may fail to capture longer term changes in consumption patterns that are precluded in the short term owing for example to not having the proper equipment to take advantage of changes in relative prices. On the other hand, it has been argued that estimates of elasticities produced from cross-sectional data implicitly incorporate these decisions about, in this instance, electricity using stock. In general, however, long run elasticities are higher than short run elasticities, and to the extent that the lack of time series data causes a downward bias in the results, care should be taken in interpreting them to predict the long term effects of improvements in electricity accessibility or price.

6.6 Computation of Consumer's Surplus

The highly concave shapes of electricity demand curves derived in this study for Yemeni households, i.e. those that are based solely on the relationship between price and quantities consumed, indicate very low levels of consumer's surplus from electrification. When the economic benefits from electrification are computed from these levels, they may be insufficient to justify investments in electrification. But this analysis would be incomplete because it does not include the benefits from electrification to household incomes in addition to the benefits from electricity consumption. As the multivariate regression analysis demonstrated, income is also a significant factor in explaining consumers' behaviour. Price and income together provide a better explanation for the shape of the curve than price alone. In effect, the best fit demand curve for the Yemen survey data is income compensated.

When households gain access to electricity supply from public networks, they usually benefit from a large reduction in the unit cost of the services provided with electricity. This reduction is the difference between the unit cost of energy services such as lighting derived from non-grid sources of electricity or other energy forms such as kerosene that were used before electrification, and the unit cost of these services when subsequently obtained from electricity supplied at regulated tariffs. In effect, household expenditure on lighting is reduced, even if consumption of lighting is increased.

In this situation, household electricity demand is said to follow a compensated demand function. This function is expressed in the Slutsky equation (or Slutsky identity)[32] which demonstrates that demand changes due to price changes are a result of two effects:

- a substitution effect, the result of a change in the exchange rate between two goods; and
- an income effect, the effect of a change in price that results in a change in the consumer's purchasing power.

In the case of household lighting, for example, the substitution effect could be the avoided cost of lighting from kerosene lamps for the amount of illumination purchased with these lamps. The income effect is the equivalent of an increase in income available for expenditure on goods and services made possible by the reduction in expenditure on lighting, even though consumption of lighting will be higher after electrification. Households are deemed to rebalance their marginal expenditures after electrification between lighting and other goods and services (and thus maximize their total utility at a given level of household expenditure, or minimizes their expenditure while delivering a fixed level of utility, in economic parlance).

The following approach shows the basic technique that may be used to establish a compensated demand curve from household survey data and thereby estimate the consumer’s surplus from electrification of households.

Let the demand curve follow the form:

$$\ln Q = A + i*\ln Y + e*\ln P$$

where Q, P, e and A are the same terms for quantity, price, price elasticity and equation constant as in the demand function used to analyse the Yemeni household energy survey data in this study. In addition, Y represents household income and i represents the income elasticity of electricity demand. Note that the values for e and A in this function differ from the values for these parameters derived in the study with the same data. Where data on household income is available at the level of individual households surveyed, as in this study, the values for Y can be included in a bivariate regression analysis for the equation given above. The values for e, i and A are determined from this regression analysis on the observed P:Q:Y data points in the same

[32] Named after Eugen Slutsky (1880-1948).

way as described in this study.[33] In principle, a lower value of income elasticity of demand leads to a higher income effect of electrification.

The consumer's surplus at a specific income level is then calculated from the usual expression:

$$\int Q(P)dP \text{ between the price limits}$$

This calculation can be done at different income levels for various observed P:Q data points at these levels.

[33] Where household income data has not been gathered from the survey, a value or stratified values by income group of income elasticity of demand can be selected from other sources, such as the review of empirical estimates given in Annex 1.

7 Conclusions

The following are the key conclusions drawn from the analysis of the previous chapters.

1. The demand curves for lighting and basic information/entertainment derived from the Yemen Household Energy Survey are downward sloping and highly concave. The shape is consistent with a demand function based on a constant and high level of price elasticity, i.e. a function of the form ln(Q) = A + ln(P) * e. The price elasticity coefficient for lighting is estimated at -0.81 and for entertainment is estimated at -0.92. The implications for the benefits associated with new or improved access to electricity are twofold. First, while the unit value of savings as a result of avoided use of non-electric substitutes may be high, the number of units replaced by access to electricity is small. Hence the amount of consumer's surplus associated with substitution (area A in Figure 1.3) is limited. Second, the amount of consumer's surplus associated with additional demand induced by access to electricity for these two applications is also limited. Because the curve quickly approaches and parallels the x-axis, the area between the curve and the rectangle that represents the amount actually paid for the electricity (area B in Figure 1.3) is very small.

This has significant implications for the analysis of electrification projects. The high price elasticity observed for residential consumers in the Yemen survey, and the consequent low level of consumer surplus, means that the average household willingness to pay for electricity (traditionally used as a measure of the benefit of increased supply) may be closer to the prices actually paid than has generally been assumed. Estimates of average willingness to pay that are significantly higher than electricity tariffs cannot be justified given the evidence of this analysis. Either tariffs will need to be sufficient to justify the investments or other benefits will need to be demonstrated to justify projects where the tariffs are not compensatory.

2. Price is a major determinant of quantity consumed for both lighting and entertainment. As noted above, in single regression models, price accounts for approximately 75 percent of the variations in the quantity of lighting consumed and 71 percent of variations in entertainment consumption. In a multivariate regression model, household size and daily hours of electricity service, income per capita and locality (urban vs rural) are also significant at the 1 percent level.

3. Locality (urban versus rural) has little effect on price elasticity although it has a definite impact on the quantities consumed, doubtless owing to the lower prevailing prices in urban areas. For both lighting and entertainment, price elasticity declines with rising incomes. The estimated income elasticity of demand was 0.12 for lighting and 0.24 for entertainment. However, the wide variation in price, as well as the limited correlation between income and the price faced by consumers, may help to explain the limited impact of income on the quantities consumed.

4. The demand curve for cooking showed virtually no correlation between fuel price and consumption. Even though electricity and LPG are the lowest-prices fuels, they are the least used. Instead, cooking is dominated by kerosene. Ownership and use of other household appliances which are fully dependent on access to electricity is primarily an urban phenomenon.

Because ownership was limited and heavily biased towards urban households, the prices charged for electricity fell within the narrow range of the PEC national grid tariff, as compared with the much broader range of prices observable for lighting and entertainment. The inverted block structure of the tariff further complicated the analysis for appliances such as fans and refrigerators. Consumption by households in the higher consumption deciles for these appliances often reached the range at which second or third block tariffs would apply; hence, the demand curve suggested that consumption increased as prices rose. There was, however, a logical relationship between price and quantity in that average prices paid by urban households are approximately 40 percent lower than those paid by the rural households, and their average consumption is approximately twice as high.

5. The Yemen survey data provides empiric evidence of the shape of the demand curves for lighting and entertainment, as well as the magnitude of the price elasticities. These can provide a guide to analysts who are studying the potential consumer's surplus benefits of new or improved access to electricity. However, while the shapes and elasticities may be transferrable, the prices of electricity and electricity substitutes and the quantities consumed are not. Some basic research needs to be done with respect to the consumption patterns of both electrified and non-electrified households, and of total spending and unit prices paid. This need not be a national survey. A small purpose-built survey focused on the project target area would probably provide sufficient guidance, although of course greater scope and detail would provide greater reliability of the findings.

6. The Yemen Household Energy Survey was originally designed to give a comprehensive picture of the supply and use of household energy, including diesel, kerosene, biomass, LPG, gasoline and fuel oil. In addition to satisfying its original purpose, the survey has provided the detailed data that was needed to carry on this more extensive study of relationships between electricity prices and consumption. Doubtless there is also sufficient data to carry out many more in depth studies into other areas of interest. Insofar as energy – and its interaction with poverty – continues to be a focus of Bank lending, there is a strong argument in favor of additional surveys of this nature, so that a household energy database can be established that provides both time series data sets and also data sets covering a range of socio-economic and geographic groupings.

Annex 1: Residential Electricity Demand Functions: Review of Empirical Evidence

Introduction

This review examines a group of empirically derived econometric functions for residential electricity demand that were published between the mid-1980s and 2009. The review also examines the estimates of the elasticities of residential electricity demand to electricity prices and to household income that are derived from these functions. It covers both short run elasticities and long run elasticities. Such functions are important for deriving forecasts of residential electricity demand that underpin plans for developing power supply capacity, estimates of the benefits from investments in new power supply capacity, and assessments of changes in electricity prices on household consumption of electricity.

The review covers functions presented in peer-reviewed papers to engender confidence in the quality of the reported analysis. This is because estimates of elasticities are generally sensitive to how demand functions are formulated, so that incorrect formulation usually results in inaccurate estimates. The review covers fifteen such papers that were published in reputable professional journals.[34] The review covers countries across the spectrum of economic development, [35] as well as periods of economic conditions that range between stable and unstable and between slow growth and high growth.[36]

The review starts from the premise that residential electricity demand functions and elasticities vary according to the economic and social factors that are specific to a group of residential electricity users during the period under analysis. In other words, the review does not seek a universal value for price elasticity or income elasticity, even in the sense of an *ex-ante* value that might be applied in a model economic environment. Consequently, the review identifies the main factors that have influenced residential electricity demand and the *ex-post* values for these elasticities. This information is useful for formulating demand functions and the *ex-ante* values of their elasticities appropriate to expected economic conditions.

A major limitation to achieving even this limited objective is the inherent imprecision of the statistical techniques used to analyse consumer behaviour. Likewise, demand functions and their elasticities are essentially mathematical formulae used to represent decisions by households about electricity consumption. These decisions in turn are based on household decisions about consumption of the services derived from consumption of electricity such as lighting, entertainment, heating, cooling, etc. The review notes how the techniques of statistical analysis have evolved during the review period to increase the statistical reliability of demand functions.

[34] These papers are listed in Table 1, which is situated in the last section of the review. References for them are listed at the end of this review.

[35] Costa Rica, Dominican Rep., Greece, Gulf Cooperation Council, India (19 states), India (urban), Israel, Kazakhstan, Korea Rep., Korea Rep. – Seoul, Namibia, Paraguay, South Africa, Sri Lanka, Taiwan

[36] These functions model demand for electricity from central power sources supplied through power networks. They do not cover electricity supplied from non-grid sources, including generation facilities owned by electricity consumers to meet their own electricity needs, at much higher costs to consumers than electricity supplied from power networks.

The next section of this review examines the way that residential electricity demand functions were formulated in the studies covered by this review. The following sections examine the specifications of demand models and the values for price and income elasticities derived from these models. The concluding section summarises the main findings of this review.

Formulation of residential electricity demand functions

Electricity demand forecasts have routinely been based on econometrically estimated electricity demand functions and elasticities. Simple prediction techniques, such as trend extrapolation and income-only based forecasts, were unreliable because of disruptions to trends in electricity consumption and pricing caused by macroeconomic disturbances.

The main determinants of residential electricity demand are generally considered to be household income and electricity price. A household income variable captures household living standards. But other factors may also influence this demand because the structure of residential electricity demand varies substantially between countries and over time, and even between regions of a country. These variations reflect differences in household lifestyles due to local factors such as demography, climate, household population, dwelling size, availability of alternative energy forms to electricity for providing energy services, and cultural norms for activities such as cooking. The studies covered by this review included household size – number of occupants and/or total floor space, price of substitute fuels (LPG, kerosene), location - urban versus rural, geographical region, and annual seasonality (summer versus winter) among these variables.

Three major factors are considered to account for the size of electricity price elasticity. First is the number and closeness of substitute fuels, since greater availability of such substitutes should increase electricity price elasticity. Competing fuels were found to be significant explanatory variables for residential electricity demand in five of the studies reviewed for this paper.[37] Second is electricity's share in the overall household budget, since a given percentage change in the electricity price would have a larger budgetary impact in households that spend a larger share of total income or expenditure on electricity. Third is the relative proportion of electricity consumption on goods that are considered by households to be luxuries, rather than necessities, since price elasticity is higher for luxury goods than for necessities. Finally, elapsed time from the price change influences price elasticity, since longer times allow more scope for households to respond to a change in electricity price (Westley (1989)).

Households combine electricity and capital equipment to produce a composite energy commodity such as lighting or heating.[38] The household stock of electric appliances strongly influences residential electricity consumption, and consumers can spend about as much for the initial purchase of major electricity-using appliances as they pay (in present value terms) for the

[37] Costa Rica (Westley (1984b)), Gulf Co-operation Council members (Al-Faris (2002)), Taiwan (Holtedahl and Joutz (2004)), India (Filippini and Pachauri (2004)), and Sri Lanka (Athukorala and Wilson (2009)).

[38] The residential demand for electricity is usually specified using the basic framework of household production theory. Filippini and Pachauri (2004) refer to Filippini (1999) for an application of household production theory to electricity demand analysis.

electricity that these appliances consume.[39] Hence, stock levels and prices of complementary household electric appliances should be factored as explanatory variables into residential electricity demand functions. The general omission of these variables from empirically derived demand formulations, however, is due to lack of reliable and comprehensive data for appliance prices in time series data on electricity consumption (Westley (1989)). This limitation does not apply to studies based cross-surveys of household income and expenditure at specific points in time that include questions designed to obtain this information. Only two of the fifteen studies covered by this review, however, were based on household surveys,[40] and the rest were based on time series data.

Long run elasticities are relevant to demand forecasting, and short run elasticities are relevant to assessing immediate responses to changes in electricity prices. According to the theory of price determination, in the short run consumers keep the same end uses and appliances but modify usage levels of electric appliances. In the long run, consumers can implement a range of responses to a price change, covering change of appliance usage level, change of appliances for the same end uses, switch to another energy source that has become cheaper than electricity for a particular end use, and elimination of end uses by taking out of use some electric appliances. In the empirical literature, short run is often used to mean a short, fixed period of time that is usually one year, and the length of the long run is usually put at about 4 – 7 years from a change in electricity price, income or other variables, meaning that by then consumers will have made all (or nearly all) of the modifications they intend to make (Westley (1989).

Demand model specification

The econometric literature lacks a clear consensus about the functional form that is best suited to estimating residential electricity demand. Following household production theory, most of the studies covered by this review used a single equation for modeling the residential demand for electricity. This specification usually adopted a linear or logarithmic form. The double logarithmic or log-log form offers a convenient functional form for investigating income and price elasticities, since the estimated coefficients amount to elasticities. This form does imply, however, that elasticities are assumed to be constant over the entire sample period, which may be questionable. Filippini and Pachauri (2004) explored a linear form and a semi-log functional form for the estimated equation, but found that the econometric specification for these forms did not appear to provide the best fit to the data.

Holtedahl and Joutz (2004) note that modeling in double log form has pitfalls because of its impact on elasticities and specification of the utility function.[41] Instead of using a partial adjustment model, they use degree of urbanization as a proxy variable to capture economic development characteristics and electricity-using capital stock not explained by income. They found that this variable provides considerable explanatory power to their model both in the short run and in the long run. This finding may be related to the rapid economic growth and urbanization experienced in Taiwan during the period studied by these authors.

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[39] Westley (1989) found this to be the case in Costa Rica for the year 1975. He surmised that the appliance price elasticity should be roughly equal the electricity price elasticity, since the cost of producing electricity-based services is split about evenly between capital and electricity costs.

[40] India (Filippini and Pachauri (2004)) and Seoul-Korea (Yoo et al. (2007)).

[41] Holtedahl and Joutz (2004) refer to Plourde and Ryan (1985) for an exposition about these pitfalls.

Since electric appliance ownership largely determines electricity consumption, the economic conditions prevailing in preceding periods that influence appliance ownership are important determinants of electricity demand. In principle the simplest approach to modelling this consideration is to include explanatory variables for the current and lagged appliance stocks and appliance utilization rate. A second approach is to use actual appliance stock measures. Unfortunately, this sort of survey data is seldom available (Westley (1989)).[42]

A third approach is to use a partial adjustment model, which asserts that in any consumption period consumption habits, the durability of electric appliances, costs of replacing existing appliance stock, and lack of information prevent consumers from rapidly adjusting their appliance stock and hence electricity consumption to their desired level. Among the studies covered by this review, this approach has had limited success in practice because of the lack of available data on household stock of electric appliances.[43]

Data analysis

Most econometrically estimated electricity demand forecasts use either time series data and /or cross section data, and sometimes survey data. Time series data are required for real income, electricity consumption and electricity prices for a sufficiently long period and large sample size and with sufficient variation to avoid the problem of multicollinearity.[44] If these three requirements are not met properly, the resulting estimates of elasticities could be too large or small (or even have the wrong sign). The estimates may also lack robustness, whereby a small change in the demand equation specification (such as the addition or subtraction of a variable) or the use of a few more observations produces dramatic shifts in the estimated parameter values.

Prior to carrying out regression estimations, scatter diagrams may be plotted between the dependent variable and each explanatory variable. Partial correlation coefficients are computed from them to reveal the relative importance of each variable in explaining observed trends in electricity consumption. These coefficients may also be examined to detect the presence of multicollinearity among these variables.[45] The diagrams were used only in the two Indian studies (Bose and Shukla (1999), Filippini and Pachauri (2004)) among the studies covered by this review. This analysis may have been motivated by the presence of power supply shortages that led to rationing of electricity and hence distortions to consumption as a measure of demand.

The simplest and most common method for estimating the coefficients of an electricity demand equation is ordinary least squares (OLS). Unfortunately, OLS suffers from simultaneous

[42] None of the studies reviewed for this paper had access to such data. Studies for electricity demand in the United States have used this type of data (Espey and Espey (2004)).
[43] India (Bose & Shukla (1999)), Israel (Beenstock et al. (1999)), and Gulf Cooperation Countries (Al-Faris (2002)).
[44] The specification of demand models treat the explanatory variables as exogenous to residential electricity demand. Multicollinearity can occur when some or all of the explanatory variables are highly correlated with each other. This phenomenon is common in time series work since aggregate time series variables often share a common growth trend. With many of the explanatory variables moving together, it becomes difficult to disentangle their separate effects on the dependent variable.
[45] In general, correlation coefficients between two regressors that exceed 0.8 to 0.9 indicate that multicollinearity could be a serious problem. Filippini and Pachauri (2004) refer to Judge et al., (1982) for further explanation.

equation bias whenever there is block rate pricing of electricity, but not whenever the tariff is a flat rate. Five of the studies reviewed for this paper analysed residential electricity prices that were structured as block rates.[46] This problem is usually dealt with by using the two stage least squares (2SLS) estimator instead of the OLS estimator, but only one of the reviewed studies (for Costa Rica) used 2SLS.[47] Westley (1989) noted that empirical evidence for US studies indicated that the magnitude of the simultaneous equation bias were sufficiently small in these cases to be a problem of only secondary importance. This view was not extended to the Latin American studies that were reviewed on the grounds that the factors that determine the magnitude of this bias in the presence of block rates normally vary substantially across countries. Instead, the requirement should be to show that simultaneous equation bias is not a serious problem.

Two commonly used measures of electricity price are the average price and the marginal price of electricity. Marginal price is the correct measure from traditional economic theory, but consumers may not bother to find out their marginal prices. Average price is more readily accessible to consumers and may be more likely to form the basis of their consumption decisions by households. Nearly all the studies covered by this review used average electricity price for residential electricity consumption, whether the tariff was a flat rate or a block rate.[48] Only two of the reviewed studies stated that they used marginal tariffs.[49]

A specific survey of households to collect data on household consumption and expenditure on electricity and competing fuels, income and/or total expenditure and on other relevant variables can produce accurate estimates of elasticities. This approach faces, however, two possible problems for deriving reliable estimates of elasticities. One is the lack of sufficient variation in prices of electricity and other fuels from a survey taken at a single point in time. The other is that this type of survey may not pick up dynamic effects such as adjustments to appliance stock that take place over many years. But an advantage of this approach is the possibility of obtaining good data on appliance stock at the time of the survey.

Studies based on cross-sectional data can yield good estimates of long-run elasticities when economic conditions have been stable (including steady changes). Filippini and Pachauri (2004) surmise that estimates of elasticity based on cross-sectional data are conventionally interpreted as long-run values. They contend that the observed difference in electricity consumption reflects adjustments to the stock of electric appliances as well as variations in appliance utilization.

The use of time series with cross-section data greatly increases the number of observations and range of variation of key variables, thus normally eliminating the problem of multicollinearity. Time series data were used with cross-section data in three of the studies.[50]

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[46] Costa Rica (Westley (1884b)), Greece (Hondroyiannis (2004)), Seoul, Korea (Yoo et al. (2007)), Korea Rep. (Sa'ad (2009)) and Sri Lanka (Athukorala & Wilson (2009)).

[47] Westley (1984a, Appendix A) includes a discussion of how this bias arises and how it is remedied by the 2SLS estimator in the context of estimating an electricity demand equation.

[48] Tariffs had flat rates for Dominican Rep. (Westley (1984a)), Israel (Beenstock et al. (1999)), Gulf Cooperation Council members (Al-Faris (2002)), Taiwan (Holtedahl and Joutz (2004)), and Kazakhstan (Atakhanova and Howei (2007)) ; tariff had block rates for Greece (Hondroyiannis (2004)), Seoul-Korea (Yoo et al. (2007)), Korea Rep. (Sa’ad (2009)), and Sri Lanka (Athukorala and Wilson (2009)).

[49] Costa Rica (Westley (1984b)) and Paraguay (Westley (1981)).

[50] Cost Rica (Westley (1984b)), Paraguay (Westley (1981)), and India (Bose and Shukla (1999)).

Recent advances for testing the time-series properties of the variables entering the energy demand function are designed to show whether a stable function exists for residential electricity demand. Tests for sample selection bias in the data have become routine and more complex. Three of the studies covered by this review applied cointegration analysis to modelling residential energy demand.[51] The Engle and Granger (1987) methodology is usually used to estimate energy demand or residential energy demand. One study used the maximum likelihood estimation procedure described in Johansen and Juselius (1990) to look for noncointegration among the explanatory variables (Hondroyiannis (2004)). In five of the studies reviewed for this paper, error-correction models were also applied with various stability tests to investigate the stability of residential electricity demand.[52] The Autoregressive Distributed Lag (ARDL) bounds testing approach (Pesaran and Shin, Y., (1999)) was used by De Vita et al. (2006) because it allows testing for cointegration under uncertainty about whether the regressors are cointegrated. Ziramba (2008) also used an ARDL model.

For estimating the long run function of residential electricity demand, most studies used multi-annual data for time series analysis, data on total household expenditure as a proxy for household income, and annual or monthly data for cross-sectional analysis. Beenstock, Goldin and Nabot (1999) used quarterly data for Israel, Filippini and Pachauri (2004) used seasonal data for India, and Hondroyiannis (2004) used monthly data for Greece. Price and income data were deflated to a common year so as to be expressed in comparable terms.

Price and income elasticities

Table A1 presents the values for own short run elasticities and own long run elasticities for income and electricity price derived in the studies covered by this review. They are arranged in order of study vintage, starting with the earliest study (1981) and ending with the latest (2009). They are also cross-referenced to various study properties, namely other explanatory variables and their cross-elasticities where statistically significant, correlation coefficients where provided, form of electricity pricing, study period, data frequency, type of data, and main estimation technique, as well as the reference for each study.

The values for the elasticities shown in Table A1 have the correct signs, namely negative for price elasticities and positive for income elasticities. They also generally lie within creditable ranges of values, namely between zero and minus one for price elasticity and between zero and plus 1.5 for income elasticity. The values for both long run price elasticity and long run income elasticity appear to be evenly distributed around their average values, since the average value is close to the median value for both of these parameters. This indicates that these average values are not being unduly influenced by outliers, which provides some confidence in their reliability. The same can be said for the average value of short run income elasticity, but not for the average value of the short run price elasticity.[53]

[51] Beenstock et al. (1999); Al-Faris (2002); Hondroyiannis (2004).
[52] Israel (Beenstock et al. (1999)), Gulf Cooperation Countries (Al-Faris (2002)), Taiwan (Holtedahl & Joutz (2004)), Greece (Hondroyiannis (2004)), and Sri lanka (Athukorala & Wilson (2009)).
[53] This difference is confirmed by the much larger value for the standard error (ratio of standard deviation to average value) for short run price elasticity than for the three other elasticities shown in Table 2.

Table A1: Estimates of Income and Price Elasticities of Residential Electricity Demand from the Reviewed Studies

Country	L / S	Price elasticity of electricity	Sig. Level	Income elasticity of electricity	Sig. Level	Cross-price elasticity of alt. fuel	R^2	Other explanatory variables (1)	Electricity price variable	Block rate tariffs?	Study period	Data frequency	Number of observations	Type of data (2)	Main estimation technique (3)	Reference
Paraguay	L	-0.50		0.38		–	–	–	marginal	no	1970-77	annual	59	TS-CS	OLS	Westley (1981), Westley (1989)
Costa Rica	L	-0.50		0.20		0.45 (LPG)		1	marginal	yes	1970-79	annual	454	TS-CS	2SLS	Westley (1984b), Westley (1989)
Dominican Rep.	L	-0.50		0.45		–	–	–	average	no	1960-82	annual	22	TS	2SLS	Westley (1984a), Westley (1989)
India (19 states)	L	-0.65	5%	0.88	5%	–	0.59	–	average	n.r.	1985-93	annual	171	TS-CS	OLS	Bose & Shukla (1999)
Israel	L	-0.53	n.r.	1.00	n.r.	–	0.68	8	average	no	1975-94	quarterly	79	TS	DRM	Beenstock et al. (1999)
	L	-0.58	n.r.	1.09	n.r.		n.r.								ML	
	L	-0.21	n.r.	1.06	n.r.		n.r.								OLS	
Gulf Coop. C.(4)	S	-0.09	5%	0.15	5-10%	–	0.60	1	average	no	1970-97	annual	28	TS	ML	Al-Faris (2002)
	L	-1.68	n.r.	2.22	n.r.	1.06 (LPG)	n.r.									
Taiwan	S	-0.15	n.r.	0.23	n.r.	0.18 (oil)	n.r.	4,7,8,9	average	no	1957-95	annual	39	TS	VAR	Holtedahl & Joutz (2004)
	L	-0.16	n.r.	1.04	n.r.	0.16 (oil)	n.r.									
United States (5)	S	-0.35		0.28												Espey & Espey (2004)
	L	-0.85		0.97												
India (urban) (6)	L	-0.41	1%	0.62	1%	-0.22	0.52	1,2,3,5,6,8	average	no	1993-94	single	c30,000	CS survey	OLS	Filippini & Pachauri (2004)
Greece	L	-0.41	5%	1.56	5%	–	n.r.	8	average	yes	1986-99	monthly	168	TS	ML	Hondroyiannis (2004)
Namibia	L	-0.30	5%	0.59	5%	insignificant	0.97	2,3	average	n.r.	1980-2002	annual	22	TS	ARDL	De Vita et al. (2006)
Seoul (Korea)	L	-0.25	1%	0.06	1%	–	0.83	5,7	average	yes	May-05	single	380	CS survey	OLS	Yoo et al. (2007)
Kazakhstan	S	-0.22	n.r.	0.12	n.r.	–	n.r.	–	average	no	1994-2003	annual	150	TS	GMM	Atakhanova & Howie (2007)
	L	-1.10	n.r.	0.59	n.r.	–	n.r.	–								
South Africa	S	-0.02	n.s.	n.r.	n.r.	–	n.r.	–	average	n.r.	1978-2005	annual	27	TS	ARDL	Ziramba (2008)
	L	-0.04	n.s.	0.31	5%	–	n.r.	–								
	S	-1.00	1%	0.30	5%	–	n.r.	–						TS	OLS	
	L	-0.01	n.s.	0.87	1%	–	n.r.	–								
Korea Rep.	L	-0.27	n.r.	1.33	n.r.	–	0.63	–	average	yes	1973-2007	annual	35	TS	ML	Sa'ad (2009)
Sri Lanka	S	-0.16	5%	0.32	5%	0.10 (kero)	n.r.	1,2	average	yes	1960-2007	annual	48	TS	VAR	Athukorala & Wilson (2009)
	L	-0.62	n.r.	0.79	n.r.	0.14 (kero)	n.r.									

Notes to Table A1

L = long run elasticity; S = short run elasticity; n.r. = not reported; n.s. = not statistically significant at 5% level.

1. Codes for other independent variables: 1 = LPG price; 2 = kerosene price; 3 = diesel price; 4 = oil price; 5 = dwelling size (floor area); 6 = age of household head; 7 = ownership of specific electric appliances; 8 = season/climate; 9 = urbanisation rate
2. TS = time series; TS-CS = time series and cross-section (pooled);
3. OLS = ordinary least squares. 2SLS = two stage least squares; ML = maximum likelihood; DRM = dynamic regression model; regression; GMM = generalised method of moments. VAR = vector autoregressive; PAM = partial adjustment model
4. Average of individual values for the GCC countries:

		Saudi Arabia	UAE	Kuwait	Oman	Bahrain	Qatar	Average
Price elasticity:	S	-0.04	-0.09	-0.08	-0.07	-0.06	-0.18	-0.09
	L	-1.24	-2.43	-1.10	-0.82	-3.39	-1.09	-1.68
Significance Level	S	>5%	5%	5%	5%	5%	5%	5%
Income elasticity:	S	0.05	0.02	0.70	0.02	0.02	0.08	0.15
	L	1.65	2.52	0.33	0.79	5.39	2.65	2.22
Significance Level	S	5%	>10%	10%	5%	10%	5%	–
LPG cross-price elas:	L	1.62	3.39	0.02	0.21	0.84	0.29	1.06
R^2	S	0.58	0.63	0.44	0.88	0.54	0.52	0.60

5. These elasticity values are the mean values for 26 studies of residential demand elasticity, 25 of which were located in the United States.
6. Average of individual values for three Indian seasons:

	winter	summer	monsoon	Average
Price elasticity:	-0.42	-0.29	-0.51	-0.41
Income elasticity:	0.64	0.63	0.60	0.62
LPG cross-price elasticity:	-0.27	0.26	-0.65	-0.22
R^2	0.54	0.52	0.50	0.52

Table A2: Summary of Statistics for Elasticities

Statistic	Price elasticity of electricity		Income elasticity of electricity		Cross-price elasticity of alter. fuel	R^2 for demand functions
	Short run	Long run	Short run	Long run		
average	-0.31	-0.40	0.24	0.75	0.23	0.69
median	-0.16	-0.41	0.27	0.79	0.13	0.63
STD	0.35	0.26	0.08	0.40	0.36	0.15
maximum	-0.02	-0.01	0.32	1.56	1.06	0.97
minimum	-1.00	-1.10	0.12	0.06	-0.22	0.52
No. obser.	5	16	4	17	8	7

Table A2 summarizes the main statistics from Table A1. The table shows that the long run price elasticity of electricity averaged minus 0.40, [54] whilst the long run income elasticity of electricity averaged plus 0.75. The former value accords with expectations that the residential demand for electricity is price inelastic (less than unity). The latter value shows that the residential demand for electricity is also income inelastic, which is contrary to the generally held view that income elasticity of this demand is greater than unity. The values of short run elasticities are found to average minus 0.31 in the case of price elasticity and plus 0.24 in the case of income elasticity, which are substantially lower than the corresponding values for long term elasticities, as expected. The average value of nearly 0.7 for the correlation coefficients of the demand models shows that the models explained most of the trends in residential electricity consumption.

Many of the values derived for the six countries of the Gulf Cooperation Council (Al-Faris (2002)), however, lie well outside the ranges of credible values for elasticities (see note 4 to Table A1) and so lack credibility, even though they were found to be statistically significant. Hence the elasticity values for these countries are excluded from the meta-analysis of the studies reported in Table A2. Two other studies were also excluded from this review altogether because of difficulties in accepting the results.[55] Table A2 also excludes the average values for elasticities derived from the meta analysis of United States studies by Espey and Espey (2004), due to major differences in relevant influences on changes in residential electricity demand between the U.S and the other countries covered by the studies. One notable difference is that household electric appliance stocks were close to their saturation level in the U.S. throughout the periods covered by the analysis, but not for the other countries. This probably accounts for the lower income elasticities found for household electricity demand in the United States than found for the other countries.[56]

[54] This finding superficially corroborates the empirical generalization advanced in the paper Clements, K., (2008), that price demand elasticities in general are scattered around minus one half, and that this value is a reasonable first approximation when nothing is known about the price sensitivity of a good.

[55] These studies were for Mexico (Berndt and Samaniego (1984)) and Lebanon (Nasr , G. E. et al. (2000)). The results of the Mexican study appeared inconclusive for reasons that are not obvious from the published study. The results of the Lebanon study lacked statistical significance because of the short time period covered by the analysis and the disrupted economic conditions during this period (mid to late 1990s).

[56] The likely explanation for this supposition is that the observed increase in electricity consumption over time by U.S. households resulted mainly from more intensive use of the existing appliance stock, and much less from expansion of appliance stock.

The statistical properties of the studies shown in Table A1were examined to reveal any interesting relationships with elasticity values. No trend or significant relationship is discernible for any of the elasticity measures over time by study vintage. Nor is there a significant relationship between pairs of income and price elasticities – such as high values for one elasticity being correlated with high values for the other elasticity. Likewise, no significant relationship appears between pairs of short run and long run elasticities. No other relationships between elasticity values and the statistical properties of the studies appear significant.

Conclusions

The following findings of this review show some important considerations for evaluating the values for price and income elasticities for residential electricity demand.

- First, the low values for income elasticity probably indicates that most electricity consumption is considered to be a basic necessity by household in these countries.
- Second, the low values for price elasticity of electricity demand show that increases in electricity prices would not be a powerful means for restraining electricity consumption by households in these countries. Such increases would effectively amount to a tax on their electricity consumption.
- Third, the low cross-price elasticities for competing fuels to electricity should be interpreted carefully, since they depend largely on the actual availability of these fuels.
- Fourth, a low share of the total household budget that is spent on electricity can explain a low value for income elasticity. A very low electricity price would also account for low cross-price elasticities with competing fuels (as found in the GCC countries). In such cases, the effect of the low budget share may off-set the effect of available alternative fuels.
- Fifth, some studies confirmed that households adjust their electricity consumption relatively slowly in response to a price shock, for example 12% of the total desired reduction in consumption occurred in the first year of a price increase in Sri Lanka (Athukorala & Wilson (2009)).
- Sixth, electricity demand can have pronounced seasonality due to climatic conditions, as found in studies for Israel (Beenstock et al. (1999)) and India urban demand (Filippini and Pachauri (2004) – see note 6 to Table 1). Moreover, Beenstock et al (1999) found that seasonality of demand was stochastic, rather than deterministic, which means that seasonality of demand tends to persist over the years, instead of being a temporary phenomenon.
- Seventh, appliance stock levels are the hidden critical explanatory variable in most residential demand functions. In the one study that attempted to capture this effect through the use of a proxy variable under high growth in household income, namely urbanization in the case of Taiwan (Holtedahl & Joutz (2004)), income elasticity was found to be much higher (plus 1.04 for the long run value) than the average value for the studies covered by this review.

Taken together, these findings show the importance of specifying the functions for residential electricity demand as fully as can be supported by the available data.

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