The Impact of Free Basic Electricity on the Energy Choices of Low Income Households: A Case Study in South Africa

Stephen Davis, Alison Hughes, Kate Louw

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Program on Energy and Sustainable Development
Freeman Spogli Institute for International Studies
Encina Hall East, Room E415
Stanford University
Stanford, CA 94305-6055

http://pesd.stanford.edu

About the Authors

Stephen Davis is a Research Officer in the Energy Research Centre at the University of Cape Town. Stephen has a background in actuarial science and statistical and mathematical modelling, having completed an MSc in modelling and risk management in deregulated energy markets at the University of Cape Town. Stephens research interests include energy efficiency, sustainability, climate change and statistical modeling of energy systems

Alison Hughes is a Senior Research Officer and PhD candidate within the Energy Research Centre at the University of Cape Town. She has a Masters in Mechanical Engineering from the University of Cape Town. Alison heads the Energy Systems Analysis group at the Energy Research Centre, focusing on energy demand and supply studies within South Africa at the local, regional and national level.

Kate Louw is a Masters candidate with the Energy Research Centre at the University of Cape Town. She completed an honors in Economics at the University of Cape Town. Her research interests include examining the social and economic impacts of policies aimed at meeting the need for basic services in low income households.

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Abstract

We investigate the impact of a Free Basic Electricity allowance (FBE) in two small rural towns in South Africa. Measurements from a national load research database in combination with socio-economic survey data are analysed and compared before and after the implementation of the FBE. The key findings are that 50 kWh per month of FBE resulted in a 21.85 kWh per month increase in average consumption in one of the sites, and an insignificant increase in the other. The observed increase in the first site was associated with an increase in the proportion of electric stove ownership. Regression analyses conducted on the combined data sets for both pre- and post-FBE indicate that income and presence of electrical cooking appliances were the key determinants of electricity consumption. We discuss the results of the analyses in light of the data limitations and the dynamic circumstances of the low income households in this study. Some unexpected, yet interesting insights are revealed with the implementation of the FBE at the two sites.

I. Introduction

It is widely acknowledged that energy is a basic human need that is a prerequisite for development. Energy is a central feature of the Millennium Development Goals (MDGs) [UNDP 2005], and whilst its lack is not directly a cause of poverty, improving poor households' access to energy services will improve their livelihood [Louw, 2008].

In order to enable impoverished households to increase their electricity consumption and alleviate the negative impact of poverty on communities, Free Basic Electricity (FBE) was introduced in South Africa in 2003. FBE is a basic services support tariff, which allocates an allowance of 50kWh of free electricity each month to poor[1] households. This work investigates the effect the introduction of free basic electricity has had on the households' electricity demand and energy portfolio.

The paper extends the work by Louw *et al* [2008] in which the determinants of electricity demand were examined for newly electrified low-income African households. The current work extends beyond the baseline and incorporates the data that was collected subsequent to the implementation of the FBE in the analysis.

A panel of two data sets was used in the analysis, one before and one after the implementation of free basic electricity. The data sets were analysed using descriptive statistics (including matched pairs comparisons) and econometric regressions. In spite of the apparent data limitations, the findings suggest that the introduction of Free Basic Electricity (FBE) does indeed increase demand for electricity. With this in mind, FBE could serve as a tool to address inequality and to help the poor to gain access to modern energy services.

Low-income households tend to use a number of different fuels to meet their energy needs, including biomass, kerosene and electricity. Many studies have sought to determine, broadly, the factors that influence the choice and use of these fuels, but few studies have looked specifically at the determinants of fuel use in low-income households. It is thought that factors such as fuel price, household income, tastes and preferences, and other external factors such as the distance to the supply point are contributing factors. South Africa provides a unique setting[2] in which to assess the determinants of electricity demand for low-income households, and observe how household choices change once interventions, such as lifeline subsidies, have been implemented in electrified households.

This study follows two sites, Antioch and Garagapola, situated in the Eastern Cape and Mpumalanga. An allocation of FBE was piloted at these sites in 2002. The 50kWh of free electricity each month from the FBE is equivalent to a monthly household subsidy of about ZAR20 (US$ 2 at 2002 rates). Questionnaire data from the sites were collated with detailed electricity consumption data.

The lower average price of electricity for households following the introduction of the free 50 kWh per month should allow the typical portfolio of fuels to be composed of lower quantities of traditional fuels such as fuelwood, paraffin and charcoal. One would hypothesise that more electricity would be used, particularly for lighting and income-generating purposes, following the introduction of the FBE (UCT, 2002). The objective of this work is to evaluate household energy transitions following the introduction of the FBE. By analysing the changes in the demand for electricity pre- and post-FBE, we hope to identify the transitions.

The paper is structured as follows: section II gives an overview of the background and literature

[1] Poor households are defined as those households falling within the lowest two quintiles of income, as was used in the EBSST study. Initially it was thought that the threshold would be approximately R800 per household; this was found to be too low and additional poverty mapping was needed.

[2] Due to the inequities of the past, South Africa has had to provide infrastructure and subsidies to enable low-income households to make use of basic services. This has meant that the opportunity was afforded for surveys and data collection to take place, allowing in-depth analyses of these households' circumstances.

review, section III explores the theoretical setting, and section IV covers the data and descriptive statistics. Econometric analysis is covered in section V, and conclusions are given in the final section VI.

II. Background

A detailed background to the state of electrification and the electricity supply and distribution industry in South Africa is given in the earlier paper by Louw *et al* (2008). A notable outcome of that study is that despite an extensive electrification drive by the government, the transition to electricity among low-income households has not been as great as anticipated. Fuel stacking to maintain fuel security remains the status quo in low-income households.

(i) Study Locations: Antioch and Garagapola

Antioch lies in a remote mountainous region in the Eastern Cape called the Drakensberg. The homesteads in the village are mostly traditional rondavels with garden plots that can be used for subsistence farming. The closest large town, Umzimkulu, is about 35km from Antioch [UCT, 2002; Louw, 2008]. Garagapola is in the north of South Africa, and lies on the border between the Northern Province and Mpumalanga. Most households in the village have large plots, also suitable for subsistence farming. Garagapola is approximately 20km from the nearest town, and is also located near mining industries where a number of residents are employed [UCT, 2002, Louw, 2008].

III. Theoretical Setting

The theoretical requirements for selecting the Ordinary Least Squares model are given in detail in Louw, 2008 and not repeated here.

The household's demand for energy services *(ES)* can be stated as follows

$$ES = (p_{ES}, m, z)$$

Where p_{ES} is the price of energy service, *m* is the income of the household and *z* the household's tastes and preferences.

To estimate the above demand function, it is necessary to specify a functional form. The appropriate form for addressing issues about price and income is the log-log specification. The empirical equation to be estimated is as follows:

$$\ln ES = \beta_0 + \beta_1 \ln Y + \beta_2 \ln P_c + \ln EX_p + \beta_3 \ln(rooms) + \beta_4 \ln(lights) + \beta_5 (cookingApp) + \beta_6 \ln(Year) + \beta_7 (entertainment) + \varepsilon$$

where Y is household income, P_c is the price of a candle, EX_p is the household expenditure on paraffin. Generally, two models are estimated, one including electricity prices and the other alternative fuel prices. In this situation, since the price of electricity did not vary much between the two locations and between time periods, it was not included in the econometric analysis.

IV. Data and descriptive statistics

(i) Data

Panel data for households in Antioch and Garagapola for 2001 (pre-FBE) and 2002 (post-FBE) was used in the analysis. Both studies took place in the winter months of each year, over approximately the same length of time. Metered electricity consumption data (readings taken every 5 minutes) for each household in Antioch and Garagapola were obtained from the NRS National Load Research (NLR) programme. Socio-economic data for each household was available from the EBSST study conducted by the Energy Research Centre (ERC) [UCT, 2002]. The two data sets were collated by household using meter numbers and addresses as a reference. The outcome was a single data set that contained the demand and socio-economic data for each household. The combined data set allowed us to study the determinants of energy demand, as well as any changes in electricity demand that occurred as a result of the introduction of FBE.

(ii) Descriptive statistics

This sub-section presents the descriptive statistics for the panel data. Descriptive statistics for the combined data sets of Antioch and Garagapola are shown before and after the introduction of FBE in Table 1; also provided in Appendix 2 are the descriptive statistics broken down by site. Differences in the panel did occur over the two years (2001 and 2002), thus matched pairs t-tests were conducted in addition to OLS regression analysis.

A summary and comparison of the descriptive statistics for both pre- and post-FBE is presented in Table 1. The table shows that over the course of the trial period, most households' electricity consumption did increase (the matched pairs test shows that the significance for this increase was at the ten percent level). It is unclear from the data why there was a decrease in average household size, or a substantial increase in the average paraffin price.

Income did not differ significantly over the two-year period (matched pairs results are shown in Table 1), however *Usage, Household Size*, and *Paraffin Price* and *Entertainment Appliances* did (at the 10% level). The decrease in household size may have meant that usage increase may have been dampened by the presence of fewer people in the households in the post-FBE study. The smaller household may also have reduced the true increase in overall household income. The average number of rooms remained constant between the two periods. The proportion of households owning cooking appliances and the average number of lights did not increase significantly between the periods.

Table 1: Differences in descriptive variables between pre- and post-FBE

Variable	Unit	Observations	Mean	Std Dev	Min	Max	Mean Difference	H_a: mean(diff) ≠ 0
Usage (monthly)	kWh						-11.07	-1.6387 (0.1048)
Pre		91	92.79	72.62	5.10	285.1		
Post		91	103.86	80.51	5.76	452.0		
Income	ZAR						-19.79	-0.2118 (0.8329)
Pre		73	874.04	792.45	100	4500		
Post		73	893.84	671.02	0	3500		
Household Size							0.63	2.4485 (0.0167)
Pre		75	5.73	2.767	1	14		
Post		75	5.11	2.275	1	12		
Lights							-0.20	-1.0185 (0.3118)
Pre		74	3.851	2.30	0	9		
Post		74	4.054	2.55	1	10		
Rooms							-0.09	-0.7084 (0.4809)
Pre		75	3.85	2.07	1	9		
Post		75	3.95	1.95	1	9		
Paraffin Price	ZAR						-6.14	-2.7641 (0.0075)
Pre		64	3.05	0.96	0.94	6		
Post		64	9.18	17.97	0.22	120		
Fraction owning cooking appliances							-0.053	-0.8147 (0.4179)
Pre		75	0.467	0.553	0	1		
Post		75	0.52	0.529	0	1		
Entertainment Appliances							-0.173	-1.6568 (0.1018)
Pre		75	1.08	0.834	0	3		
Post		75	1.253	0.772	0	3		

Numbers in parentheses are the p-values for the matched pairs t-tests

V. Econometric Analysis (regressions and results)

The following section details the regression analysis undertaken in this study. Using OLS regression analysis, the factors affecting household choice in electricity use were assessed. Two important factors related to sampling are sample size and incidental truncation. Since the accuracy of sample statistics increase with the sample size (usually in proportion to its square root), the very small size of the sample used in this work is expected to reduce the accuracy of the analysis.

(i) Regression results pre-FBE

Methodology

Six models were tested on both the pre- and post-FBE data sets, using a stepwise multiple regression procedure. The data were screened for outliers and the model examined for collinearity. The assumptions of the regression model were also checked. The first model is the simplest, and demonstrates the relationship between consumption of electricity and household income. The second model looks at how income and number of rooms affect the consumption of electricity; aside from cooking appliances, these are the two most significant variables. The third and fourth models add lighting and cooking appliances (respectively) to the equation to determine whether there is a linear relationship to entertainment appliances and/or a shift in the regression curve associated with cooking appliances (an indicator variable). Years electrified is added to the fifth model, and all variables are tested together in the sixth model. Not all of the predictor variables are seen to be significant in the sixth model.

Discussion

In the pre-FBE study results (Table 2 below), Model 4 appears to provide the best fit according to the Adjusted R-squared and F-statistic, and by virtue of its simplicity. As expected, electricity consumption increases with ln(*income*), ln(*number of rooms*) and (presence of) *cooking appliances*. The other variables do not appear to be significant. The increase in explanatory power obtained by moving from Model 4 to Models 5 and 6 are not justified in light of the presence of non-significant predictor variables and lower F-statistic.

There was little difference in the unit cost of electricity between the different households. The price variable was therefore omitted from the regression analysis.

The sample is heteroskedastic (i.e. the variables do not have constant variance over the ranges of predictor variable), which means that whilst the estimators are still linear and unbiased (two of the four conditions that need to be satisfied for Ordinary Least Squares (OLS) regressions), they are slightly inflated [Gujarati, 2003]. This does not impact on the results presented below since the fundamental relationships that exist between variables are still observable.

Income was significant and inelastic across all models. This finding corresponds with other studies that have found that income is significant when making energy consumption decisions. As income increases, energy expenditure becomes a proportionately smaller part of the household budget.

The number of rooms within a house was found to be significant. The number of lights in a household is strongly correlated with the number of rooms (ρ=0.8424) and thus, also significant in determining demand. The collinearity between these two variables justifies leaving *number of lights* out of the model, particularly since it was not linearly related to the dependent variable in this data set.

Table 2: Regression results - Pre-implementation

Variable	Model 1	Model 2	Model 3	Model 4	Model 5	Model 6
Dependent variable[3]	ln(kWh)	ln(kWh)	ln(kWh)	ln(kWh)	ln(kWh)	ln(kWh)
Ln(income)	0.5224 (3.23)***	0.4596 (3.03)***	0.5181 (3.20)***	0.4048 (2.93)***	0.3821 (2.74)***	0.2677 (1.77)*
Ln(number of rooms)	--	0.6029 (3.60)***	0.4763 (1.19)	0.5311 (3.47)***	0.491 (3.12)***	0.5674 (1.54)
Ln(lights)	--	--	0.1182 (0.29)	--	--	-0.3432 (-0.93)
cooking appliances	--	--	--	0.7435 (4.22)***	0.7564 (4.29)***	0.7919 (3.78)***
entertainment appliances	--	--	--	--	--	0.1548 (1.19)
Ln(Candle expenditure)	--	--	--	--	--	-0.5351 (-1.91)*
Ln(Paraffin price)	--	--	--	--	--	0.4466 (1.52)
Ln(Years electrified)	--	--	--	--	0.6871 (1.07)	0.3487 (0.619)
Constant	-4.339 (-4.11)***	-4.624 (-4.68)***	-5.005 (-4.78)***	-4.538 (-5.07)***	-5.273 (-4.68)***	-4.680 (-3.92)***
N	80	80	78	80	80	64
R^2 (Adjusted R^2)	0.1178 (0.1065)	0.2446 (0.2250)	0.2604 (0.2304)	0.3880 (0.3638)	0.3971 (0.3650)	0.4704 (0.3934)
F-statistic (Prob>F)	10.41 (0.002)	12.47 (0.000)	8.68 (0.000)	16.06 (0.000)	12.35 (0.000)	6.11 (0.000)

*Numbers in parentheses are the t-statistics. *, **, *** indicate significance at the 10%, 5% and 1% level respectively.*

Cooking appliances was found to be the most statistically significant predictor of ln(*kWh*). These appliances consume large amounts of electricity and therefore the linear relationship to ln*(kWh)* is expected. Entertainment appliances did not impact significantly on the amount of electricity used.

The ln(*years-electrified*) variable is positive but not significant – this indicates that there is an inherent willingness to use electricity even within households with little previous experience with electricity. "Years-electrified" is a time variable and indicates whether usage of electricity increases or decreases over time.

The price of two alternative fuels were tested, namely candle and paraffin price. Candle price was found to be slightly significant whereas paraffin price was not significant at all.

(ii) Regression results post-FBE

The procedure for the post-FBE regression was the same as that of the pre-FBE, however the number of times FBE was received was included in these regressions[4]

[3] The logarithm of the 5-minute average consumption was used for the regression analyses.

[4] This is a continuous variable - i.e. for how many months did the households obtain their free units of electricity.

Discussion

The post-FBE OLS regression results are shown in Table 3 below. The significant variables post-FBE in Model 4, which offers the best fit, are ln(*number of rooms*) and ln(*household income*) as well as presence of *cooking appliances.* Number of *entertainment appliances* was only marginally significant in the sixth model, however this model includes too many of the possible predictors and is likely to be collinear with spurious results and conclusions due to the large number of variables for the given sample size.

Table 3: Regression results - post-implementation

	Model 1	**Model 2**	**Model 3**	**Model 4**	**Model 5**	**Model 6**
Dependent variable	ln(kWh)	ln(kWh)	ln(kWh)	ln(kWh)	ln(kWh)	ln(kWh)
Ln(income)	0.2967 (1.95)**	0.2378 (1.60)*	0.1963 (1.30)	0.2304 (1.59)*	0.2364 (1.61)*	0.0930 (0.60)
Ln(rooms)	--	0.4977 (2.67)***	0.1891 (0.65)	0.4703 (2.58)***	0.4522 (2.39)**	0.2108 (0.78)
Ln(lights)	--	--	0.3271 (1.39)	--	--	--
cooking appliances	--	--	--	0.4131 (2.19)**	0.4316 (2.21)**	0.2036 (0.92)
entertainment appliances	--	--	--	--	--	0.2376 (1.62)*
Times FBE Received	--	--	--	--	--	0.1026 (1.97)**
Ln(Years electrified)	--	--	--	--	0.2365 (0.40)	--
Constant	-2.721 (-2.71)***	-2.939 (-3.03)***	-2.669 (-2.70)***	-3.077 (-3.24)***	-3.475 (-2.52)***	-2.478 (-2.52)***
N	81	81	80	81	81	79
R^2 (Adjusted R^2)	0.0458 (0.0337)	0.1256 (0.1031)	0.1461 (0.1124)	0.1767 (0.1447)	0.1784 (0.1352)	0.2353 (0.1829)
F-statistic (Prob>F)	3.79 (0.0551)	5.60 (0.0053)	4.33 (0.0071)	5.51 (0.0018)	4.13 (0.0044)	4.49 (0.0013)

*Numbers in parentheses are the t-statistics. *, **, *** indicate significance at the 10%, 5% and 1% level respectively.*

During both phases of the study, income and number of rooms remain important factors in explaining the level of electricity consumption for these low-income households.

Cooking appliances are large consumers of electricity and are thought to be an important indicator of demand levels for households, as confirmed by the OLS regressions. An obvious conclusion in the post-FBE data is that the number of times the FBE was received definitely explains the increase in the level of consumption, and when introduced to the model, explains the demand better than any of the other variables.

VI. Policy implications and conclusion

This work examined the effect that introducing a basic services support tariff for electricity - in this case a monthly free allocation of 50kWh - had on the electricity consumption and fuel use of poor households in two rural villages, namely Antioch and Garagapola. A comparative study was performed on two data sets, one from surveys before the introduction of FBE and the other from surveys after the introduction of FBE was carried out. The data was analysed using econometric regressions (OLS method).

The advantage of this study was that it combined data from two sources, namely a load research database and a socio-economic survey. The combined information set led to some useful and unexpected insights regarding the implementation of a free basic electricity allowance. The descriptive statistics indicated that the circumstances of the households studied were diverse and the societies dynamic, with large variability present in all the information collected. The number of times the FBE was actually utilised varied between households; more unexpectedly, variables such as household size and income tended to fluctuate dramatically in both pre and post-FBE surveys.

The dynamic circumstances made it difficult to conclusively assess the impact of the FBE on the energy behaviour of the households[5]. The free 50 kWh per month was not observable as a kick up in demand in the data (particularly in Garagapola), however with Antioch there was a significant increase in average consumption of 21.85 kWh (standard deviation = 52.08 and p-value = 1.25%) and much of this may have been a consequence of the 18.75% increase in the proportion of electric stove ownership at that site (standard deviation = 10.47% and p-value = 0.084). The increase in electric stove ownership may or may not have been triggered by the FBE. Further data in the form of survey questions would be needed to corroborate that fact.

A potential limitation of this study was the sample size requirements for running the OLS models. We combined data from two different areas so that we could undertake a reasonable modelling exercise pre- and post-implementation of the FBE. The heterogeneity of the sample with respect to location should not detract from the predictive power obtained by combining them for the OLS regressions.

The study shows that the main determinants of consumption of electricity for low-income households are income and ownership of cooking appliances. The number of times the FBE was received did increase the consumption of electricity and, as such, was a key determinant of consumption in the post-implementation analysis, overshadowing the other variables when included in the model.

When comparing the regression results from before and after the FBE we are able to identify the impact that the FBE has had on the explanatory power of the various independent variables. The presence of the FBE has a significant impact on the overall consumption of electricity, as one would expect with subsidies for what could be termed essential services. What is important to note is that the presence of the FBE as an explanatory variable has the effect of smothering the importance of the other variables, since it is a stronger predictor of kWh consumption than any of the others. It is important to point out that it is the "presence" of the FBE that impacts the regression model, as distinct from the variable "Times FBE received", which is also significant. In summary, we also observe a decrease in the coefficients of the significant variables in absolute terms post-FBE.

[5] See also Appendix II for a note on some of the other challenges relating to the interpretation of the data.

Due to the small sample size, OLS results were not as robust as desired; therefore to increase the robustness of results and overcome the limitation of OLS, matched pairs analysis was carried out to confirm the significance of predictor variables.

Income and the cost of alternative fuels affect electricity demand. The introduction of FBE lowers the average cost per unit of electricity, compared to that of alternative fuels.

There is also an indication that FBE encourages appliance ownership (or perhaps appliance *usage)*; what remains unclear in the analysis is whether the appliance ownership has increased due to new appliance purchases or if broken appliances have been repaired so as to take advantage of the free electricity grant.

Whilst demand did increase, the increase was neither as large nor as significant as anticipated. Income was less useful in explaining electricity consumption after the introduction of the FBE; however, the number of times the FBE was received hides the significance of income (and other variables) when introduced into the model. However, as stated previously, the regressions show that the presence of the FBE does genuinely impact on the explanatory power of the other significant variables (i.e. *income, number of rooms* and *presence of cooking appliances*).

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Appendix

I. Description of electricity access

All the households in Antioch and Garagapola are connected to the grid and are able to buy electricity from local vendors. Residents in Antioch however have experienced problems in purchasing electricity from vendors due to vendors rationing sales of electricity units, or running out of units to sell (UCT, 2002). The implication is that use of electricity in Antioch may have been dampened.

II. Descriptive statistics- pre implementation of FBE

	Variable	Unit	No. of Observations	Mean	Std Dev	Min	Max
kWh (monthly average)			91	91.86	72.78	4.97	284.83
	Antioch		39	63.58	62.74	4.97	228.53
	Garagapola		52	113.61	73.01	4.97	284.83
Income		Rands	73	874.04	792.45	100	4500
	Antioch		32	638.44	589.74	100	3500
	Garagapola		41	1057.93	884.16	100	4500
Household Size			83	5.59	2.794	1	14
	Antioch		39	5.15	2.915	2	14
	Garagapola		44	5.98	2.654	1	12
Lights			74	3.851	2.304	0	9
	Antioch		32	2.718	1.529	0	7
	Garagapola		42	4.714	2.432	0	9
Fraction of households with cooking appliances			75	0.467	0.533	0	1
	Antioch		32	0.469	0.567	0	1
	Garagapola		43	0.465	0.549	0	1
Number of entertainment appliances owned			75	1.08	0.834	0	3
	Antioch		32	0.969	0.897	0	2
	Garagapola		43	1.163	0.785	0	3
Paraffin Price		Rands	64	3.05	0.956	0.94	6
	Antioch		28	2.70	0.852	0.94	4
	Garagapola		36	3.31	0.959	1.40	6
Year Electrified		Years	75	3.89	0.559	2	6
	Antioch		32	3.59	0.559	2	4
	Garagapola		43	4.42	0.448	3	6

III. Descriptive statistics- post implementation of FBE

Variable	Unit	No. of Observations	Mean	Std Dev	Min	Max
kWh (monthly average)		91	103.83	80.48	5.8	452.09
Antioch		39	86.94	68.56	5.8	296.42
Garagapola		52	116.58	86.94	5.8	452.09
Income	Rands	73	893.84	671.02	0	3500
Antioch		32	845.00	589.74	0	3500
Garagapola		41	931.95	639.99	0	2800
Household Size		75	5.11	2.275	1	12
Antioch		32	4.97	2.57	1	12
Garagapola		43	5.21	2.05	2	12
Lights		74	4.05	2. 303	1	10
Antioch		32	5.36	2.44	1	6
Garagapola		42	2.34	1.47	1	10
Fraction of households with cooking appliances		75	0.52	0.529	0	1
Antioch		32	0.66	0.545	0	1
Garagapola		43	0.42	0.499	0	1
Number of entertainment appliances owned		75	1.253	0.772	0	3
Antioch		32	1.03	0.739	0	2
Garagapola		43	1.41	0.763	0	3
Years Electrified	Years	75	4.81	0.896	3	8
Antioch		32	4.38	0.659	3	6
Garagapola		43	5.14	0.915	3	8
Number of times FBE Received		90	3.26	1.894	0	6
Antioch		38	3.03	1.852	0	6
Garagapola		52	3.42	1.852	0	6