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Household Consumption of
Electricity: An estimation of the
price and income elasticity for
pre-paid users in South Africa

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This paper explores the electricity consumption of households using pre-paid technology. A cross sectional analysis is used based on a comprehensive set of household information, which not only details household characteristics, expenditure and income; but also the electricity price facing a household. A Heckman two-stage selection model is applied to a log-linear functional form in order to obtain coefficients of demand. Although a wide range of determinants of electricity demand are analysed, particular attention is paid to estimates of income and price elasticity of demand. The income and price elasticity of demand is estimated to be 0.32 and -1.35 respectively. The price elastic demand can be explained by the apparent strong substitutability of electricity with other household fuels. This suggests that any change in the price of electricity is likely to have a large impact on the electricity consumption of pre-paid users. Estimates of price and income elasticity, such as the ones presented in this paper are crucial as they begin to allow policy makers to understand the relationship between price and consumption.

1. INTRODUCTION

An effective power sector is crucial for a country's economy and powers the engine of development. The South African electricity industry is considered by international standards to be relatively efficient¹, providing a reliable source of electricity to the country at a comparatively low price. In fact South African users, in particular industrial users, currently experience some of the lowest electricity prices in the world (Eberhard, 2002). Despite such impressive accolades, the South African electricity sector is not exempt from the heritage of dramatic social inequality left in the wake of apartheid.

Over the last decade, there have been two major developments in the South African electricity industry. Firstly, there has been a determined drive by ESKOM and local municipalities to increase access to electricity. This initiative has targeted previously marginalised households and has seen access of electricity increase roughly from one-third to two-thirds of the population. Secondly, there has been a clear move toward the liberalisation of the electricity industry. Both of these projects however have been hampered by a lack of accurate demand-side information. This is

¹ It should be noted that although the operations of ESKOM are widely considered as efficient the performance of some of the smaller licensed local authorities has been criticised (Eberhard, 2002).

particularly true concerning low-usage households. There is a need for accurate estimates of demand elasticity, with specific regard to changes in price and household income (ESKOM and Department of Minerals and Energy, 2002: 57). Without such information, it is extremely difficult to estimate the viability, and sustainability of these projects. To date no such locally derived price elasticity estimates exist due to the lack of data simultaneously capturing electricity price information as well as detailed household characteristics, expenditure and income patterns.

This paper aims to analyse the determinants of electricity demand for pre-paid domestic customers. The price and income elasticity of these users is of primary concern to policy development. An understanding of these elasticities is essential in ensuring that the social benefits associated with the roll out of the electrification program are not undone through a collapse in demand. This is particularly relevant given the imminent price increases associated with necessary capacity expansion, proposed restructuring of the industry and a move toward a more cost based approach of pricing (Bond, 2002:343 ; Davis, 1995).

In order for this analysis to be possible, household data was amalgamated from a number of different sources. Firstly, the Income and Expenditure Survey (IES)² of 2000 and the Labour Force Survey (LFS) of the same year were merged to obtain household expenditure and income data as well as information regarding a wide range of detailed household characteristics. Secondly, electricity price information was attached to each household falling within the relevant electricity distributor's jurisdiction. This process created a database of information from which, for the first time in South Africa, price elasticity of demand for electricity could be estimated. This paper takes a short-run approach to the modelling of electricity demand. A log-linear functional form is used to estimate the income and price elasticity of demand, as well as to analyse other important determinants of electricity consumption.

The South African government has made it clear that providing widespread access to affordable electricity is a priority since this is crucial for promoting equality and improving the standard of living of South African households. Understanding the determinants of electricity consumption is crucial since the consumption of these households is directly related to the viability of the electrification programme and necessary in order for government to devise an appropriate pricing and subsidy strategy for the electricity industry (Department: Minerals and Energy Republic of South Africa, 2001).

² A full list of acronyms used in this paper can be found in Appendix C.

2. SOUTH AFRICAN ELECTRICITY INDUSTRY

2.1. *Distribution, structure and pricing in SA*

In South Africa ESKOM holds a monopoly in the generation and transmission of electricity, while the distribution is shared between ESKOM and numerous local authorities. In 1991 there were approximately 450 municipalities distributing electricity throughout South Africa. Due to the rationalisation of local government the number of licensed municipalities over the last decade has been reduced to approximately 250.³ All other households not lying in the constituencies of these municipalities are supplied by ESKOM. If a municipality was created in an area where ESKOM already supplied electricity, then it is usual for ESKOM to retain service rights for that area. Some municipalities may also give ESKOM rights to provide electricity within their municipal boundaries (Department: Minerals and Energy Republic of South Africa, 2001). Domestic electricity tariffs vary quite significantly between municipalities. This variation in municipal electricity prices is primarily due to the different sizes of the municipalities and their distance from generation facilities (Davidson and Sparks, 2002: 47). Prices charged by municipalities are on average 47% higher than those charged by ESKOM (Galen, 1998: 18).

The vast majority of municipalities offer both a two-part tariff and a single energy charge per unit of electricity. The two-part tariff consists of a fixed monthly levy and an additional energy charge per unit of electricity. The single unit charge is generally in the form of prepaid technology. Although this menu of tariffs is the norm it is not necessarily true for all municipalities. ESKOM also offers its domestic customers a similar menu of tariff options. Since prepaid tariffs do not include a fixed service fee, the pre-paid energy charges are normally higher per unit of electricity than those of a two-part tariff. However, when only small amounts of electricity are consumed the average unit price for a two-part tariff is generally higher than that of the pre-paid tariff. The reason for this is that a two-part tariff will only be able to spread the fixed fee over a small consumption base. Therefore it is usually cheaper for low-usage households to use the pre-paid option, as opposed to a two-part tariff.

2.2. *National Electrification Program*

Over the last decade there has been a shift in the focus of the South African energy industry from one of national security, which was consistent with the ideology of the apartheid era, to one of social benefit and equity. As early as 1991 ESKOM and various licensed municipalities embarked on a drive to increase access to electricity across the country. Up to that point in time the majority of the black population, and other marginalised households, did not have access to electricity and were forced to use alternate, and normally inferior, household fuels. These fuels included wood,

³ In 2000 there were approximately 380 licensed municipalities due to the rationalisation process, the number of municipalities has been further reduced to the current standing of approximately 250 (NER, 2000).

candles, paraffin and batteries (Department: Minerals and Energy Republic of South Africa, 2001).

In 1994 the Government of National Unity endorsed this initiative to increase access to electricity as the National Electrification Program. The first phase of the electrification program ran from 1994 to 1999 and saw access to electricity increase from one third to roughly two thirds of the households across the country (Eberhard, 2002). By 2000 approximately 46% of rural households had access to electricity while the figure for urban households was 74% (NER, 2000).

Both ESKOM and local authorities have met the connection targets developed at the onset of the National Electrification Program. ESKOM has been responsible for the vast majority of new household connections, claiming to have connected more than 2 million households since 1994 at a cost of over 8 billion Rand, making it one of the largest electrification programs in the world (Bond, 2002:341). In this regard, the National Electrification Program thus far has been a resounding success. It should however be noted that the cost of these connections was drastically underestimated and many houses were connected with a load limit⁴ in order to curb costs (Department: Minerals and Energy Republic of South Africa, 2001 ; Davis , 1996). A load limit simply restricts the level of electric current, which is available to a household.

In the roll out of the National Electrification Program the use of prepaid meters has been preferred. It was found during the initial phase of the electrification program that pre-paid technology drastically reduced the amount of non-payment for electricity (Department: Minerals and Energy Republic of South Africa, 2001). As previously discussed, it is also generally cheaper for low-usage households to face a single energy charge per unit of electricity as opposed to a two-part tariff. The second phase of the electrification program is under way. In addition, the Government has confirmed its commitment to promote social equity and benefit through recent promises of free life-line electricity (with load limits) to the poor (Eberhard, 2000). The best options for the roll out of this life-line electricity are still under investigation.

2.3. *Domestic Consumption of Electricity*

When analysing the South African electricity industry it is not sufficient to exclusively examine the supply of electricity, although this has been a problematic area characterised by immense inequality in the past. The sustainability of the electrification program is directly linked to the domestic demand for electricity. ESKOM has recently begun the electrification of more costly areas of the country. The financial viability of this process has long been questioned since the cost of a rural connection can be double that of an urban connection (Davis, 1995). Furthermore, it has been documented that the electricity consumption of these newly

⁴ Various load limits have been used including 60Amp, 40Amp, 20Amp and 2.5Amp. Most connections in rural areas have been made with a standard load limit of 20Amp (Department: Minerals and Energy Republic of South Africa, 2001).

connected, usually low-income households, is far less than anticipated (Department: Minerals and Energy Republic of South Africa, 2001). Research at eight representative electrification sites⁵ across the country revealed that, on average, the newly connected households only consumed 38% of the expected monthly household consumption of 350kW/H (Department: Minerals and Energy Republic of South Africa, 2001). Due to the unexpectedly low consumption of newly connected households the electrification process is not financially viable for electricity distributors in the absence of large subsidies (Department: Minerals and Energy Republic of South Africa, 2001). The low consumption levels result in the failure of electricity distributors to recover the connection costs associated with the electrification program. Therefore, the South African government has been considering ways of ensuring the continuation of the electrification program through transparent funding (Eberhard, 2000).

This low consumption of electricity can be put in context by considering the energy consumption patterns of South African households. It has been repeatedly reported in South African energy research literature that even households who have access to electricity use multiple fuels to meet their energy needs (Cowan, 2003: 18 ; Methlwana, 1999, ; Leitner and Van der Byl, 1997). This is true, primarily, of low-income households. Bond (2002: 323) suggests that in general households prefer electricity since it is safer, faster, healthier and more convenient. Yet, due primarily to cost factors, the use of electricity for particular purposes such as heating and cooking may be substituted for alternate fuels (Methlwana, 1999). In South Africa the most basic need for electricity is lighting, since this uses a relatively small amount of electricity compared to cooking or heating (Methlwana, 1999).

In analysing the electricity consumption patterns of South African households one can distinguish between the three main domestic uses of electricity: lighting, heating and cooking (although entertainment may be a common use there is very little information regarding this use). This consumption pattern of electricity by South African households is seen in Table 1. This table considers all the households in South Africa in 2000 that claim to use electricity as an important fuel.⁶ These households are broken down into three groups: urban, rural and total. Approximately a fifth of all electricity users only use electricity for lighting purposes, while 66.3% use electricity for all three major purposes.

⁵ This sample of sites was taken across eight provinces and had combination of Eskom and municipal providers. These sites were Mmabatho (North West Province), Venderburg (Northern Province), Khayelitsha (Western Cape), Kimberly (Northern Cape), Orange Farm (Gauteng), TED (Mpumalanga) and Kwa Noobuhle (Eastern Cape).

⁶ Calculations presented in this section represent households that claim electricity to be the most important source of fuel for any of the three uses and not necessarily all electrified households.

Category of electricity user	Urban Households	Rural Households	Total Households
Use electricity as the main source of energy for lighting and cooking and heating	77.6%	34.2%	66.3%
Use electricity as the main source of energy for lighting and heating only	2.6%	5.4%	3.3%
Use electricity as the main source of energy for lighting and cooking only	6.9%	12.1%	8.3%
Use electricity as the main source of energy for cooking/heating only	0.1%	0.4%	0.2%
Use electricity as the main source of energy for lighting only	12.7%	48.0%	21.9%
Sum	100%	100%	100%

Table 1 Electricity consumption patterns of South African households

Source: Labour Force Survey 2000, September- General data (Authors calculations)

Of particular interest in Table 1 is the consumption pattern of rural households. As one would expect the use of multiple fuels by households is particularly common in these areas. Almost half of the households in the rural areas that use electricity only use it for lighting purposes. This energy mix is largely due to the fact that many of the rural households cannot afford the large amounts of electricity needed for cooking and heating, while alternative sources of fuels, such as wood, are often easily accessible at a low cost (Cowan, 2003:18). Low-income households in South Africa, who use multiple fuels, generally only use electricity extensively when disposable income is available (Methlwana, 1999). In urban areas this pattern of mixed household fuels is also found to exist, but not to such an extent with 12.7% of the households that use electricity only using it for lighting. It should be noted that the substitutability of electricity might not exclusively explain the energy mix of many households. It has been suggested that a lack of electrical appliances for heating and cooking may also be a factor in determining the mix of fuels observed in many South African households (Holtz, 1995).

Thus it appears that a significant portion of electrified households use alternative fuels for heating and lighting purposes. These results support a substantial degree of substitutability between electricity and alternate fuels as suggested by a significant volume of South African energy research (Methlwana, 1999 ; Cowan 2003: 18 ; Holtz, 1995 ; Leitner and Van der Byl, 1997). The mixing of electricity and alternate fuels by households is not a new phenomenon, nor does it appear to be purely a transitional phase in which users switch from alternative fuels to electricity. It has been reported that although there has been a slight increase in the percentage of households using electricity as the most important source of lighting between 1995 and 2000, there has been little change in the proportion of households using electricity for cooking and heating (Statistics South Africa, 2002). In fact the percentage of households using primarily paraffin for cooking has risen by 8% over this period (Statistics South Africa, 2002). These results are somewhat surprising given that access to electricity has increased by roughly 30% since 1994 (Department: Minerals and Energy Republic of South Africa, 2001).

These consumption patterns and the apparent substitutability of electricity imply a high price elasticity of demand. However to date there has been no such locally derived estimate on a national scale (ESKOM and Department of Minerals and Energy, 2002: 57). Although it is true that ESKOM and the National Electricity Regulator (NER) are likely to have a good feel for the response of domestic electricity demand to changes in income and price, little or no quantitative work has been done in this regard. The reason for this exclusion of quantitative analysis is primarily lack of detailed national household data, which includes information on electricity prices.

In retrospect the roll out of the electrification program was characterised by a lack of information with regard to aspects vital for the viability of such a program. Not only was there extensive underestimation of connection costs on the supply side, but on the demand side consumption of these newly connected household was grossly overestimated. The over-estimation of newly connected households' consumption of electricity highlights the need for a better understanding of the determinants of domestic electricity consumption.

2.4. ***Proposed restructuring of the South African Electricity Industry***

The electricity industry is set to be further restructured by Government in roughly three steps. The first step involves the amalgamation of the numerous municipal distributors into six Regional Electricity Distributors (REDs). Secondly, competition to ESKOM in the generation sector is to be introduced. Finally, it has been proposed that competition in the distribution sector be introduced some time in the future. In reality the proposed transformation has been slow, which is partly due to a lack of accurate quantitative research with regard to crucial aspects of the industry (Galen, 1998: 2).

Electricity prices are likely to rise in the near future since there is a compelling need to increase electricity capacity within the next few years. It is widely accepted that this need to invest in capacity is the major driving force behind the deregulation of the electricity industry (Eberhard, 2002 ; Galen, 1998: 19). As the electricity distribution industry embarks on its course of liberalisation, the NER has emphasised its desire for a more cost-based approach to pricing of electricity. It has also been argued that this deregulation is expected to have the impact of further increased prices for domestic users as the extensive cross subsidisation by industrial users, currently in place, will no longer be available (Bond, 2002:343 ; Davis, 1995).⁷ Doubts concerning the financial viability of the proposed restructuring process also seem to advocate that electricity price increases are likely in the near future. Preliminary research suggests that at least two of the proposed REDs will not be financially viable without large price increases or additional funding. It is estimated that a 16% increase in domestic electricity prices, or a general electricity price increase of 4% is needed to ensure viability of all the REDs (Davis, 1996).

⁷ This argument would not necessarily hold if the REDs are permitted to sufficiently tax any sale of electricity within their jurisdiction.

There is very little information with regard to the impact of the inevitable price increases on consumer demand since ESKOM and other major stakeholders do not have reliable quantitative estimates of price elasticity (ESKOM and Department of Minerals and Energy, 2002: 57). In the absence of such information there is a possibility that the demand for domestic electricity, primarily of low-usage households, will collapse given the upward pressure on electricity prices. Such a collapse would undo much of the progress made by the electrification program in terms of social benefit associated with increased access to electricity. Although this paper makes no attempt to assess the possible implications of commercialising the electricity distribution industry in relation to electricity demand, it does take a first step toward making such research possible by providing quantitative estimates of price and income elasticities.

3. **REVIEW OF ELECTRICITY DEMAND LITERATURE**

There is a vast range of international literature analysing demand for electricity. By far the majority of these studies focus on electricity demand in first-world countries, with very little research focusing on developing countries (Tiwari, 2000). Two important exceptions have been the work done by Berndt and Samaniego (1984) in Mexico and Tiwari (2000) in Bombay.

Studies of electricity demand vary widely in their modelling approach, type of data used and the econometric methodology employed. The reason for this variation is found in the fact that characteristics of a national electricity industry are often unique to that specific country. The non-availability of data may also limit the approach taken. Therefore, researchers are forced to adapt research methodology to meet the challenges posed by that particular environment. Times-series, cross sectional as well as panel data has been used to analyse demand for electricity. Studies that use time-series data generally take on a macro approach while the use of cross-sectional data allows for a more micro approach. Despite its popularity and ability to easily identify long run relationships, time series data generally requires a high level of aggregation, which could result in important information being lost (Bjorner, 2001). Panel data is able to combine dynamics of time series data and the richness of cross-sectional data. However, access to accurate panel data on household energy choices is often not readily available, as is the case in South Africa. Much of the modelling techniques and econometric approaches used in international literature are not directly relevant to the South African situation given the structure of electricity tariffs and data available. This section aims to provide an overview of the literature on the demand for electricity, summarising the different approaches, and important results that were obtained.

3.1. *Determinants*

The large body of literature concerning electricity demand tends to be in agreement on the major determinants of household electricity consumption. Only slight deviations from these common determinants are offered by individual analysis. The most common determinants reported in literature are household income, price of electricity, stock of electrical appliances and household size (Halvarsen and Larsen, 2001 ; Tiwari, 2000 ; Branch, 1993 ; Filippini, 1995).

In line with fundamental economic theory Bentzen (1992) suggested that the price of alternative fuels also partly determines the extent to which a household consumes electricity. This determinant is only applicable in countries where alternative fuels can be seen as realistic substitutes for electricity. Furthermore cross sectional data concerning this determinant is not widely available.

In countries where households readily have access to heating facilities the use of these heating devices is a major determinant of electricity (Filippini, 1995). Various proxies to estimate the extent to which a household will use electricity for heating purposes are common in literature (Halvarsen and Larsen, 2001 ; Filippini, 1995 ; Mountain, 1993 ; Branch, 1993). A household's physical characteristics have also been shown to be important determinants of electricity consumption. These include type of housing structure (Tiwari, 2000 ; Branch, 1993), number of rooms in household (Tiwari, 2000) and date of household construction (Halvarsen and Larsen, 2001 ; Tiwari, 2000). It has been found that the smaller and older the household, the less electricity the household is likely to consume. The culture of the household and age of the household head have also been reported as important determinants for electricity demand (Tiwari, 2000).

Berndt and Samaniego (1984) point out that electricity demand in developing countries appears to be highly elastic relative to developed countries. They suggest that the reason for this is the impact of electrification programs which are common to many developing countries, and that newly connected households may display very different consumption characteristics compared to those households with established connections (Berndt and Samaniego, 1984).

Although no attempt has been formally made to explicitly model electricity demand in South Africa there is extensive literature on household's energy choice, which highlights some possible determinants peculiar to South Africa. Since a large proportion of electrified households in South Africa use pre-paid technology, it has been suggested that a household's proximity to outlets where pre-paid tokens can be bought affects the electricity consumption choices of these households (Department: Minerals and Energy Republic of South Africa, 2001). It has also been suggested that the gender of the household head may have an indirect effect on the household's electricity consumption through the purchase of electrical appliances. This link is suspected since a female head is more likely to purchase electrical appliances for cooking, while a male head is more likely to purchase electrical appliances for

entertainment purposes (Methlwana, 1999). Since cooking generally requires the use of more electricity than does entertainment it is likely that households with a female head will consume relatively more electricity.

3.2. **Modelling**

It is generally accepted that the demand for electricity depends on the demand for the services which electrical appliances provide. These services include cooking, heating, lighting, entertainment as well as general household upkeep. Thus in the long run electricity demand can be viewed as being derived to some extent from the demand for electrical appliances (Branch, 1993). In the short run the demand for electricity is determined by the extent to which the stock of electrical appliances is used. In this regard energy consumption could be seen as a habit of lifestyle and of social status (Hackett, 1991).

The actual modelling of household electricity demand in the literature takes the form of two foremost approaches. Some models, both macro and micro in nature, focus on a predetermined stock of electrical appliances. Although such analysis makes no attempt to model the dynamics of demand for electrical appliances over time it does provide a short run analysis of electricity demand, taking the stock of household electrical appliances as given (Halvorsen and Larsen, 2001). Such a model is very popular in literature due to its simplicity. Tiwari (2000), Hsing, (1994) and Branch (1993) carry out useful analysis based on such a model.

A more thorough and in depth approach is the use of a two stage model. The dynamic properties of such an approach take account of the modelling of the demand for electrical appliances from which the demand for electricity is derived (Halvorsen and Larsen, 2001). Such a model is able to capture long run effects as it allows the stock of electrical appliances to vary over time. This approach is becoming more popular as variations of the two-stage modelling are applied. Examples of this approach can be seen in the work done by Baker, Blundell and Micklewright (1987); Wilder et al (1990) as well as Halvorsen and Larsen (2001).

3.3 **Functional form and econometric methods used**

The functional form and econometric method used in literature largely depends on the theoretical modelling, availability of data and the structure of the electricity industry being researched. In particular, electricity tariffs across the world are often not simple marginal charges but could be a multi-part tariff, a rising or declining block scheme, time-of-use (TOU) tariffs, or a combination thereof. Therefore, although literature agrees that price is an important determining factor of electricity demand there is no universal consensus on how it should best be modelled. Given these complications electricity demand analysis can be challenging, and in particular, estimates of price elasticity of demand can be very difficult to calculate (Hirshberg, 1991).

Use of time series data generally requires some variant of co-integration or error correction modelling using single equations or systems of demand equations (Bakirtas et al, 2000 ; Cheung and Thomson, 2001, Bentzen, 1992). When using cross-sectional data a number of analytical methods have been used. Some analyses has used a system of equations with appropriate restrictions (Tiwari, 2000). This is especially common for analysis in literature which takes a two-stage modelling approach to the demand for electricity (Baker, Blundell and Micklewright, 1987 ; Wilder et al, 1990 ; Halvorsen and Larsen, 2001). In order to estimate price and income elasticities numerous econometric techniques have been used. These include the Almost Ideal Demand System (AIDS) (Filippini , 1995 b); the trans-log and generalised logit model (Rothman, Hong and Mount, 1994) and the log-linear application of ordinary, weighted or generalised least squares (Tiwari, 2000 ; Filippini, 1995 ; Wilder and Willenborg, 1975 and Branch, 1993).

The most common specification of household energy demand is a single equation applied in log-linear form. Filippini (1995), Tiwari (2000) and Branch (1993) are responsible for some of the most important electricity demand analysis using this specification. Although such a functional form cannot be regarded as flexible, it does have numerous advantages. These advantages include ease of elasticity estimation as well as other desirable properties such as drastically reducing the likelihood of heteroscedasticity occurring in the data, as well as reducing the influence of extreme observations on parameter estimates (Tiwari, 2000). A variety of more flexible functional forms have also been used to model electricity demand, in both a single demand equation as well as a system of demand equations. The use of a system of demand equations, and more flexible functional specifications is primarily true of attempts to model the more complicated pricing structures.⁸

Table 2 summarises some of the most important literature with regard to electricity demand and highlights the important characteristics of the research done and their elasticity estimates. As can be seen in Table 2 estimates of price and income elasticity vary quite substantially across studies. Short run estimates of price elasticity range from -0.2 to -1.33 , while the short run estimates of income elasticity vary between 0.16 and 1.50 . As expected the long run estimates of income and price elasticity are generally more elastic than the short run counterparts since they also take into account the indirect affects of changes in income and price on electricity demand. Long run estimates of price elasticity range from -0.71 to -2.3 , while the long run estimates of income elasticity vary between 0.34 and 1.10 . These estimates are clearly heavily dependant on, and specific to, the area in which the study was conducted.

⁸ For a detailed discussion regarding the use of generalised leontief and other members of the generalised Box-Cox family of cost functions see Tishler and Lipovetsky (1997) as well as Nan and Murry (1992).

RESEARCH TEAM (DATE)	DATA TYPE	AREA	METHOD	ELASTICITY TYPE	INCOME ELASTICITY	PRICE ELASTICITY
Filippini (1995)	Time-series	Switzerland	log-linear OLS and error component model	Short Run Long Run	none	-0.60 (peak) -0.79 (off peak) -0.71 (peak) -1.92 (off peak)
Wilder et al (1975)	Household	Los Angeles	Weighted OLS	Short Run Long Run	0.16 0.34	-1.00 -1.31
Branch (1993)	Panel Data	U.S.	Generalised Least Squares	Short Run	0.23	-0.20
Twari (2000)	Household	Bombay	Log-linear OLS	Short Run	0.34	-0.70
Cheung and Thomson (2001)	Time series	China	Co-integration and error correction	Long Run	1.10	-1.30
Donatos and Mergos (1991)	Time series	Greece	Ridge regression	Short Run	1.50	-0.58
Wilder et al (1990)	Panel Data	US	2 stage model	Short Run	0.30	none
Filipini (1995 b)	Panel Data	Switzerland	AIDS model	Long Run	none	-1.29 (peak) -2.30 (off peak)
Wilson (1971)	Household	US	System of demand equations	Short run	0.46	-1.33
Berndt and Samaniego (1984)	Time series	Mexico	Log-Linear OLS and logistics model	Short run Long Run	0.32 0.75	-0.35 -0.81

Table 2 Estimates of price and income elasticity presented in literature

4. RESEARCH METHODOLOGY

4.1. Model formulation

This paper only analyses the electricity consumption of pre-paid users, as opposed to households which face a two-part electricity tariff, or some variant thereof. The reasons discussed below explain this choice and outline the approach taken.

It is assumed by ESKOM and the NER that low-usage households fall into the category of prepaid users. This assumption is based on the notion that a prepaid tariff is the cheapest option for these households given the absence of a fixed monthly charge. Research concerning these low-usage households is of primary interest for policy makers, especially since the consumption of these households has been so grossly overestimated in the past. In addition, since the National Electrification Program involves the roll out of prepaid electricity, research concerning households using this technology is crucial for the central planning of the program.

Furthermore, restrictions in price data make accurate analysis of consumption by households facing a two-part tariff impossible. Only the average per unit electricity prices for two-part tariff users across municipalities are readily available from the NER. This average price is calculated at 800KW/H. Since these households face a two-part tariff this price does not represent the marginal unit cost, nor necessarily the

true average unit cost of electricity consumption faced by the household. Use of this price data would overestimate the average unit price facing households consuming more than 800KW/H, and underestimate the average unit price faced by households consuming less than 800KW/H. Therefore any analysis of high-usage households using this estimate of the electricity price would not be accurate⁹. The electricity consumers analysed in this paper face only a single energy charge, therefore the average price of a unit of electricity is identical to the marginal price.

An important aspect of modelling electricity demand in South Africa is to distinguish between those households which do not have access to electricity and those households which do. This is crucial since the marginal electricity consumption of the non-electrified households is clearly not determined directly by the price of electricity, nor indeed any other possible determinant described in this paper. However, it is likely that some of the determinants of electricity consumption also affect the probability of a household having access to electricity. It is therefore plausible that households which do have access to electricity are systematically different from households which are not electrified. Simply analysing those households which are electrified may lead to inaccurate results due to a sample selection bias (Breen, 1996 : 37). Thus, as Berndt and Samaniego (1984) point out, to obtain unbiased estimates of electricity demand it is crucial to take into account the probability of a household having access to electricity. This necessitates electricity demand being modelled conditional on the household having access to electricity. To adequately analyse such a conditional demand some variant of a two-stage selection model is required. In the first stage, known as the selection stage, determinants of household electrification should be identified and quantified. In the second stage the electricity demand of electrified households should be modelled, taking into account the results of the selection stage. Only by understanding the determinants by which households are electrified is it possible to correct for possible sample selection bias in demand estimates.

4.2. **Selection Stage**

A household's access to electricity is not likely to be completely exogenous and is modelled in this paper as a function of electricity price (P_i), income (Y_i) and various household characteristics (HC_i). The selection stage is expressed in equation (1).

$$\text{Electrification} = f(Y_i, P_i, HC_i) \quad (1)$$

⁹ An analysis including both pre-paid and two-part tariff users was attempted, however due to inaccurate price data the elasticities reported were well over the value of 2 and thus implausible.

In the selection stage a dummy variable for electrification¹⁰ is used as the dependant variable. The various household characteristics identified as possible determinants of electrification are: the existence of water services and street lights, whether or not the household has a fixed telephone line, number of rooms, structure of dwelling, type of residential area, number of people in living in the household and the province of residence.

The price of electricity could partly determine access to electricity as electrification might be more viable for municipalities charging a higher price.¹¹ Household income is identified as a possible determinant of electrification since those households with a higher income are more likely to be able to pay connection costs. Historically the rollout of the electrification program has not focused on the electrification of rural areas since these areas are more costly to connect. Since electrification is more costly in the rural areas, and given the statistics on electrification in South Africa, it is clear that the area of residence affects the probability that a household will have access to electricity. The inclusion of the dummy variable which indicates presence of streetlights is used as a proxy for whether or not any form of electrification exists in the area of the dwelling. Households, which live in an area where some form of electricity is used, are more likely to be connected.

By a similar line of thought, households which are provided with other services such as a telephone line and water supply are also more likely to be connected to electricity than those who are not supplied with these services. The number of people in a household and the number of rooms in a dwelling are suggested as possible determinants of electrification since as the magnitude of these variables increases so too does the need for electricity. In addition, a larger dwelling could be associated with a higher social status, and thus a greater probability of electrification. The structure of the household is also likely to have an affect on the probability of being electrified since more modern houses with facilities such as running water and flushing toilets are more likely to be constructed with an electricity connection in place. The province each household belongs to could also partly determine the probability of electrification as this may be linked to the varying progress of the National Electrification Program between the provinces.

1.3. *Demand conditional on electrification*

In this paper the use of cross sectional data concerning South African households allows one to obtain an estimate of short run elasticity of demand. In line with international literature it is accepted that in the long run the demand for electricity is derived from the demand for electrical appliances, and the services these appliances provide (Branch, 1993). Thus it is clear that the stock of, and demand for, household electrical appliances is a critical determinant of electricity demand. The intensity to

¹⁰ This dummy variable is more fully described in Section 5 of this paper.

¹¹ The higher electricity prices may enable municipalities to sufficiently recover connection costs so as to render these new connections as viable.

which these household appliances are used in the short run depends on household income, price of electricity, stock of electrical appliances and household characteristics (Branch, 1993). For the purpose of analysing short run elasticity of demand it is assumed that the household prior to, and independently of, the decision to consume electricity decides on the stock of household electrical appliances. The decision of households to purchase electrical appliances is not modelled in this paper.¹² Thus, in this paper the stock of electrical appliances for each household is assumed to be fixed. This treatment of electrical appliances is common in international literature analysing the short run demand for electricity (Branch, 1993 ; Wilder and Willenborg, 1975 ; Tiwari, 2000). This paper does not take a multi-stage modelling approach of appliance ownership primarily due to lack of accurate data.

The model of electricity consumption presented here, which closely follows the work of Tawari (2000) and Anderson (1973), is conditional on the household's access to electricity and can be set out as follows. A household aims to maximize utility (U_i), which is a function of electricity consumption (E_i) and the consumption of other goods (G_i).

$$U_i(E_i, G_i) \tag{2}$$

The household is constrained by its income and existing stock of electrical appliances. Thus, electricity demand is found by maximizing household utility subject to these constraints. Demand for electricity is a function of income (Y_i), price (P_i), stock of electrical appliances (APP_i) and household characteristics (HC_i).

$$E_i = f(Y_i, P_i, APP_i, HC_i) \tag{3}$$

In this paper the quantity of electricity consumed by each household is not directly known, instead monthly household expenditure on electricity ($ELEC_i$) is used as the dependant variable. Electricity expenditure is simply the unit cost of electricity (P_i) multiplied by the quantity of electricity consumed (E_i). Therefore the relationship in equation (3) becomes:

$$ELEC_i = P_i \cdot E_i = f(Y_i, P_i, APP_i, HC_i) \tag{4}$$

¹² It should be noted that a load limit on a household may in a long-run model effect electricity demand since it will partly determine the stock of appliances purchased. In a short run model this is less of a concern as it assumes a household's stock of appliances to be given.

As shown in equation (4) this paper models electricity consumption as a function of income, price, stock of electrical appliances and household characteristics. Household characteristics that are included as possible determinants of electricity consumption are as follows: household size, the number of rooms in the dwelling, dwelling structure, type of residential area and the province of residency.

An index to capture the impact of a household's stock of electrical appliances on the household's demand for electricity is used in this paper. This index is based on the use of five important electrical appliances, weighted by the relevant average power requirements of each appliance. The five electrical appliances used to make up the index are: *television, lights, radio, hotplate/microwave/stove and heater*. This approach of creating an appliance index is also taken by Tiwari (2000). This index is weighted by the average power usage of the individual appliances so as to more accurately control for the effect that the stock of appliances has on electricity consumption. The details of this index can be found in Appendix B. The inclusion of an electrical appliances index allows one to test the proposition that electricity usage is related to the stock of electrical appliances in the possession of the household.

The number of people living in the household is also included as a possible determinate of electricity expenditure since it can be rationally expected that the more people in the household, the greater the household's demand for electricity will be. It is also expected that the more rooms a dwelling has, the greater the demand for electricity given the more extensive need for household lighting and heating. This relationship was found to hold true in the work of Branch (1993), Tiwari (2000) and Filippini (1995).

Dummy variables denoting dwelling structure, type of area and the province of residence are included in our model to control for these particular household characteristics. The determinant of area type is expected to isolate differences in consumption habits between urban and rural households. The dummy variable for dwelling structure depicts whether or not a household has running water or a flushing toilet within their dwelling. This variable is a simple proxy for whether or not the dwelling structure is modern and conducive to use of electrical appliances. If such plumbing exists in a dwelling it is also likely that the structure of the dwelling is amendable to the easy use of electrical appliances. An alternative to this proxy could be a more detailed and complicated classification of household structure and types of building materials used. Such a classification is however deemed to be unnecessary for the purposes of this paper. The inclusion of dwelling structure as a possible determinant of domestic electricity demand follows the work of Branch (1993) and Tiwari (2000). The set of dummy variables denoting the province in which the dwelling is situated is expected to isolate the effect of varying consumption patterns between the provinces in South Africa. This difference between the consumption patterns of electrified households in different provinces can be expected given the variation across provinces in cultures, weather patterns, as well as the availability and price of alternative fuels (Methlwana, 1999).

The explanatory variables of most interest to the focus of this paper are the price of prepaid electricity for domestic users and the household income. Since the prepaid tariff is a single energy charge, this variable reflects both the marginal and average price facing domestic prepaid users. Given the apparent substitutability of domestic fuels in South Africa it is expected that both the price of electricity and the household's income will have a large impact on the consumption of household electricity.

A few possible determinants, which were suggested by literature, were excluded from the model presented in this paper. Although Mountain (1993) and Branch (1993) suggested that a possible determinant of electricity demand is the number of days which heating is needed within a dwelling, no suitable proxy is available in South Africa. It is however expected that the provincial dummy variable will partly pick this effect up through the variation in weather patterns across the provinces.

Unfortunately no data on the prices of alternate fuels to electricity is available and thus the model can not be used to confirm the substitutability between electricity and other fuels by the conventional analysis of cross-price elasticities. Neither is a reliable proxy available to take into account whether a household's proximity to a shopping centre, where pre-paid tokens could be brought, is an important determinant of electricity consumption.¹³ Although this determinant suggested by Methlwana (1999), is not explicitly modelled it is expected that the urban/rural dummy variable will partly capture this effect.

Finally, variables depicting the gender and age of the household head were excluded. These were excluded on the grounds that Tiwari (2000) and Branch (1993) only suggest these as important due to their *indirect* effect on electricity consumption through the purchase of electrical appliances. Therefore including these variables in a short run model as presented here would be inappropriate.

4.4. **Functional Form**

The price and income elasticity of demand for electricity can be estimated from the model presented in this paper fairly simply using a single equation log-linear functional form. This functional form is commonly used in literature (Nan and Murry, 1992; Tiwari, 2000; Filippini, 1995). Such a functional form is appealing in its simplicity and allows for the easy identification of income and price elasticity; even if the dependant variable is electricity expenditure as opposed to actual electricity consumption. This paper uses such a functional form for the modelling of electricity demand, conditional on the household having access to electricity. In equations (5) to (9) this is shown formally for a simple log-linear model of electricity consumption (E) with just two explanatory variables of income (Y) and price (P).

¹³ Although a proxy is available for a household's distance to a shopping centre, this proxy was deemed as unreliable for the purposes of this paper as there is no guarantee that prepaid token would be available from these shopping centres, which is a problem particularly associated with rural areas.

$$\ln E = \beta_y \ln Y + \beta_p \ln P \quad (5)$$

$$\text{where } \beta_y = \frac{d \ln E}{d \ln Y} = \frac{dE}{dY} \cdot \frac{Y}{E} = \text{Income Elasticity of Demand}$$

$$\text{and } \beta_p = \frac{d \ln E}{d \ln P} = \frac{dE}{dP} \cdot \frac{P}{E} = \text{Price Elasticity of Demand}$$

Therefore it can be seen in a log-linear model, such as in equation (5), that the estimated coefficients of income and price represent the income and price elasticity of demand (Wilder and Willenborg 1975). Unlike equation (5) this paper does not use actual electricity consumption as the dependant variable since no such data is currently available in South Africa. Instead monthly expenditure on electricity (ELEC) is used. The calculation of the income and price elasticity with this adjustment is formally shown in equations (6) to (9).

$$\ln \text{ELEC} = \ln(E \cdot P) = \alpha_y \ln Y + \alpha_p \ln P \quad (6)$$

$$\ln E = \alpha_y \ln Y + (\alpha_p - 1) \ln P \quad (7)$$

From comparison of equations (7) and (5) it can be seen that

$$\alpha_y = \beta_y = \text{Income Elasticity of Demand} \quad (8)$$

$$\text{and } \alpha_p - 1 = \beta_p = \text{Price Elasticity of Demand} \quad (9)$$

As discussed earlier in Section 3.3 of this paper, the use of a log-linear model has the desirable property of drastically reducing the likelihood of heteroscedasticity occurring in the data as well as reducing the influence of extreme observations on parameter estimates (Tiwari, 2000). In the absence of using a double-log model the problem of heteroscedasticity is very likely to have been found in the sample used in this paper due to the large variation occurring in household income.

In order to model electricity demand, this paper employs a Heckman selection model using a Maximum Likelihood estimator. Such an approach is recommended by Breen

(1996:42) as it firstly takes into account the probability of each household being electrified through the use of a probit, and then estimates the log-linear demand function conditional on being electrified. This ensures that the demand coefficients are corrected for any sample selection bias that might occur between electrified and non-electrified households.

5. DESCRIPTION OF DATA AND VARIABLES USED

5.1. *Data*

The data used in this paper, with the exception of the electricity tariffs, is a household data set which combines the September 2000 Labour Force Survey (LFS) and the October 2000 Income and Expenditure Survey (IES). Both the IES 2000 and the LFS 2000 are comprehensive nationwide surveys conducted by Statistics South Africa. The IES captures earning, expenditure and consumption patterns of South African households and is conducted every five years. The LFS looks at a variety of issues related to the labour market and includes comprehensive information on household characteristics and demographics. The LFS is conducted bi-annually. Both surveys use the same sample which roughly contains 27 000 households. The common sample was based on a regularly updated master sample, using the enumerator area boundaries delineated for the 1996 Census as the sampling frame. The two surveys were conducted in a manner to ensure compatibility with each other to the extent that such a merging of the datasets is accurate. In the merging process 26 206 household observations were found to be satisfactorily compatible and thus suitable for merging, while the remaining households were not deemed to be adequately compatible and omitted from the sample analysed in this paper.

From the data used in this paper is not possible to determine which households have access to electricity and which households do not, except by the assumption that those households that report no electricity expenditure, are in fact not electrified. The validity of this assumption was confirmed by comparing the electrification figures for the complete data set (a merge of the 2000 IES and LFS appropriately weighted to represent the entire population) under this assumption, with the official electrification figures produced by the NER for 2000. By interrogating the data set it was found that 33% of the households reported not spending any amount on electricity in the previous month.¹⁴ This figure appears to be a close fit to the 37% of households reported not having access to electricity by the NER in 2000 (NER, 2000). Although these figures are not identical they are relatively close, especially considering that the figure reported by the NER is also an estimate based on reports by municipalities

¹⁴ This data set included both pre-paid and two-part tariff users. It should be noted that this dataset was also "cleaned" by conventional means with households reporting contradictory or impossible observations being excluded.

which have an incentive to misreport.¹⁵ Other proxies such as ownership of electrical appliances were also considered, however these did not approximate the official figures as closely as the chosen proxy. The assumption with regards to electrification used in this paper appears to be the most accurate measure available.

A possible concern in the identification of electrified households is that households may be electrified but choose not to use electricity at all, and therefore have no record of electricity expenditure. If a significant number of such households do exist this would indeed suggest that the analysis presented in this paper could be biased to some degree, as these households would not be recognised as electrified. It is however unlikely that in South Africa such households do in fact exist on any significant scale. This point is supported by energy consumption research in South Africa, and in particular work done by the Energy Development Research Centre (EDRC) who have carried out numerous studies focused on electricity consumption of poor, usually newly connected, households across the country. Although none of these studies used a national sample, they still are useful in order to help understand the electricity consumption of households. This research has revealed that many of these households have an extremely low expenditure on electricity and that often electricity is only used for lighting purposes. However, none of these reports suggest that households who have access to electricity choose not to use any electricity at all for more than a two week period (Davis, 1995b ; ESKOM and Department of Minerals and Energy, 2002 ; Thom, 2001).

This paper limits the analysis of electricity demand to households using prepaid technology. This was possible as the 2000 IES clearly identifies those households reporting pre-paid electricity expenditure¹⁶. Pre-paid users are the focus of this paper since it is research concerning these customers that is of primary relevance. Furthermore, as outlined in Section 4.1 it is not possible to identify the average price per unit faced by a consumer on a two-part tariff. Under a two-part tariff, the average price will vary with consumption levels and without data on the monthly fixed fee it is impossible to calculate the marginal usage rate and therefore the average price faced by a consumer given their level of expenditure. It should be noted that this paper presents an analysis of pre-paid electricity demand under the assumption that households do not readily switch between tariff options. Such switching is costly and inconvenient. Furthermore, the use of pre-paid electricity is becoming more and more widespread, partly due to the roll out of the electrification program and partly due to convenience of being able to monitor and manage electricity expenditure.

Municipal electricity prepaid tariffs for 2000 were obtained from the NER database. Prices across electricity providers varied sufficiently to warrant their use in an

¹⁵ Since funding for municipal electrification is done partly through subsidies, it is plausible that municipalities may have an incentive to overestimate the number of new connections in their area. Accurate audit of these reports may prove very difficult.

¹⁶ Pre-paid electricity users were identified from the IES 2000. In this survey, respondents are asked to identify their electricity expenditure in terms of a fixed monthly fee and a usage fee which includes expenditure on pre-payment cards. Those respondents who list no monthly fee were considered pre-paid users.

econometric exercise.¹⁷ An appropriate municipal prepaid price tariff for domestic customers is available for approximately 90% of the licensed municipalities. All the households belonging to the municipalities where no price data was available were omitted from the sample. Where municipal price data was available only for years other than 2000, the tariffs were adjusted by ESKOM's average domestic electricity price increases over the relevant years, to render an approximation of 2000 tariffs.

The municipal price tariffs were attached to the households falling within the relevant municipal boundaries as set out in the 1996 Census. This was not performed directly since it could not be identified from the survey's unique household number which municipality each household belonged to. However, it could easily be identified which magisterial district each household belonged to. Therefore, the process of attaching the relevant electricity price to each household was done by firstly identifying the municipalities which fell within each magisterial district. This information is readily available from the 1996 Census.

Only magisterial districts which contained a single licensed municipality, or which only encompassed unlicensed municipalities, were considered in this paper. Only for these households could the unique pre-paid tariff facing the household be confidently identified. All the other magisterial districts where households from individual licensed municipalities could not be appropriately identified were omitted from the sample. These households were not included since it was impossible to determine the actual pre-paid tariff facing each of these households, given the numerous licensed local authorities within the magisterial district. Approximately 40% of the magisterial districts were not found to be appropriate and thus omitted. This is very unlikely to bias our results since this selection was random in the sense that there is no reason to believe that the excluded households are systematically different from those for which an electricity price could be attached.¹⁸

All the urban households falling within a magisterial district, which encompassed only a single licensed municipality, were assigned the electricity prices of that particular municipality. All households falling in magisterial districts that only encompassed unlicensed municipalities were assigned ESKOM's electricity prices. All rural households were also assigned ESKOM's electricity prices. Unfortunately, it was impossible to identify areas inside licensed municipal boundaries where ESKOM supplies electricity. This method of attaching electricity prices to the relevant households gives a good approximation of the electricity prices, which the households face and is the most accurate approximation possible given the coding structure of the surveys used.

The merged data set was "cleaned" by conventional means with households reporting contradictory or impossible observations being omitted. Households that had missing

¹⁷ The variation of electricity price data used in this paper is presented in Appendix A.

¹⁸ Green (1996, p35) suggests attempts to correct for sample selection bias should only be done in cases where one strongly suspects the selection process to be non-random.

information concerning specific variables of interest to this paper were also dropped from the sample.

Once all the described adjustments to the data had been made, the final sample used for analysis in this paper contained 8415 households. All these households contained a full set of information relating to household characteristics, expenditure and income patterns as well as pre-paid electricity prices facing the household.

5.2. Variables

Table 3 below summarises some relevant characteristics of the sample used in this paper. Households in the sample have a diverse range of characteristics including income and expenditure patterns. All household expenditure reflects monthly values, while household income reflects an annual amount. All expenditure and income is measured in rand.

CHARACTERISTICS		Freq.	%	CHARACTERISTICS		Freq.	%	Cum %	
Province	Western Cape	456	5.42	Is there a flush toilet or running water in the dwelling?	No	7051	83.79		
	Eastern Cape	1978	23.51		Yes	1364	16.21		
	Northern Cape	113	1.34		Total	8415	100		
	Free State	1019	12.11		Electrical appliance expenditure	0	7164	85.13	85.13
	Kwa-zulu Natal	1688	20.06			1/100	366	4.36	89.48
	North West	849	10.09			101/250	330	3.92	93.4
	Gauteng	474	5.63			251/500	132	1.57	94.97
	Mpumalanga	682	8.10			501/1500	174	2.07	97.04
	Limpopo	1156	13.74			1501/max	249	2.96	100
Total	8415	100	Total	8415		100			
Type of Residence	Rural	5412	64.31	Expenditure on other fuels		0	1530	18.18	18.18
	Urban	3003	35.69			1/20	2602	30.92	49.1
	Total	8415	100		21/50	2061	24.49	73.59	
Does the household pay for a telephone service?	No	7334	87.15		51/80	1112	13.21	86.81	
	Yes	1081	12.85		81/120	593	7.07	93.88	
	Total	8415	100		121/max	515	6.12	100	
Does the household pay for a water service?	No	6012	71.44		Total	8415			
	Yes	2403	28.56		Total income	Min/5000	1504	17.87	17.87
	Total	8415	100			5001/10000	2746	32.63	50.51
Is the dwelling within a close proximity to shops (i.e. 2km radius)?	No	1057	12.56	10001/20000		2144	25.48	75.98	
	Yes	7358	87.44	20001/30000		1703	20.24	96.22	
	Total	8415	100	30001/Max		318	3.78	100	
Number of people in household	1/3	3431	40.77	Total		8415	100		
	4/8	3196	37.98	Electricity expenditure		0	4076		
	7/10	1515	18			1/20	1255	28.92	28.92
	10/23	273	3.24			21/50	1374	31.67	60.59
	Total	8415	100		51/100	981	22.61	83.2	
	Number of rooms in dwelling	1	1025		12.18	101/150	303	6.98	90.18
2/3		2864	34.03		151/250	308	7.1	97.28	
4/8		3547	42.15		251/Max	118	2.72	100	
7/20		979	11.63		Total	8415	100		
Total		8415	100		Are there Streetlights outside the dwelling?	No	2497	29.67	
Are there Streetlights outside the dwelling?		No	2497	29.67		Yes	5918	70.33	
	Yes	5918	70.33	Total		8415	100		
	Total	8415	100						

Table 3 Characteristics of sample*Source: Sample used in analysis*

Table 4 gives a detailed description of each variable used in the analysis of households' conditional demand of electricity, as well as any technical information that may be required. Table 4 includes variables used both in the selection and outcome stage of the analysis.

Variable Name	Source of variable	Description
Electricity Expenditure (ELEC)	IES 2000	Monthly household expenditure on pre-paid electricity.
Electricity price (P)	NER database	Price of pre-paid electricity for domestic users
Total Income (Y)	IES 2000	Total annual household income.
Electrical Appliances Index (APPINDEX)	Authors calculations based on information from LFS 2000 (September)	Electrical appliance index weighted by power use of individual appliances.
No. people in household (HHSIZE)	LFS 2000 (September)	The total number of people living in the household at time of interview
No. rooms in dwelling (ROOMS)	LFS 2000 (September)	Total number of rooms in the dwelling
Urban (URBAN)	LFS 2000 (September)	Dummy variable: Place of residence Either Urban (assigned a value of 1) or Rural (assigned a value of 0)
Dwelling Structure (STRUCTURE)	LFS 2000 (September)	Dummy variable: Dwelling Structure Either has running water/ flush toilet in dwelling (assigned a value of 1) or not (assigned a value of 0)
Province (PROV)	LFS 2000 (September)	Dummy variable: Divided into 9 dummy variables for each province; WC, E.C, NC, F.S., KZN, NW, Gaut, Mp, NP If household lives in the province in question (assigned a value of 1) else (assigned a value of 0)
Electrification (ELECTRIFICATION)	IES 2000	Dummy variable: Access to electricity? Either has access (assigned a value of 1) or has no access (assigned a value of 0)
Water services (WATERSERVICES)	LFS 2000 (September)	Dummy variable: Does the household pay for water services? Either yes (assigned a value of 1) or No (assigned a value of 0)
Telephone services (TELEPHONE)	LFS 2000 (September)	Dummy variable: Does the household have a fixed line telephone? Either yes (assigned a value of 1) or No (assigned a value of 0)
Street Lighting (STREETLIGHTS)	LFS 2000 (September)	Dummy variable: Are there streetlights in the households area? Either yes (assigned a value of 1) or No (assigned a value of 0)

Table 4 Description of variables used in analysis*Source: Sample used in analysis*

APPENDIX A contains a detailed description concerning the range, mean and variation of the continuous variables used in this paper.

5. PRESENTATION AND DISCUSSION OF RESULTS

5.1. Results

Table 5 presents the results of the Heckman selection model, as well as naive OLS estimations limited to only those households in the sample which have access to electricity.

Selection Stage		Conditional Electricity demand		
Dependant variable: Electrification		Dependant Variable: Electricity Expenditure (logged)		
Heckman Selection stage (ML)		Conditional demand: Heckman (ML)		Naive OLS
Variable	Coefficient (Std Error)	Variable	Coefficient (Std Error)	Coefficient (Std Error)
Price (logged)	1.1252*** (0.262)	Price (logged)	-0.3487** (0.1215)	-0.3255 (0.125)
Income (logged)	0.2363** (0.021)	Income (logged)	0.3239*** (0.0127)	0.3330 (0.012)
Water services	0.2844*** (0.044)	Appliance Index	0.0056*** (0.0003)	0.0056 (0.003)
Telephone services	0.8337*** (0.078)	No. Rooms	0.0612*** (0.0057)	0.0649 (0.005)
Streetlights	0.6584*** (0.053)	No. Persons	0.0134*** (0.0044)	0.0132 (0.004)
No. Rooms	0.0843*** (0.009)	Urban	0.0592* (0.0316)	0.0906 (0.028)
No. Persons	-0.0106 (0.006)	Structure	0.1727*** (0.0305)	0.1928 (0.029)
Urban	0.2822** (0.053)	Eastern Cape	-0.5180*** (0.0479)	-0.5411 (0.047)
Structure	0.6103*** (0.069)	Northern Cape	-0.3235*** (0.0779)	-0.3186 (0.779)
Eastern Cape	-0.5100*** (0.115)	Free State	-0.4324*** (0.0448)	-0.4217 (0.045)
Northern Cape	0.0290 (0.194)	Kwa-Zulu Natal	-0.2008*** (0.0478)	-0.2303 (0.046)
Free State	0.1572 (0.119)	North West	-0.1929*** (0.0460)	-0.1889 (0.046)
Kwa-Zulu Natal	-0.7951*** (0.113)	Gauteng	-0.3322*** (0.0551)	-0.3536 (0.054)
North West	0.1477 (0.123)	Mpumalanga	-0.3114*** (0.0490)	-0.2982 (0.049)
Gauteng	-0.6951*** (0.124)	Limpopo	-0.3640*** (0.0461)	-0.3634 (0.046)
Mpumalanga	0.2292 (0.124)	Constant	1.5917*** (0.4419)	1.3465 (0.435)
Limpopo	0.0940 (0.118)	R-Squared		0.54
Constant	-6.5063*** (0.922)	Prob > chi2 = 0.0332		

Table 5 Results of Heckman selection model and naive OLS¹⁹

¹⁹ *** is significant at 1% level
 ** is significant at 5% level
 * is significant at 10% level

Table 5 presents robust standard errors, which have been adjusted using the standard White adjustment procedure. The vast majority of coefficients presented are significant at the 1% level. Use of the Heckman selection model appears to be justified, as the results indicate that indeed some degree of sample selection bias does exist in the naive estimations. The regression results presented in Table 5 seem to be plausible, and in line with previous research concerning elasticity of electricity demand and general household energy use within South Africa. From the conditional demand coefficients the price and income elasticity of demand can be calculated by use of equation (8) and (9) respectively. The price and income elasticity of electricity demand is shown in Table 6.

Price Elasticity	-1.35
Income Elasticity	0.32

Table 6 Estimates of price and income elasticity

Source: Calculated from coefficients presented in Table 5 in accordance with equation (8) and (9)

6.2. **Determinants of Electrification**

As expected numerous determinants of electricity demand also appear to affect the probability of a household having access to electricity. Electricity price, household income, household structure, provision of water and telephone services, presence of streetlights and number of rooms in the dwelling all appear to have a positive affect on the probability of electrification. Predictably, urban households are more likely to be electrified than rural households. The relationship between these variables and the probability of being electrified is discussed earlier in Section 4.2 of this paper. It is noted that the number of people in a household does not appear to have an affect on whether or not a household is electrified.

In the analysis of the provincial dummy variables, the Western Cape is the base province. It appears that households in the Eastern Cape, Gauteng and Kwa-Zulu Natal are less likely to be electrified than households in the Western Cape. Households in Kwa-Zulu Natal have the lowest probability of being electrified. This result is in line with figures presented by the NER which report that in 2000 Kwa-Zulu Natal had the lowest level of electrification in the country with only 50.2% of households being electrified (NER, 2000). It should be noted that although these determinants are important, much of the driving force behind the electrification of households may be random given the nature of the electrification program in South Africa.

6.3. *Demand conditional on electrification*

Table 6 highlights that the domestic demand for pre-paid electricity is price elastic. To be more specific a price elasticity of -1.35 means that if the price of electricity were to increase by 10% the demand for electricity, holding all other variables constant, would decrease on average by 13.5%. This result is relatively elastic compared to short-run price elasticity estimates presented in international literature which range roughly from -0.2 to -1.33 (Branch, 1993 ; Wilson, 1971).²⁰ This sensitivity of demand for electricity to price in South Africa is expected given the apparent high degree of substitutability between electricity and alternate fuels. This result may further explain the low consumption of electricity by many households in South Africa as a reaction to the price of electricity. This may still be true despite South African electricity prices being relatively low by international standards. This result suggests that any future increase in the price of pre-paid electricity will result in a significant fall in electricity consumption.

Household income is an important determinant of electricity consumption. The income elasticity of demand is 0.32 and therefore inelastic. When all other variables are controlled for, a 10% increase in household income will on average be associated with a 3.2% increase in electricity consumption. This result shows the estimated income elasticity presented in this paper to be relatively more elastic than some short run estimates of developed countries (Wilder and Willenborg, 1975 ; Branch, 1993). However this estimate is closely in line with the income elasticity calculated for other developing countries (Tiwari, 2000 ; Berndt and Samaniego, 1984). It is proposed by Berndt and Samaniego (1984) that generally electricity demand in developing countries is highly income elastic relative to that of developed countries. The quantitative estimate presented in this paper supports earlier research that suggests income plays a particularly crucial role in determining the demand for domestic electricity in South Africa (Cowan 2003: 18). It should be further noted that although these results suggest that income is a significant determinant of electricity consumption in the short run, the long run effect is expected to be much larger through the indirect effect of household income on electrical appliances (Wilder et al, 1990).

Unsurprisingly the stock of electrical appliances positively affects household expenditure on electricity. This is in line with propositions made in international and South African literature (Methlwana, 1999 ; Tiwari, 2000). This result supports recent recommendations made to provide electric appliance starter packs to newly connected households in an attempt to increase their consumption of electricity (Department of Minerals and Energy, 2001).

As expected the number of people in a household also has a positive effect on household electricity consumption. To be more precise, holding the other variables

²⁰ Long run estimates of price elasticity presented in literature are generally more elastic than their short run counterparts and range from roughly -0.71 to -2.3 (Filippini, 1995 ; Filippini, 1995b).

constant, for every extra person belonging to a household the electricity consumption of that household is likely to rise on average by 1.3%. This result suggests that when considering the consumption of electricity the analysis should take into account the number of people in each household as this appears to be a major determinant of the household's electricity demand. This is important with regard to the provision of free electricity since it has been suggested that this be done using the individual as the unit of analysis rather than the household (Bond, 2002: 328). Although this is a significant determinant, the marginal effect on electricity consumption of an extra occupant of the house is relatively small. The reason for this minimal effect is likely to be found in the large portion of the population which only use electricity for lighting purposes. For these households electricity demand is not likely to depend heavily on the number of people who use the lights, but is heavily dependant on the number of rooms which need light.

Indeed, the number of rooms in a dwelling is a significant determinant of household electricity consumption. This is likely since a greater number of rooms is likely to require a more extensive use of lighting and heating devices. For every extra room a dwelling has, the household is likely to use 6.1% more on electricity.

The results presented in Table 5 suggest that the consumption of electricity does not differ significantly between urban and rural users at a 5% significance level, once all other variables have been controlled for. It should be noted that although the Urban coefficient is not significant at the 5% level, it is significant at the 10% level. Thus the results presented in this paper are indeterminate when analysing differences in consumption of electricity between urban and rural households. Interestingly, in the naive OLS estimation this coefficient is significant at the 1% level. This suggests that the type of area in which a household is situated may have a particularly strong effect on the sample selection bias. Literature supports the notion that electricity consumption patterns differ between the type of area in which one lives. Rural areas have a greater access to alternative fuels, such as wood, and therefore generally use a mix of energy fuels. Since much of the rural areas are newly connected households this result could also incorporate differences in consumption patterns between newly connected and more established connections. Newly connected households are more likely to use a mixture of energy fuels since using alternate fuels may be a habit of their lifestyle (Leitner and Van der Byl, 1997). It can be expected that other explanatory variables such as dwelling structure and province of residence partly pick up differences between rural and urban households.

The physical structure of a dwelling is also an important determinant of household electricity consumption. This significant result suggests that although our proxy for dwelling structure is crude it is sufficient to capture the effect of this variable.

In the analysis of provincial electricity consumption Western Province is used as the base province since it is not included in the regression. The results show that once the other variables have been accounted for, households in the Western Province, on

average, consume more than households in other provinces. On the other extreme households from the Eastern Cape spend the least on electricity every month. Although it is difficult to identify the causes of this variation in provincial consumption patterns, it is likely that the varying prices of alternate fuels, as well as differing cultures and weather patterns between the provinces are important factors.

7. CONCLUSION

The provision of widespread access to affordable electricity is crucial for promoting equality, not only within the electricity industry but within South Africa in general. Government, in partnership with Eskom and local municipalities, has made such provision a priority. This can be seen in the application of the national electrification program over the past decade as well recent promises by Government of free life-line electricity to the poorest households.

In the initial phase of the national electrification program the consumption of newly connected households was grossly over estimated. This low consumption has raised serious questions regarding the viability of the electrification program and has highlighted the need for a better understanding of domestic electricity consumption, specifically of poor households. In particular, there has long been a need for locally derived estimates of price elasticity of electricity demand (Eskom and Department of Minerals and Energy, 2002: 57). However, to date no such estimates have been made due to lack of data.

In this paper it was possible to develop a large database of household information including household characteristics, expenditure and income patterns, as well pre-paid electricity prices faced by the households. From this dataset, a Heckman sample selection model was used to analyse the determinants of electricity demand. The stock of electrical appliances, number of people in the household, size and structure of the dwelling, type of area and province of residence were all found to be important determinants of electricity consumption. Of particular interest, the income and price elasticity are estimated to be 0.32 and -1.35 respectively. These results suggest that the demand for electricity is very sensitive to changes in price. Such an elastic demand ties in with domestic energy literature, which reports a high degree of substitutability between electricity and alternate fuels (Methlwana, 1999 ; Cowan 2003: 18 ; Holtz, 1995 ; Leitner and Van der Byl, 1997).

Research, such as presented in this paper is vital since the consumption of newly connected households is linked to the viability of the electrification program. In particular, information regarding the sensitivity of demand to changes in price is essential to devise an appropriate pricing and subsidy strategy. Such a strategy should not aim only to guarantee the viability of the electrification program but also ensure that the social benefit associated with the roll out of electricity connections is

not undone through a lack of demand. This is of absolute importance in light of the proposed restructuring of the electricity industry, where price increases are likely and there is pressure for the industry to move toward a more cost based pricing scheme. It is essential in a developing country such as South Africa that the benefits from deserving social goals, such as increased access to electricity, are not lost in the eagerness for competitive forces to control the market. In order to devise a strategy which achieves a healthy balance it is crucial to have quantitative estimates, such as presented in this paper, regarding the determinants of electricity demand. Given the elastic demand for electricity estimated in this paper, any future price increases are likely to have a significant effect on the consumption of pre-paid users. This impact needs to be taken into account by policy makers in South Africa.

Further research needs to be done with regards to the long run price and income elasticity of electricity demand, as well as the speed at which demand adjusts to these forces. Furthermore, research concerning the consumption patterns of users facing a two-part tariff will also provide additional insights. The results in this paper suggest that an analysis of each specific province might be of interest since the electricity consumption of households appears to be significantly different across the provinces.

Insights flowing from this further research, as well as results presented in this paper, should be applied to assess the South African electricity distribution industry, and in particular the impact a restructuring of this industry will have on electricity demand. Such research will better enable electricity authorities to achieve both their social as well as efficiency goals, and to understand the trade-offs between these that might exist.

8. BIBLIOGRAPHY

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9. APPENDIX A

Table A1 below presents a summary outlining the range, mean and variation of the continuous variables used in this paper's analysis of electricity demand.

<i>Variable</i>	<i>Mean</i>	<i>Std Deviation</i>	<i>Min</i>	<i>Max</i>
Monthly Electricity Expenditure (Rand)	72.6	96.765	2	3000
Electricity price (c/KWH)	31.2	3.0657	23.6	51.96
Annual Household Income (Rand)	28828.3	89757.49	140	3815376
No. People	4.53	2.656	1	23
No. Rooms	4.32	2.1157	1	20

Table A1 Description of continuous variables

10. APPENDIX B

From the survey data used in this paper it can be determined whether a household makes use of certain appliances. The electrical appliance index (APPINDEX) used in this paper, as a proxy for the household's stock of electrical appliances is weighted by the average power requirement of these appliances. The method by which this index is calculated for each household (APPINDEX_H) is shown in equation (B1).

$$APPINDEX_H = \frac{\sum_{i=1}^5 PW_i \times D_{Hi}}{\sum_{i=1}^5 PW_i} \times 100 \quad (B1)$$

Where PW_i represents the average power usage of the five electrical appliances used to make up the index, which are: television, lights, radio, hotplate /microwave /stove and heater. These average power requirements are shown in Table B1. D_i is a dummy variable that takes on a value of 1 if the electrical appliance in question is used by the household, or if not, takes on a value of 0.

APPLIANCE	AVERAGE POWER REQUIREMENT (W)
Radio	18
Television (black and white)	35
Lighting	400
Hotplate/microwave/stove	1500
Heater	2000

Table B1 Average power requirement of various electrical appliances

Source: Eskom residential usage/Bill estimator tool (www.Eskom.co.za)

Unfortunately it is not possible to distinguish how many of the above appliances each household possesses. Thus the electrical appliance index is based on the simplified assumption that each household can not possess more than one of each appliance. Furthermore, it is not possible from the data to determine whether or not a household possesses other specific appliances that may use significant amounts of electricity, such as a fridge, geyser and iron. Despite these limitations the appliance index will still provide the most accurate proxy available for household stock of electrical appliances. The five electrical appliances used in the index give a good indication of a household's stock of electrical appliances. It is unlikely that the relative value of the household's appliance index would change significantly, even if it were possible to include other appliances such as a fridge, geyser and iron.

Expenditure on electrical appliances was also considered as an alternative proxy. This proxy was however deemed to be very unreliable, primarily because it would only provide information on recently purchased electrical appliances, and not the household stock of appliances as desired.

11. APPENDIX C

A full list of acronyms used in this paper is as follows:

AIDS-Almost Ideal Demand System

EDRC- Energy Development Research Centre

IES- Income and Expenditure Survey

LFS- Labour Force Survey

NER- National Electricity Regulator

REDS-Regional Electricity Distributors

TOU-Time-Of-Use

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