To the Graduate Council:

I am submitting herewith a dissertation written by Ana Maria Majano entitled "Residential Demand for Electricity in El Salvador: An Application of a Quasi-Newton Method to the Estimation of the Transformation Parameters of a Generalized Box-Cox Form." I have examined the final copy of this dissertation for form and content and recommend that it be accepted in partial fulfillment of the requirements for the degree of Doctor of Philosophy, with a major in Economics.

Robert A. Bohm, Major Professor

We have read this dissertation
and recommend its acceptance:

Accepted for the Council:

Associate Vice Chancellor
and Dean of the Graduate School

RESIDENTIAL DEMAND FOR ELECTRICITY IN EL SALVADOR: AN APPLICATION OF A QUASI-NEWTON ALGORITHM TO THE ESTIMATION OF THE TRANSFORMATION PARAMETERS OF A GENERALIZED BOX-COX FORM

A Dissertation

Presented for the

Doctor of Philosophy

Degree

The University of Tennessee, Knoxville

Ana Maria Majano

December 1993

DEDICATION

To my parents

Jose Angel Majano and Angela Fidelia Guerrero de Majano

and my children

Luz de Maria and Sara del Carmen

with love and gratitude.

ACKNOWLEDGMENTS

I would like to express my gratitude to my academic advisors, Dr. Robert A. Bohm and Dr. Hui-Shyiong Chang, for their guidance and understanding during the past four years.. I would also like to thank Dr. Chanaka Edirisinghe, Dr. Hans Jensen, and Dr. Feng-Yao Lee for their valuable comments and suggestions in the development of this dissertation.

My appreciation goes to LASPAU/Fulbright, UT Economics Department, UT National Alumni Association, the Center for International Education, and Dr. Burton English, all of whom provided me with financial support at different stages of my graduate studies, and to the personnel of PLANICEL in San Salvador for their kindness and their invaluable help with the data collection.

I thank my family and friends in El Salvador, especially my parents and my children, for their love and understanding. Finally, I thank Samuel Ebong, for his encouragement and patience, and for being my best friend and my companion all this time.

ABSTRACT

The purpose of this work was to estimate a generalized form equation for residential electricity demand in El Salvador, and to identify the most appropriate demand-side management options for that sector.

A Quasi-Newton algorithm was applied for the estimation of the transformation parameters of the generalized Box-Cox form. This technique was shown to be superior to the commonly use grid search in terms of accuracy and computational effort.

The estimations show that price of electricity is not a significant determinant of residential electricity consumption in El Salvador, while per capita income and availability of the service have a significant positive effect on household consumption of electricity. The responsiveness of consumers to price changes is expected to increase slightly as prices increase.

After an analysis of existing alternatives for electricity demand-side management and of the situation of the country, it was recommended that time-of-use tariff schemes and energy-efficiency promotion programs be considered and implemented by El Salvador's electric utility.

TABLE OF CONTENTS

Chapter			Page
INTRODUCTION			1
1	THE ENERGY CRISIS IN EL SALVADOR		3
	1.1	Introduction	3
	1.2	El Salvador: General Information	3
	1.3	Electricity Consumption	4
		1.3.1 The Structure of Energy Use in El Salvador	4
		1.3.2 The Importance of Electriciy in the Salvadoran Economy	7
	1.4	Generation and Distribution of Electricity	7
		1.4.1 Historical Background	7
		1.4.2 Current Generation Capacity	11
		1.4.3 Costs and Prices	14
	1.5	The Crisis	16
2	ISSUES ON RESIDENTIAL DEMAND FOR ELECTRICITY: A SURVEY		20
	2.1	Introduction	20
	2.2	Review of Previous Studies of Residential Electricity Demand	21
		2.2.1 Short Run versus Long Run	22
		2.2.2 The Price Variable	25
		2.2.3 Residential Electricity Demand in Developing Countries.	27
		? 2.4 The Functional Form	29
	2.3	Summary and Implications for This Study	30
3	RESIDENTIAL DEMAND FOR ELECTRICITY IN EL SALVADOR		32
	3.1	Introduction	32

3.2 The Model 33
3.2.1 Determinants of Residential Demand for Electricity in El Salvador 33
3.2.2 The Functional Form 36
3.2.3 The Demand Equation 38
3.3 The Estimation Technique 40
3.3.1 The Likelihood Function 40
3.3.2 The Grid Search Method 41
3.3.3 The Quasi-Newton Method 43
3.3.4. A Combination of Grid Search and Quasi-Newton Method for the Estimation of a Generalized Box-Cox Form 45
3.4 Empirical Findings 47
3.4.1 The Data 47
3.4.2 The Search for the Optimal Transformation Parameters 48
3.4.3 Analysis of Regression Results 53
3.4.4 Elasticities and Their Behavior 58
3.5 Summary and Conclusions 61
4 ALTERNATIVES FOR THE MANAGEMENT OF RESIDENTIAL DEMAND FOR ELECTRICITY IN EL SALVADOR 64
4.1 Introduction 64
4.2 Demand-Side Management 66
4.3 DSM Options for the Residential Sector 67
4.3.1 DSM Alternatives 67
4.3.2 Residential Demand Management Experience Around the World 72

4.4 Feasible Demand-Side Management Alternatives for the Residential Sector in El Salvador 73
4.5 Summary and Conclusions 78
5 CONCLUSIONS AND RECOMMENDATIONS 79
5.1 Overview of the Work 79
5.2 Conclusions 81
5.3 Suggestions for Further Research 82
BIBLIOGRAPHY 84
APPENDICES 92
A Geographic Situation of El Salvador 93
B Computer Programs 94
B.1 FORTRAN Program to Perform Four Dimensional Grid Search 94
B.2 FORTRAN Program for Quasi-Newton Method 98
C Data Used in the Estimations 103
VITA 104

LIST OF TABLES

Table		Page
1.3.1	Net Energy Consumption, by Source, 1989-1990	5
1.3.2	Per Capita Consumption of Electricity in El Salvador, Selected Years	8
1.3.3	Percentage of Salvadoran Families Using Electricity, by End Use and Region, 1987	9
1.4.1	Generation System of CEL: Installed and Available Capacity, December 1991	12
1.4.2	CEL: Average Cost of Electricity Generation by Type of Energy Source, 1980-1991	15
1.4.3	Nominal and Real Average Price of Electricity to the Final Consumer, 1980-1991	17
3.4.1	Optimal Transformation Parameters and Maximum Value of Objective Function for Grid Search Method	49
3.4.2	Grid Search: Frequencies of Possible Values of Transformation Parameters in the Fifty Greatest Values of L	52
3.4.3	Optimal Transformation Parameters and Maximum Value of Objective Function for Quasi-Newton Method	54
3.4.4	Values of Likelihood Function and χ^2 Statistic for Alternative Functional Forms of the Model $E_t = f(P_t, Y_t, A_t, E_t, W_t)$	55
3.4.5	Box-Cox General Form: Parameter Estimates and Standard Errors for the Model $E_t = f(P_t, Y_t, A_t, E_t, W_t)$	56
3.4.6	Transformation Parameters, Regression Coefficients, and Elasticities at Mean Values for the Model $E_t = f(P_t, Y_t, A_t, E_t, W_t)$	59
4.4.1	CEL: Time and Amount of Minimum and Maximum Demand, 1980-1991	75

LIST OF FIGURES

Figure		Page
1.4.1	Total Cost of Sabotage to The Transmision and Generation System and Number of Sabotage Acts, 1980-1991	13
1.4.2	Average Cost and Average Price per Kwh, 1980-1990	18
3.4.1	Likelihood Surface for the Two-Parameter Case	51
4.2.1	Load Shape Modification Objectives	68
4.4.1	Planning and Implementation of Demand-Side Management Programs	77

INTRODUCTION

As is the case of many electricity demand studies in the United States in the mid-seventies, this dissertation was motivated by an energy crisis in El Salvador. Political and environmental problems have severely limited the ability of El Salvador's electric utility to satisfy growing demand requirements. Residential consumption is the most important component of total electricity consumption in the country, and due to the special characteristics of household consumption, this sector is one of the most seriously affected by the crisis.

The purpose of this dissertation is to analyze the determinants and the behavior of residential demand for electricity in El Salvador, and to identify the most appropriate demand-side management options for that sector. An expanded Box-Cox general form is used in order to allow for maximum flexibility in the fit of an equation to the data.

One hypothesis to be tested is that the use of arbitrarily-chosen linear or double-log functional forms would introduce a specification error. A second hypothesis is that, contrary to the assumption of the commonly used double-log form, the values of elasticities are not constant for all values of the explanatory variables.

The Box-Cox model applied here requires the estimation of four different transformation parameters. In this case, the application of the standard grid search method is extremely laborious and may lack accuracy. One of the major contributions of this dissertation is the development of a gradient-based algorithm that permits the reduction of the number of iterations, and that provides more accurate results. Computer programs were written for both grid and gradient searches, and a comparison is made in terms of results and computational effort.

Results of electricity demand studies are generally used by electric utility planners in the formulation of pricing and investment plans. Traditionally, demand projections are used to determine the increased generating capacity required to satisfy future demand. However, increasing costs and environmental concerns have caused a change in the approach to utility planning, and demand is no longer seen as given. Electric utilities everywhere are now using their knowledge of the factors that determine electricity consumption to design instruments for the manipulation of demand through changes in consumption patterns .

In the case of El Salvador, the financial and physical limitations of the electric utility make demand management a very attractive alternative to complement supply-expansion measures. For this reason, this dissertation describes demand-side management measures used by electric utilities around the world, and identifies those options that deserve consideration and detailed analysis on the part of utility planners in El Salvador. Suggestions are given as to the steps necessary for the analysis and implementation of these measures.

The dissertation is divided into five chapters. The first chapter provides an overview of the production and consumption of electricity in El Salvador and of the circumstances that have led to the current crisis. Chapter 2 reviews the literature dealing with theoretical and empirical issues relevant to the estimation of the residential electricity demand equation. Chapter 3 contains the description of the model to be used, including the variables and the functional form chosen; the exposition of the estimation technique; and the empirical results and their interpretation. Chapter 4 contains a description of the demand-side management alternatives utilized by electric utilities in other countries and identifies the most appropriate options for El Salvador. The conclusions of the study and suggestions for further research are presented in Chapter 5.

CHAPTER 1

THE ENERGY CRISIS IN EL SALVADOR

1.1 INTRODUCTION

A rush of energy demand studies in the United States was precipitated by the oil crisis of the mid seventies. Concerns over energy security and the construction of a national energy policy raised interest in the study of the factors that determine energy demand. An energy crisis of a different nature has motivated this study. In El Salvador, political and environmental problems have seriously hindered the country's capacity to meet the increasing requirements for electricity, and the residential sector is one of the most affected by this crisis.

The purpose of this chapter is to present an overview of the conditions in the electricity-producing and consuming sectors in El Salvador. Section 1.2 provides some general information about the country. Section 1.3 is concerned with the importance of electricity for the Salvadoran economy, especially for the residential sector. Section 1.4 provides background information on the generation and distribution of electricity in El Salvador. Section 1.5 describes the circumstances that led to the crisis that the electric power industry is facing.

1.2 EL SALVADOR: GENERAL INFORMATION

El Salvador is a Central American nation with an area of approximately 21,000 square kilometers and a population of 5.1 million. The capital city is San Salvador. The map in Appendix A shows the location of the country relative to the United Sates.

In 1991, 44 percent of the population lived in urban areas, and per capita gross

national product was approximately 1,070 U.S. dollars. According to data from the World Bank, in 1989 the agricultural sector contributed 12 percent of the gross domestic product, while 21 percent corresponded to the industrial sector and 67 percent to the services sector.

From 1979 to 1991, El Salvador was afflicted by a civil war which affected the course of all economic activities and caused serious infrastructure destruction. Bridges, highways, water distribution, electric and telephone networks were severely damaged. In January of 1992 a peace agreement was signed by the guerrilla leaders and the right-wing government, bringing an end to the conflict. A United Nations peace-keeping force has since been deployed in El Salvador to insure the compliance of the terms of the agreement by both parties involved in the confrontation.

1.3 ELECTRICITY CONSUMPTION

1.3.1 The Structure of Energy Use in El Salvador

Energy use in the residential sector is the most important component of total energy consumption in El Salvador. Residential and commercial consumption constituted almost 52 percent of net energy consumption in 1990[1], while the industrial and agricultural sectors combined represented only 22 percent of total energy use.

Wood still provides more than half of all the energy consumed by the different sectors of the Salvadoran economy. Petroleum derivatives and electricity are second and third, respectively, in relative importance. The shares of the different sources of energy in total net energy consumption are presented in Table 1.3.1.

As can be seen from the table, wood consumption decreased by 1.5 percent from 1989 to 1990. More importantly, its share of total energy consumption decreased. It is

[1] The source of these data considers residential and commercial as one group for all reporting purposes.

Table 1.3.1 Net Energy Consumption, by Source,1989-1990.

	1989		1990	
Source	Tcal*	%	Tcal	%
Wood	10,133.0	53.1	9,979.2	50.6
Petroleum Derivates	6,698.1	35.1	7,091.5	5.9
Electricity	1,532.2	8.0	1,663.5	8.6
Vegetal Residues	627.1	3.3	902.7	4.6
Charcoal	104.8	0.5	103.1	0.5
TOTAL	19,095.2	100.0	19,740.0	100.0

* Teracalories (1 Tcal = 10^{12} calories)

Source: Comision Ejecutiva Hidroelectrica del Rio Lempa, CEL (1990). *Balance Energetico Nacional* .

expected that wood use will continue this decreasing trend in the near future. In 1990, wood made up 85 percent of household fuel consumption and 28 percent of industrial fuel use.

The widespread use of wood as fuel is a consequence of the socioeconomic conditions of the country, since it is one of the most affordable fuels available. Wood is not considered a "commercial" source of energy, since most of the wood used in different activities is collected by the users or bought from small-scale distributors. However, its indiscriminate use is causing deforestation and other ecological problems. For this reason, the government is attempting to discourage the use of wood, or at least promote the use of efficient wood-burning appliances.[2]

The use of petroleum-derived fuels for the industrial and transportation sectors shows an increasing trend over time. Fuel oil represents more than 70 percent of industrial fuel use in 1990. Fuel and diesel oil are basically the only sources of energy utilized in transportation activities. Household use of oil products is less significant: Liquefied Petroleum Gas (LPG), kerosene, and diesel and fuel oil represent 4, 1, and 0.1 percent of total residential consumption, respectively. Imports of crude oil and petroleum derivatives impose a heavy financial burden on the national economy since the country does not have any petroleum-producing capacity. Petroleum derivatives are also used as a primary source of energy in the generation of electricity, although they are not sources. Diesel-operated power plants are considered emergency resources.

Generation of electricity is discussed in Section 1.4. The following section is concerned with the importance of electricity for the different economic sectors, especially the residential sector.

---

[2] CEL (1990a)

1.3.2 The Importance of Electricity in the Salvadoran Economy

The relative weight of electricity in the national energy consumption is expected to rise in the near future as the relative weight of wood decreases. Table 1.3.2 shows the evolution of per capita consumption of electricity in this century. Aggregate and per capita consumption of electricity in El Salvador increased rapidly between the 1940s and the 1970s. The growth rate slowed during the 80s due mainly to supply restrictions.

In 1991, electricity made up almost 10 percent of total household energy consumption. The main household uses of electricity are lighting, refrigeration, cooking, ironing of clothes, and entertainment (operation of television sets, radios, etc.). The importance of electricity for households varies from urban to rural areas. For example, according to a recent survey[3], 93 percent of the households in the San Salvador metropolitan area use electricity for lighting their dwelling units, against 34 percent in the rural areas. Table 1.3.3 shows the percentage of families using electricity for different purposes in the metropolitan area, the urban-provincial areas, and the rural areas.

The differences shown in the table are a result of the lack of electricity availability in many rural areas. Rural electrification projects are underway but they have been obstructed by political and financial problems. In 1990, only 25 percent of the inhabitants in rural areas had access to electricity. If electrification projects stay on course in the near future, it is estimated that by the end of the next decade, more than 70 percent of the rural population will have access to the service.[4]

1.4 GENERATION AND DISTRIBUTION OF ELECTRICITY

1.4.1 Historical Background

Electricity was first produced for commercial purposes in El Salvador in 1890,

---

[3] The CEL/BID survey described in Section 3.2

[4] CEL (1991a).

Table 1.3.2 Per Capita Consumption of Electricity in El Salvador Selected Years

(Kg. of Coal Equivalent per Inhabitant)

Year	Per Capita Consumption
1920	40
1937	40
1950	68
1960	117
1970	192
1971	197
1972	199
1973	241
1974	234
1975	230
1976	251
1977	259
1978	260
1979	261
1980	199
1981	186
1982	177
1983	185
1984	179
1985	175
1986	166

Source: SALA 1990.

Table 1.3.3 Percentage of Salvadoran Families Using Electricity, by End Use and Region, 1987.

	Region		
End Use	SSMA*	Urban-Province	Rural
Cooking	10.1	2.0	0.0
Lighting	93.1	86.5	33.5
Ironing	49.4	74.5	27.1
Refrigeration	48.9	49.7	11.2

* San Salvador Metropolitan Area

Source: Martinez Montalvo et al (1987). *Demanda de Energia por Uso Final en el Sector Residencial, Area Urbana y Rural* (CEL/BID Survey).

when a group of private investors founded Compañía de Alumbrado Eléctrico de San Salvador (Electric Lighting Company of San Salvador (CAESS)). A steam plant was installed to provide electric lighting to the inhabitants of downtown San Salvador. Four years later, a hydroelectric plant was built just outside the capital city in order to use the waterfalls existing in the vicinity as a cheap source of energy. Other firms were established to provide electricity to other major cities, but by 1929 CAESS had acquired several of them, dominating the supply of electricity in about one-third of the national territory. At the time, all electricity was produced either thermally or through small hydroelectric plants.

In 1945, the government created the Comisión Ejecutiva del Río Lempa (Executive Commission of the Lempa River (CEL)) for the purpose of studying industrial, agricultural, social, and sanitation issues associated with the building of a dam on the Lempa River, the longest river in the country. The dam was built during the 1950s, and a government decree in 1950 declared CEL in charge of all energy production in the country. At that point, CAESS and the other electricity providers received 30-year concessions to distribute the electric energy generated by CEL.

Three new dams were built during the 1970s and 80s, making electricity relatively cheap. In addition, the possibility of new sources of energy for the generation of electric power started being considered during the 1970s. By the end of the decade, a geothermal plant was built in the western part of the country.

The concessions to CAESS and the smaller distributors of the electricity produced by CEL ended in 1986. From that time, the administration of such firms shifted to the government, and they are now managed by CEL. Eighty-eight percent of the national market is covered by those distributors, and the rest--mostly rural areas and government

institutions--is served directly by CEL's distribution division, DISCEL.[5]

1.4.2 Current Generation Capacity

By December 1990, CEL's electric power generation system included four hydroelectric, one geothermal, and five thermal plants. Installed and available capacity are shown in Table 1.4.1. Installed capacity refers to the total electric power that can be generated according to the specifications of the equipment. Available capacity refers to the electric power that can actually be generated given the current conditions of the equipment. As is apparent from these figures, hydroelectric installations constitute almost 60 percent of installed capacity, the rest of the capacity corresponding to diesel-operated and geothermal plants (25 and 15 percent, respectively).

The civil war, which began in 1979, severely affected the generation and distribution of electricity in the country. Between 1981 and 1990 there were 7,730 attacks to transmission and sub-transmission lines. The total cost of sabotages to the electric system is estimated at 400 million colones[6] (approximately U.S. $50 millions). Figure 1.4.1 shows the evolution of the number of sabotage acts and of total sabotage costs per Kwh from 1978 to 1990.

Most of the investments made by CEL during the 80s, with the exception of the development of geothermal energy sources, were directed at replacing damaged equipment and transmission lines. The second column of Table 1.4.1 illustrates the effect of sabotages and obsolescence on the percentage of installed capacity which is available for electricity generation--only 85 percent of hydroelectric capacity and less than 50 percent of thermal capacity.

---

[5] FUSADES (1991), p. 91.

[6] FUSADES (1991), p. 95.

Table 1.4.1 Generation System of CEL: Installed and Available Capacity, December 1991.

	Installed Capacity		Available Capacity	
Type	Mw	Percent[a]	Mw	Percent[b]
Hydraulic	388.0	59.7	326.1	84.0
Geothermal	95.0	14.6	47.3	49.8
Thermal	167.4	25.7	104.7	62.5
Total	650.4	100.0	478.1	73.5

[a] Percentage of total installed capacity.

[b] Percentage of installed capacity for each type.

Source: CEL (1991b). *Estadisticas Electricas, Boletin No. 22.*

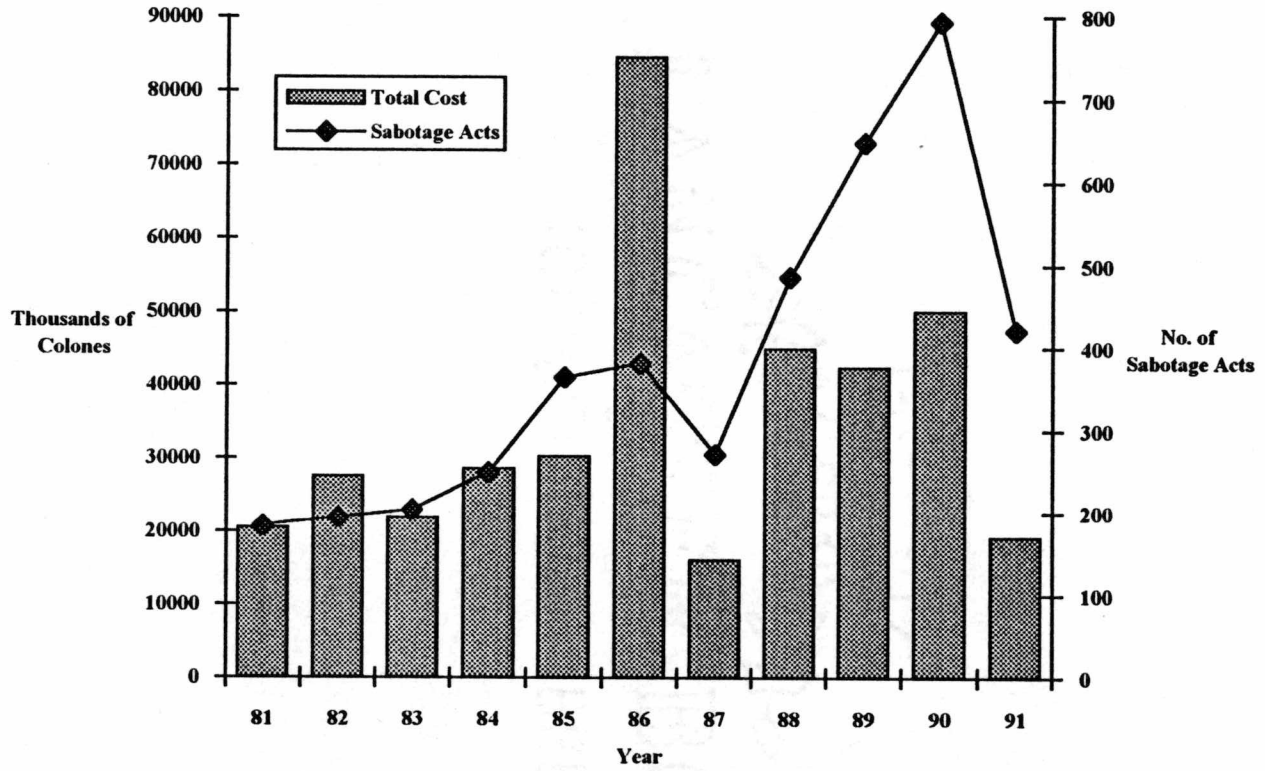


Figure 1.4.1 Total Cost of Sabotage to the Transmission and Generation System and Number of Sabotage Acts, 1980-1991.

Note: Based on data provided by personnel of the Strategic Planning Division of CEL.

1.4.3 Costs and Prices

Damage to the hydroelectric plants and droughts during the recent years have forced CEL to increase the use of diesel-operated thermal plants. Table 1.4.2 shows average cost of generation by type of primary fuel from 1988-1990. The figures show that generation cost per Kwh for diesel-operated plants is more than 5 times greater than the cost for hydroelectric power. As a consequence of the shift from hydraulic to thermal generation, the average cost per Kwh increased by more than 100 percent between 1989 and 1991.

In addition to generation costs, the total cost of producing one Kwh includes the cost of institutional security, sabotage costs, and financial and administrative costs. These components have also increased considerably during the past decade and, as a consequence, the total cost per Kwh has gone from 0.055 colones in 1978 to almost 0.45 colones in 1991.

Increasing costs have considerably raised CEL's debt, since the price paid by consumers is much lower than the cost of production. Historically, and especially during the past decade, pricing of electricity in El Salvador has been based on political rather than economic or financial criteria, and the tariffs seldom reflect production costs. The shift from the use of hydraulic to thermal power has contributed to widening the gap between generation costs and price.

The mean price of electricity for residential consumers in 1990 (0.27 colones/Kwh) was the lowest among Central American countries[7] and one of the lowest in Latin America.[8] The situation is similar for industrial and commercial customers. The slow growth of electricity prices, combined with severe inflation in the 1980s, have contributed

[7] CEL 1990b.

[8] OLADE 1989.

Table 1.4.2 CEL: Average Cost of Electricity Generation by Type of Energy Source, 1980-1991 (In current Colones* per Kwh)

	Type			
Year	Hydraulic	Geothermal	Thermal	Average
1980	0.0.139	0.0254	0.8717	0.0199
1981	0.0220	0.0298	0.3333	0.0387
1982	0.0205	0.0382	0.3030	0.0430
1983	0.0178	0.0376	0.3418	0.0383
1984	0.0355	0.0377	0.4215	0.0517
1985	0.0343	0.0535	0.3751	0.0616
1986	0.0462	0.0789	0.7021	0.0800
1987	0.0548	0.0780	0.2516	0.0939
1988	0.0511	0.0767	0.2931	0.0871
1989	0.0534	0.0778	0.3707	0.0843
1990	0.0541	0.1383	0.5926	0.1066
1991	0.0702	0.0853	0.5693	0.2042

* US $1 approximately equals 8.70 colones in 1993.

Source: CEL (1991b).

to a loss in the real value of such prices, as can be seen in Table 1.4.3.

An increasing-block tariff scheme, which charges a higher price per Kwh to those who consume more electricity, is currently used. The alleged purpose of this tariff structure is to discourage wasteful consumption of electricity. Overall, however, the tariffs are too low to have an effect on customers' behavior. This situation is discussed in detail in Chapters 2 and 3.

The gap between prices and costs in the last decade is shown in Figure 1.4.2. CEL's planners, along with others, have recently called for a change in the tariff structure in order to generate the revenues necessary to cover the costs of production. Furthermore, the existence of various cross-subsidies in the current structure needs to be examined. However, pricing decisions are still being made mainly on political grounds.

1.5 THE CRISIS

As population and other determinants of aggregate consumption of electricity increase, the demand for this source of energy is expected to grow. The lack of investments during the war period and the deficit created by the problems mentioned above make it very difficult for CEL to meet new electricity demand.

Very short rainy seasons during the past two or three years, have further hindered electricity generating capacity. In February of 1992, the level of water in El Salvador's four dams was so low that electricity had to be rationed to the point of being provided only 16 hours a day. A similar situation was expected for 1993.

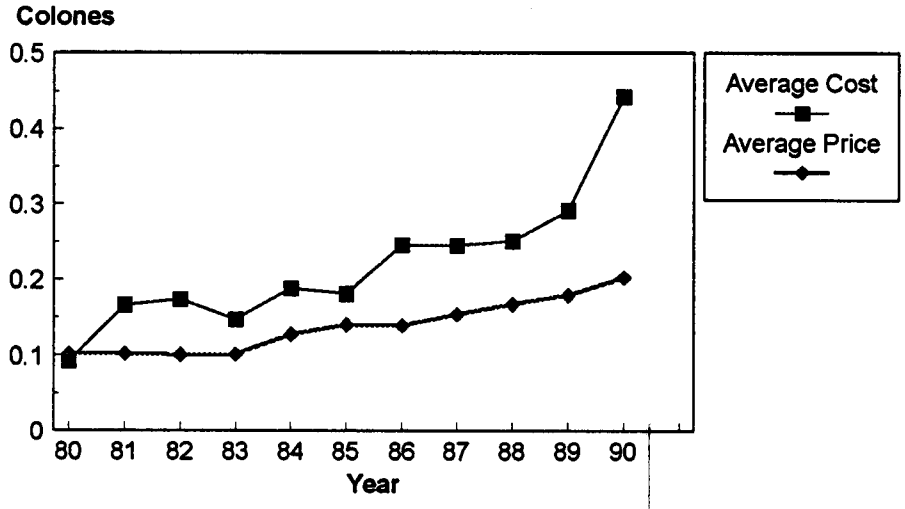
The residential sector is one of the most affected by rationing. Productive activities in the industrial sector can be scheduled to accommodate the times of the day when the electricity flow is not interrupted. Furthermore, many factories and commercial establishments in the country have emergency electrical plants. The nature of household electricity use and the low income of the majority of the families in the country make it

Table 1.4.3 Nominal and Real Average Price of Electricity to the Final Consumer, 1980-1991

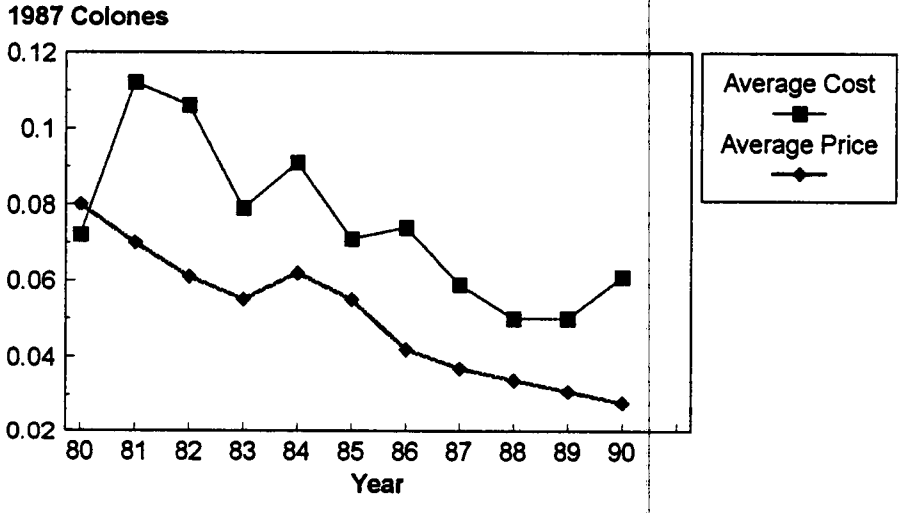
Year	Average Nominal Price (Colones/Kwh)	Average Real Price (1978 Colones/ Kwh)
1980	0.1320	0.1035
1981	0.1340	0.0915
1982	0.1340	0.0819
1983	0.1321	0.0714
1984	0.1600	0.0774
1985	0.1700	0.0672
1986	0.1750	0.0525
1987	0.1900	0.0455
1988	0.2100	0.0421
1989	0.2250	0.0383
1990	0.2560	0.0352
1991*	0.3582	0.0431

* Estimated.

Source: CEL (1991a). *El Salvador: Perspectivas de la Demanda de Energia Electrica 1991-2010.*



a) Nominal Values



b) Real Values

Figure 1.4.2 Average Cost and Average Price per Kwh, 1980-1990.

Source: CEL (1991b).

very difficult to resort to the same measures as the other sectors.

CEL's strategic planning division, PLANICEL, has formulated capacity expansion plans that include the development of new sources of geothermal energy, the acquisition of additional thermal plants, and even the development of other hydroelectric projects. The possibility of managing the demand by means of appropriate tariff structures or rationing schemes is mentioned in several of PLANICEL's documents, but no definite proposals have been presented. One of the objectives of this dissertation is to provide recommendations on the type of instruments that constitute the best alternatives for management of demand in the residential sector given the factors that determine household consumption of electricity and the country's financial situation.

CHAPTER 2

ISSUES ON RESIDENTIAL DEMAND FOR ELECTRICITY: A SURVEY

2.1 INTRODUCTION

Studies of demand for energy are useful tools for planners and policy-makers at both the government and private levels everywhere. In particular, analyses of demand for electricity are considered important because they provide information that can be used by electric utilities in their investment and pricing decisions. Although the earliest econometric studies of energy demand can be dated back several decades, the oil crisis of the mid-seventies gave rise to a large number of empirical works on demand for electricity and other energy sources in the United States and other industrialized countries. Similar studies in non-oil producing developing countries in the past twenty years have been motivated by the importance of energy in their economies and the weight of energy imports on their trade balance.

The determinants of electricity demand vary across sectors of the economy. For this reason, sectoral studies yield more meaningful results than analysis of total consumption of a given energy source.[1] Studies of electricity demand in developed nations generally use this approach and deal separately with electricity demand in one or more of the main sectors of the economy--industrial, commercial, residential, and agricultural.

In developing countries, however, the lack of reliable data has been an obstacle to the conduction of sectoral studies. Most early studies of energy demand for those countries look at total demand for an energy source or at energy consumption as a whole.

[1] Munasinghe (1990b).

Fortunately, the development of reliable sources of data in recent years has opened the door for more research on the factors that determine the consumption of electricity in different economic sectors.

Among the different components of total electricity demand in any country, the residential sector is one of the most important and, consequently, it has received a great deal of attention on the part of researchers. In El Salvador, the largest fraction of energy consumption corresponds to the residential sector, but little work has been put into the study of the factors that determine the behavior of residential electricity demand.

The purpose of this chapter is to review previous works on residential demand for electricity in both developed and developing countries. Although literature is abundant and covers a wide variety of issues, this chapter concentrates on those studies dealing with issues relevant to the scope of this dissertation.

2.2 REVIEW OF PREVIOUS STUDIES OF RESIDENTIAL ELECTRICITY DEMAND

Most of the existing empirical literature on residential demand for electricity focuses on industrialized countries. In the first published econometric study using computers for the calculation of least squares estimates[2], Houthakker (1951), uses cross-sectional data for 42 towns in the years 1937 and 1938 to estimate a double-log equation for average annual residential electricity consumption in the United Kingdom as a function of average household income, marginal price of electricity, marginal price of gas, and the average holdings of heavy domestic equipment per customer.

On residential electricity demand in the United States, one of the earliest published studies is that of Fisher and Kaysen (1962), who analyze industrial and residential consumption of electricity by estimating demand functions based on aggregate time-series

[2] Berndt (1991), p.328

data for 47 states. Their analysis of the residential sector includes the estimation of double-log equations for the short-run and long-run demand.

Many other studies of residential demand for electricity in the U.S., England, Canada, Japan, and other industrialized countries have been undertaken during the past 40 years. Taylor (1975), Hartman (1979), and Kouris (1983) present surveys of the existing literature at the time of their publication. Empirical research on residential demand for electricity in developing countries is less copious. Bhatia (1987) and Westley (1992) present surveys of literature on energy demand in developing nations. Some of these works are reviewed in Section 2.2.3 below.

Empirical works dealing with both developed and developing nations generally use time-series or cross-sectional, aggregate or disaggregate data in order to investigate the relationship between the household consumption of electricity and a number of economic, socio-demographic, and climatic variables. The following sections examine the works whose methods and/or conclusions are of interest for the study of residential demand for electricity in El Salvador. To facilitate the exposition, the works have been grouped according to the main issues that arise when deciding the variables to be included and the functional form to be used in this type of demand equation.

2.2.1 Short Run versus Long Run

Wilson (1971), after an analysis of cross-sectional data for 77 cities in the U.S., concludes that the price of electricity is the most important determinant of residential demand for electricity in the United States and that the demand for electricity is price elastic. Results from other empirical works, such as those surveyed by Kouris (1983) suggest that this conclusion applies to the long run only, while in the short run the household demand for electricity tends to be price inelastic.

The difference between short-run and long-run elasticity is attributed to the fact

that electricity demand is derived from "the demand for services that involve electricity-using equipment...[which is usually] long-lived and durable",[3] and therefore in the short run the demand for electricity is tied to the stock of electricity-consuming equipment, while in the long-run it varies directly with changes in such a stock.

The first econometric study to distinguish explicitly between short and long run residential demand for electricity is that of Fisher and Kaysen's (1962). The importance of variations in the stock of electricity-using appliances on the long-run variations in household consumption of electricity leads them to identify long-run demand for electricity with the stock of a series of electricity-consuming capital goods, or "white goods," which they consider a function of per capita permanent income, per capita personal income, price of the white good in question, price of gas-using substitutes, and other variables. In the short run, residential electricity demand is identified with the rate of utilization of the stock of "white goods," which is a function of the average price of electricity and real per capita personal income.

Subsequent works, especially those working with micro data, attempt to include the stock of electric appliances among the explanatory variables. For example, Garbacz (1984), using data from the 1980 National Interim Energy Consumption Survey, estimates simultaneously an equation for residential electricity demand and an equation for appliance stock. The survey provides information on the type and number of appliances owned by each household in the sample, and the author uses an Electric Appliance Index to obtain a homogeneous measure of appliance stock for each observation.

It is very difficult, however, to find accurate measurements of appliance stock when aggregate data are used. To avoid such difficulties, Houthakker and Taylor's (1970) specification of a flow adjustment model has been used by several researchers, including Shin (1985) and Chang and Hsing (1991). In the flow adjustment model it is assumed that

---

[3]Berndt (1991) p. 308.

the long-run desired consumption of electricity, E_t^* , is affected by a set of explanatory variables $X_1,..., X_k$. For convenience, this relationship is specified as a double-log equation:

$$\ln E_t^* = \beta_0 + \beta_1 \ln X_{1t} + ... + \beta_k \ln X_{kt} + U_t , \qquad (2.2.1)$$

where U_t is assumed to be normally distributed with mean zero and constant variance. The model further assumes that consumers are constantly attempting to bring actual consumption of electricity, E_t, to the desired level, but "within any time period they are only partially successful in doing so."[4] Therefore, at any given time, the ratio of actual demand in the current period to the actual demand in the preceding period is proportional to the ratio of the desired demand in the current period to the actual demand in the preceding period:

$$\frac{E_t}{E_{t-1}} = \left(\frac{E_t^*}{E_{t-1}} \right)^{\Theta} \qquad 0 < \Theta \leq 1, \qquad (2.2.2)$$

or, equivalently,

$$\ln E_t^* = \frac{1}{\Theta} \ln E_t - \frac{1-\Theta}{\Theta} \ln E_{t-1} . \qquad (2.2.3)$$

Since E_t^* is unobservable, for empirical estimation, equation (2.2.3) is substituted into (2.2.1) to obtain an expression involving observable variables only:

$$\ln E_t = \Theta\beta_0 + \Theta\beta_1 \ln X_{1t} + ... + \Theta\beta_k \ln X_{kt} + (1-\Theta) \ln E_{t-1} + \Theta U_t , \qquad (2.2.4)$$

where, given the double-log specification, $\Theta\beta_i$ and β_i can be interpreted as the short-run and long-run elasticities of E_t with respect to X_{it}, respectively.

The flow adjustment model can also be specified in linear and nonlinear form. Chang and Hsing (1993) use a general form flow adjustment model in their analysis of the demand for higher education.

---

[4]Berndt, p.315.

2.2.2 The Price Variable

The fact that consumers of electricity face a "multi-step block price schedule," rather than a single rate, poses a special problem for the study of electricity demand. Taylor (1975) points out that the presence of a price schedule rather than a single price for electricity makes the budget constraint nonlinear and non-convex, causing a series of theoretical problems, namely, that the equilibrium of the consumer cannot be derived using differential calculus, that demand and Engel curves are not continuous, and that the demand curve is not single-valued. He admits, nevertheless, that the relevance of such problems is more theoretical than practical.

Of more practical importance is the problem of which variable should be used to measure the effect of price changes on demand for electricity. Many works, including that of Houthakker (1951), assume "that a well-informed consumer facing multiple prices responds to marginal price rather than average price because he [or she] equates benefits with costs at the margin."[5] Taylor, however, points out that marginal price is relevant to an individual's decision only when he is consuming in the block to which the price concerns, but it does not determine the choice between consuming in that block and consuming in any other block. He recommends the use of both marginal and average price in order to capture all the factors involved in the consumers decision process.

Shin (1985) presents empirical evidence that "rational" residential consumers of electricity do not necessarily respond to marginal prices due to the substantial cost of determining the actual marginal price corresponding to the different levels of consumption. He argues that determining the true marginal price is costly to consumers because they "may not be aware of the declining block nature of electricity prices," and consequently, they "may not recognize the difference between marginal and average price and its effect on [their] consumption". Even in the case that a consumer recognizes the existence of

---

[5] Shin (1985), p. 594.

declining block rates, the complexity of the rate schedule and billing statements would make it difficult for an ordinary customer to process relevant information at a reasonable cost. Furthermore, even a "sophisticated consumer ... would over- or underestimate the marginal price if there is a switch in the marginal block ." Finally, additional information such as fuel adjustment clauses is available only ex-post, making it impossible for the consumer to adjust his estimate of the marginal price.[6] His alternative hypothesis is that, given the high cost of determining actual marginal prices, rational consumers respond instead to the average price as perceived from the electricity bill.

Using pooled data for the period 1960-1980 on seven Ohio utilities, Shin applies a flow adjustment model to find evidence for his hypothesis. He considers the desired consumption of electricity as a function of mean real per capita personal income, the *perceived* real price of electricity, the average real price of natural gas, and heating and cooling degree days. The perceived price of electricity , P_t^*, is a function of average price, AP_t, marginal price, MP_t, and a price perception parameter k such that

$$P_t^* = MP_t\left(\frac{AP_t}{MP_t}\right)^k . \qquad (2.2.5)$$

If k is equal to zero, then perceived price is equal to marginal price, but if k is equal to one, the perceived price is equal to the average price. Based on the empirical results, the hypothesis that k is equal to zero is rejected, but the hypothesis that k is equal to one cannot be rejected, leading to the conclusion that "rational" consumers of electricity respond to average prices because it is too costly to determine actual marginal prices.

The use of ex-post average price as an explanatory variable has received additional criticism due to the loss of desirable properties of the OLS estimates caused by the simultaneity in the determination of quantity consumed and the average price. This simultaneity generally results in biased and inconsistent parameter estimates. However,

---

[6]Shin, p.592.

Betancourt (1981) maintains that the bias resulting from the use of average price is very close to zero and of unknown sign.

2.2.3 Residential Electricity Demand in Developing Countries

Most studies of demand for energy in developing countries have been concerned with wood and fuel oil (e.g., Dunkerley et al (1990); and Hyman (1985)). Some have estimated demand functions for energy as a whole; for example, Pougerami and von Hirschhausen (1991) use time-series data to study total energy consumption in Bangladesh and India, as a function of each country's gross domestic product, the general price index for energy, and population.

The literature on residential electricity demand in developing countries is considerably more limited. Dias-Bandaranaike and Munasinghe (1983) look at the effect of the quality of supply on residential consumption of electricity using pooled time series and cross-sectional data from nine rural electric networks in Costa Rica. Berndt and Samaniego (1984) estimate an equation for residential demand for electricity in Mexico. Their results, plus those of studies of residential electricity demand for Costa Rica, Paraguay, and the Dominican Republic, are reported by Westley (1992).

Glackpe and Fazzolare (1985) analyze household electricity consumption in the residential sector for seven West African countries. Their model considers total electricity consumption in the residential sectors as a function of the average real price of electricity, total real disposable income, and the number of households with access to electricity.

Berndt and Samaniego address a very important issue in electricity demand studies in developing nations--household's access to the service. They point out that for industrialized countries the distinction between access and consumption may be superfluous since "for already some considerable time, virtually all households have enjoyed access to electricity." The situation is much different in developing nations, where

electricity consumption is not an option for a large proportion of households, especially in the rural areas. Increased access through electrification projects is thought to be responsible in part for the growing demand for energy in many developing countries.

There is much discussion on the issue of price and income elasticities in developing countries as compared with those in developed countries. Pindyck (1979) suggests that, for any given energy source, income elasticities of residential demand should be higher in low-income countries than in high-income countries:

> as incomes rise, additional expenditures are not allocated proportionately to larger homes or to more heat or light in existing homes. Thus expenditures in energy ... represent a large fraction of the consumer budget when incomes are low but a smaller fraction as incomes rise.[7]

Similarly, he claims that price elasticities of residential demand for an energy source should be lower in less developed countries because

> at low levels of income most energy is consumed as a necessity, while as incomes grow the additional use of energy becomes more discretionary, allowing for greater substitution away from energy prices.[8]

However, this is not necessarily true in the case of residential electricity demand. The results of Glackpe and Fazzolare's (1985) study show that for all but one of the West African countries included in their study, the short-run elasticities fall in the same range of values as those for the developed countries reported in Taylor's (1975) survey. A similar situation regarding Latin American countries is reported by Westley (1992)

Westley points out a very important difference between countries like the U.S. and Latin America regarding interfuel substitution. He indicates that in the United Sates there are close substitutes for electricity in the major residential end-use areas--space and water heating, cooking, and clothes drying. Demand studies in Latin America show only one case of significant competition between electricity and other fuel-- LPGs for cooking in

---

[7] Pindyck (1979), p. 250.

[8] Ibid.

Costa Rica. In the rest of the countries there is no important inter-fuel substitution in any end-use area.[9]

In El Salvador, the only estimations of electricity demand equations are those of PLANICEL. They use a double-log equation to specify total consumption of electricity in the residential sector as a function of the quantity consumed in the preceding period, the mean price of electricity, the number of residential customers, national disposable income, and the total number of dwelling units in the country. Their estimations yield a price elasticity equal to -0.06. However, test statistics suggest that this coefficient is not significantly different from zero. They attribute the low own-price elasticity to the "low weight that electric energy expenditures have had in family expenditures, given that electricity tariffs have been subsidized."[10] This result agrees with the findings of Glackpe and Fazzolare, who notice that in countries like Nigeria and Ghana, where electricity is considerably inexpensive, the coefficient of own-price elasticity in the regression equation is not significantly different from zero, while in countries where electricity is more expensive, such as Burkina Faso, the price elasticity of electricity demand tends to be higher. According to data from the Latin American Energy Organization (OLADE), El Salvador has one of the lowest tariffs in Latin America--approximately US $0.03 per Kwh against US $0.19 per Kwh in Grenada and Haiti.

2.2.4 The Functional Form

PLANICEL's estimations, as well as the majority of works in both developed and underdeveloped countries, use a double-log form for their demand equation. Such a form is generally chosen because it is easy to estimate, and the regression coefficients are interpreted directly as elasticities.

---

[9]Westley (1992) p.67

[10] CEL (1991), p. 24.

Economic theory does not suggest a specific functional form for electricity demand, and the use of double-log forms imposes, among others, the restriction that elasticities do not vary with the level of prices, income, and other determinants (Plourde and Ryan (1985)). It is generally expected that the absolute value of price elasticity will increase with increases in price and decline with increases in quantity demanded and income. Similarly, income elasticity is expected to decrease with increases in income and consumption and to fall with rises in price.[11]

There have been attempts, such as that of Dias-Bandaranaike and Munasinghe (1983), to formulate logarithmic demand equations with varying coefficients, but such attempts have proven unsuccessful[12]. Lyman (1973) and Chang and Hsing (1991) use the type of general forms suggested by Box and Cox (1964) as a way to avoid the restrictions imposed by the double-log forms. Lyman applies an extended Box-Cox form to analyze residential, commercial and industrial demand for electricity. Chang and Hsing (1991) estimate a simple Box-Cox form using aggregate time-series data from the United States in order to provide evidence that price and income elasticities of residential demand for electricity change over time. Their empirical results support the hypotheses concerning elasticities. The evidence also leads to the rejection of the hypotheses that the functional form is double-log or linear, and therefore to the conclusion that the use of those forms would generally introduce specification error. The Box-Cox transformation method is discussed in Section 3.1.

2.3 SUMMARY AND IMPLICATIONS FOR THIS STUDY

Several issues arise when deciding how to estimate a demand equation for residential electricity. Electricity demand is derived from the utilization of electricity

---

[11] Gemmill (1980) p. 147.

[12] See Plourde and Ryan (1985).

consuming appliances. The stock of appliances is assumed to be fixed in the short run but variable in the long run. It is very difficult to include an explicit measure of this stock in long-run specifications of demand equations when using aggregate data. However, this problem can be circumvented by employing a flow adjustment model. The use of average ex-post price in electricity demand equations has been criticized for theoretical and empirical reasons. However, the use of marginal price also has a number of flaws, and the empirical disadvantages of the use of average price have not been shown to be considerable. Unlike studies in developed nations, the analysis of residential consumption of electricity in developing countries must take into account the fact that the service may not be available to some sectors of the population. In addition, there may not be close substitutes for electricity in the principal end-use areas. Finally, the functional form to be used should be chosen carefully to fit the behavior of the data, since elasticity estimates and projections from the estimated demand equation are generally the basis for pricing and investment decisions.

CHAPTER 3

RESIDENTIAL DEMAND FOR ELECTRICITY IN EL SALVADOR

3.1 INTRODUCTION

The search for ways to meet future requirements for electricity in the Salvadoran residential sector, given the financial and physical constraints discussed in Chapter 1, requires the understanding of the factors that determine household consumption of electricity in the country.

The purpose of this chapter is to estimate an equation for residential electricity demand in El Salvador. Three major tasks are involved in the estimation process. The first is the selection of a model that best describes the relationships implicit in the data. This includes the selection of the variables to be included as well as the functional form to be used. The results of this selection are presented in Section 3.2.

The second task comprises the choice of an estimation procedure that provides estimates with desirable statistical properties while optimizing the use of time and resources employed. One of the main contributions of this dissertation is the application of non-linear programming techniques in order to reduce the time and computational effort involved in the estimation, relative to the techniques commonly used in similar applications.

The final task is the application of the chosen techniques to the estimation of the parameters in the model from available data and the evaluation and interpretation of the parameter estimates. These empirical results are contained in Section 3.4. The last section contains the conclusions drawn from the estimation results.

3.2 THE MODEL

3.2.1 Determinants of Residential Demand for Electricity in El Salvador

Residential consumption is the most important component of total consumption of electricity in El Salvador. In 1991, total consumption constituted approximately 1.9 million Mwh, 36.5 percent of which corresponded to the residential sector, 30.4 percent to the industrial sector, 18 percent to the government, and 15.7 percent to commercial consumption; the rest was for public lighting.[1]

Results from the CEL/BID 1987 survey of end-uses of residential energy in El Salvador[2] and studies by the Division of Strategic Planning of CEL (PLANICEL) provide insights into the factors that determine residential consumption of electricity in the country. The CEL/BID survey was conducted on a stratified random sample of Salvadoran households in different areas of the country. The sample included 986 households from the San Salvador metropolitan area (SSMA), 725 from other urban areas, and 604 from rural areas. This is a very comprehensive study. Unfortunately, disaggregated data from the survey are not available for the estimations undertaken in this dissertation.

The price of electricity is considered the most important determinant of residential demand for electricity in many countries,[3] but this does not seem to be the case in El Salvador. PLANICEL's estimations suggest that the response of residential electricity demand to real price changes is insignificant. This phenomenon may be due to the fact that the price of electricity in the country has been subsidized by the government for a long period of time, and the typical electricity bill represents a very small fraction of the consumer's monthly expenditure. The CEL/BID survey shows that the average family income for the sample was 14,773 colones a year, while the average annual expenditure on

[1] CEL (1991b), Cuadro No. 44, p.67.
[2] Martinez et al (1987).
[3] See discussion in Ch.1.

electricity was 181 colones, which is less than 1.25 percent of annual family income.

A deficiency of PLANICEL's estimations is that, by using double-log demand equations, they assume that price elasticity is constant for all price levels. It is the contention of this study that the absolute value of the coefficient of price elasticity of demand varies directly with price, and that, if electricity tariffs in El Salvador were to reflect actual costs, residential electricity demand would be more responsive to price variations. The price variable included in a demand equation for the country should be the mean price, because even though electrical tariff changes are published in the limited-circulation official newspaper, the majority of people are not aware of marginal prices, and, as discussed in Section 2.2.2 above, it is reasonable to assume that they respond instead to mean prices as reflected by the electricity bill.

Consumption of electricity by a given household in El Salvador is subject to the availability of the service. All major cities and most small towns in the country have access to electric energy services. Approximately 90 percent of the dwellings in urban areas have electricity connections; this percentage is even larger in San Salvador's metropolitan area. Although rural electrification projects were initiated in 1965, a large proportion of the rural population still does not have access to electrical services. In 1991, only 33.4 percent of the dwellings in rural areas had electricity connections.[4] Total consumption of electricity in the country should be an increasing function of the percentage of households that have access to the service.

Prices of alternative sources of residential energy are often considered determinants of household electricity consumption since they can be substituted for each other in some circumstances. For example, in the United States, a large proportion of dwellings have access to both natural gas and electricity and they can decide whether to use one or the other for cooking, space and/or water heating, and other uses. In El

[4]CEL/BID Survey, p.46.

Salvador, however, the relationships between electricity and other sources of household energy appear to be of a different nature. Natural gas is not available in the country. The main sources of household energy are wood, electricity, liquefied petroleum gas (LPG), and kerosene, with charcoal, candles, and vegetable residues being used at a smaller scale. According to the 1987 CEL/BID survey, electricity is used mostly for lighting, refrigeration, and operation of household appliances. There are no alternative sources of energy for the latter two. Kerosene is used for lighting in households without electricity connections, but as soon as they have access to electric energy, people shift from kerosene lamps to electric lighting devices, resorting to kerosene and candles only in emergency situations. The choice between kerosene and electricity is then a matter of accessibility and not of price differentials.

The most commonly used cooking fuels are wood and LPG. The CEL/BID survey concludes that electricity can not be considered a substitute for wood or LPG in this use, since only 1.3 percent of the households use electric stoves, while 77.3 percent use wood, and 14.6 use LPG stoves. Moreover, comparisons of energy consumption between 1971 and 1987 indicate that a transition from the use of wood stoves to LPG stoves has occurred in many of the households, especially in those of people migrating from rural to urban areas, but no transitions from the use of wood or LPG to electricity were reported.

The number and type of electricity-consuming appliances owned by the family play an important role in the amount of electricity consumed. In El Salvador, the most common household equipment includes refrigerators, radios, television sets, stereos, and small kitchen appliances. Due to the climatic characteristics of the country, space heating is not necessary, and only a very small percentage of the dwellings have air conditioning or water heating.

In areas where electricity is available, disposable income is an important determinant of a family's use of the service. Data from the CEL/BID survey show that the

average annual consumption of electricity for families with a monthly income of less than 400 colones was 692.4 Kwh, while for families with monthly incomes greater than 2300 colones, average annual consumption was 1752.29 Kwh. A higher income not only makes electricity services more affordable to a household, thereby affecting electricity demand directly, but also has an indirect effect by facilitating the accumulation of a larger stock of electric appliances.

Climatic variables are not likely to influence residential electricity demand since the country's weather makes space heating unnecessary, and very few households have air conditioning or water heating devices.

Finally, it is very plausible that the relationship between quantity consumed and its determinants was somewhat modified by the Civil War that lasted 12 years. Consequently, any demand estimation should account for the influence of the war on electricity consumption.

3.2.2 The Functional Form

Economic theory asserts that the demand for a good depends on the consumer's level of income, the prices of the good and other related commodities, and a number of socioeconomic and demographic variables that affect consumer tastes. Still, the theory does not specify the functional form of those relationships. Empirical demand studies therefore face the problem of deciding what functional form should be used.

As discussed in Section 2.2.5, many researchers use linear forms because they are easy to estimate using the least squares method. Exponential forms are also common since by using logarithmic transformations they can be converted into linear equations, with the additional advantage that the regression coefficients can be interpreted directly as elasticities. However, as Hsing (1989) points out, the choice of functional form should be "a matter of economic theory or empirical evidence, rather than convenience or

simplicity." Linear or logarithmic forms may not be appropriate in many instances, since the relationships implicit in the data are often non-linear and non-exponential, and the assumption of constant elasticities of the latter is very restrictive and generally unrealistic.

The problem of selecting a functional form that captures the relationships suggested by the data can be handled by transforming the variables involved in the relationship in such a way that ordinary least squares can be used in the estimation of the regression parameters, without restricting the function to be a linear or double-log form.

Zarembka (1974) points out that the linear form

$$Y = \beta_0 + \beta_1 X_1 + \ldots + \beta_m X_m, \tag{3.2.1}$$

the double-log or log-linear form

$$\log Y = \beta_0 + \beta_1 \log X_1 + \ldots + \beta_m \log X_m, \tag{3.2.2}$$

and the semi-log form

$$\log Y = \beta_0 + \beta_1 X_1 + \ldots + \beta_m X_m \tag{3.2.3}$$

are all special cases of the general transformation

$$Y^{(\lambda_0)} = \beta_0 + \beta_1 X_1^{(\lambda_1)} + \ldots + \beta_m X_m^{(\lambda_m)}, \tag{3.2.4}$$

where $X_k^{(\lambda_k)}$ indicates that the variable X_k is transformed by some parameter λ_k (k=1,...m). One of the most popular transformations is the one suggested by Box and Cox (1964), where

$$X^{(\lambda)} = \begin{cases} \dfrac{X^{\lambda} - 1}{\lambda}, & \text{when } \lambda \neq 0, \\ \ln X, & \text{when } \lambda = 0 \end{cases} \tag{3.2.5}$$

Even though Box and Cox considered the transformation of the dependent variable only, subsequent works have used the same type of transformation for the independent variables as well. This transformation was originally intended to correct for heteroscedasticity, but it is now used mainly for detecting nonlinear functional forms.[5]

[5]Kmenta (1986), p.521.

Different versions of the Box-Cox transformation have been used in demand studies. Chang (1977 and 1980) applies both a simple Box-Cox form, where the transformation parameter is the same for all variables, and a general Box-Cox form, with a different transformation parameter for each variable, to the study of the behavior of aggregate demand for meat in the United States. Hsing (1989) utilizes an Expanded Box-Cox form, where there is one transformation parameter for the dependent variable and another for all the independent variables, to test the hypothesis of flexible employment elasticities in U.S. manufacturing. The same form is used by Lyman (1973) and Chang and Hsing (1991) to estimate equations of residential demand for electricity in the United States.

3.2.3 The Demand Equation

Since the results of the estimations undertaken in this work are the basis for policy recommendations, it is very important that the functional form chosen fits the data as close as possible. Furthermore, the use of a flexible form would allow for the test of the hypothesis that elasticities vary with the levels of the independent variables. For these reasons, a Box-Cox general form is estimated for the relationship

$$E_t = f(P_t, Y_t, A_t, W_t), \qquad (3.2.6)$$

where E_t is per-capita consumption of electricity for period t; P_t is the mean price of electricity; Y_t is the real per capita disposable income in colones; A_t, the ratio of the number of residential customers to the number of dwellings in the country, is a measure of availability of the service; and W_t is a dummy variable whose value is 1 for the civil war periods and 0 otherwise. To facilitate the exposition, these variables will be called X_1 to X_4, respectively, when convenient.

The stock of household electric appliances is an important determinant of electricity consumption in the Salvadoran residential sector, however no accurate

measures of that stock are available for this estimation. This problem is circumvented by using the flow-adjustment model discussed in Section 2.2.1. The Box-Cox general function for equilibrium per capita consumption of electricity can be written as

$$E_t^{*(\lambda_0)} = \alpha_0 + \alpha_1 P_t^{(\lambda_1)} + \alpha_2 Y_t^{(\lambda_2)} + \alpha_3 A_t^{(\lambda_3)} + \alpha_4 W_t + U_t \,. \qquad (3.2.7)$$

The model assumes that actual per capita consumption of electricity, E_t, is adjusted to the equilibrium quantity, E_t^*, only partially in a given year. A Box-Cox general form is also used for the adjustment equation[6]

$$E_t^{(\lambda_0)} - E_{t-1}^{(\lambda_0)} = \Theta(E_t^{*(\lambda_0)} - E_{t-1}^{(\lambda_0)}) \qquad (3.2.8)$$

The combination of equations (3.2.7) and (3.2.8) yields the demand equation to be estimated:

$$E_t^{(\lambda_0)} = \beta_0 + \beta_1 P_t^{(\lambda_1)} + \beta_2 Y_t^{(\lambda_2)} + \beta_3 A_t^{(\lambda_3)} + \beta_4 W_t + \beta_5 E_{t-1}^{(\lambda_0)} + U_t \qquad (3.2.9)$$

where the short run and long run marginal effects of any transformed variable, $X_{it}^{(\lambda_i)}$, i=1,..,4, on $E_t^{(\lambda_0)}$ are measured by β_i and β_i/Θ, respectively. Note that the lagged variable has the same transformation parameter as the dependent variable.

The short-run marginal effect of any of the original variables, X_{it}, on E_t can be found by reordering the terms of the Chain Rule, which specifies that

$$\frac{\partial E_t^{(\lambda_0)}}{\partial X_{it}} = \frac{\partial E_t^{(\lambda_0)}}{\partial E_t} \frac{\partial E_t}{\partial X_{it}} \qquad (3.2.10)$$

to obtain an expression for $\frac{\partial E_t}{\partial X_{it}}$:

$$\frac{\partial E_t}{\partial X_{it}} = \frac{\partial E_t^{(\lambda_0)} / \partial X_{it}}{\partial E_t^{(\lambda_0)} / \partial E_t} = \beta_i X_{it}^{\lambda_i - 1} E_t^{1-\lambda_0}, \quad i=1,2,3,4. \qquad (3.2.11)$$

The multiplication of (3.2.11) by $\frac{X_{it}}{E_t}$ yields the formula for the short-run elasticity of E with respect to X_i

$$\varepsilon_{X_{it}} = \beta_i X_{it}^{\lambda_i} E_t^{-\lambda_0} \qquad (3.2.12)$$

The long-run elasticities can be obtained by dividing the right hand side of the

[6]Chang and Hsing (1993).

latter equation by Θ, where the value of the adjustment parameter, Θ, is equal to 1 minus the estimated coefficient of the transformed lagged dependent variable.

3.3 THE ESTIMATION TECHNIQUE

3.3.1 The Likelihood Function

Zarembka (1974) proposes the use of a maximum likelihood method to determine the parameters in a Box-Cox general form. Given the model

$$Y_t^{(\lambda_0)} = \beta_0 + \beta_1 X_{1t}^{(\lambda_1)} + \ldots + \beta_m X_{mt}^{(\lambda_m)} + U_t \qquad (3.3.1)$$

where Y_t and X_{kt} (t=1,...,n; k=1,...m) are transformed by λ_0 and λ_k, respectively, as in equation (3.2.5), and the disturbance terms, U_ts, are assumed to be independently and normally distributed with mean zero and constant variance σ^2, that is,

$$f_t(U_t) = \frac{1}{\sqrt{2\pi}\sigma} \exp[\frac{1}{2\sigma^2} U_t^2] \qquad (3.3.2)$$

the probability distribution for the dependent variable Y is given by

$$f_t(Y_t) = f_t(U_t)\left|\frac{\partial U_t}{\partial Y_t}\right| = \frac{1}{\sqrt{2\pi}\sigma} \exp\{\frac{1}{2\sigma^2}[Y_t^{(\lambda_0)} - \beta_0 - \sum_{k=1}^{m} \beta_k X_{kt}^{(\lambda_k)}]^2\} Y_t^{(\lambda_0 - 1)}, \qquad (3.3.3)$$

and the likelihood function for a set of n observations of the dependent and the independent variables and a specific set of λs is given by

$$\ell = f_t(Y_1, \ldots, Y_n) = \prod_{t=1}^{n} f_t(Y_t) = \frac{1}{(\sqrt{2\pi}\sigma)^n} \exp\{\frac{1}{2\sigma^2} \sum_{t=1}^{n} [Y_t^{(\lambda_0)} - \beta_o - \sum_{k=1}^{m} B_k X_{kt}^{(\lambda_k)}]^2\} \prod_{t=1}^{n} Y_t^{(\lambda_0 - 1)}. \qquad (3.3.4)$$

The problem of maximizing the likelihood function in (3.3.4) is facilitated by maximizing instead the log-likelihood function

$$L = \ln \ell = -\frac{n}{2} \ln(2\pi) - \frac{n}{2} \ln \sigma^2 - \frac{n}{2} + (\lambda_0 - 1) \sum_{t=1}^{n} \ln Y_t \qquad (3.3.5)$$

where σ^2 can be estimated by

$$\hat{\sigma}^2 = \frac{1}{n} \sum_{t=1}^{n} [Y_t^{(\lambda_0)} - \beta_o - \sum_{k=1}^{m} B_k X_{tk}^{(\lambda_k)}]^2 \qquad (3.3.6)$$

Simultaneous estimation of the transformation and regression parameters that

maximize (3.3.5) becomes extremely complicated, since it requires finding the optimal values for 2(m+1) unknowns. As indicated below, the process can be simplified by assuming that the transformation parameter is the same for all variables. However, the scope of this work requires the estimation of a different transformation parameter for each variable in the model.

Zarembka (1974) suggests searching over a "reasonable range" of values for the "optimal" set of transformation parameters. For each set of λs in that range, the observed values are transformed as in equation (3.2.5), and the transformed dependent variable is regressed on the transformed independent variables. The problem is then reduced to finding the values of the regression parameters that maximize the log-likelihood function which, disregarding the constant term, can be written as

$$L(\lambda_0,\ldots,\lambda_m) = -\frac{n}{2}\hat{\sigma}^2(\lambda_0,\ldots,\lambda_m) + (\lambda_0 - 1)\sum_{t=1}^{n}\ln Y_t \,. \qquad (3.3.7)$$

If the assumptions of normality, independence, and homoscedasticity hold, the Ordinary Least Squares (OLS) method yields maximum likelihood estimates of the regression parameters. Therefore OLS estimation can be used to compute the value of L for each set of transformation parameters, and some optimization technique can be used to identify the set of λs which maximizes L.

3.3.2 The Grid Search Method

Zarembka's suggestions imply the use of a grid search when looking for the appropriate transformation parameters. This technique involves the evaluation of the likelihood function at a series of grid points generated by successively increasing the values of the parameters by a given step length.

The number of iterations needed for the search depends on the width of the search intervals, the step-lengths, and the number of transformation parameters involved. Substantial computational effort is usually required for this type of search, but it can be

reduced by using simplifying assumptions. For instance, the simple Box-Cox form, which assumes that $\lambda_0 = \lambda_1 = ... = \lambda_m$, facilitates the estimation by reducing the problem to an unidimensional search.

Chang (1977) uses a simple form in his estimation of the demand equation for meat in the U.S. However, his assumption of the same transformation parameter for all variables reduces the flexibility of the Box-Cox general form, and is criticized by Gemill (1980), because its use imposes "unreasonable" constraints on the behavior of price and income elasticities. Gemill suggests that the use of a different transformation parameter for each variable would result in a more desirable behavior of the elasticities.

As a response to Gemmill's comments, Chang (1980) extends his search procedure to the estimation of three transformation parameters, which obviously involves a large number of regressions. He indicates that in his original search for one parameter, 161 regressions were necessary, and if the same range and intervals were used in the search for three parameters, more than four million regressions would be needed. Nevertheless, the widening of the intervals between grid points allows the computational task in that specific application to be reduced to a "manageable scope."[7]

Unfortunately, a very precise grid search cannot be performed when more than three transformation parameters are considered, due to the enormous number of regressions it would require. It is usually advised in those cases to use only two transformation parameters--one for the dependent variable and another for all the independent variables. Lyman (1973) uses such a technique to estimate his equations of electricity demand.

3.3.3 The Quasi-Newton Method

The large number of iterations necessary to find the maximum-likelihood estimates

[7]Chang (1980), p.149.

of the Box-Cox transformation parameters through the standard grid search procedure raises the question of whether other non-linear optimization techniques can be used in order to reduce the amount of calculations involved.

The Quasi-Newton algorithm is one of the gradient based methods that can be used to solve unconstrained minimization problems of the form

$$\min_{\lambda \in \Re^m} f(\lambda), \quad \text{where } \lambda = (\lambda_1,...,\lambda_m)'. \tag{3.3.8}$$

The m×1 vector of first partial derivatives

$$g = (g_1(\lambda), ..., g_m(\lambda))', \quad \text{where } g_i(\lambda) = \frac{\partial f(\lambda)}{\partial \lambda_i}, \ i=1,...,m \tag{3.3.9}$$

is called the *gradient* of the function f, and the m×m matrix of second partial derivatives

$$H = \left[\frac{\partial g}{\partial \lambda_1},...,\frac{\partial g}{\partial \lambda_m}\right], \quad \text{where} \quad \frac{\partial g}{\partial \lambda_i} = \left(\frac{\partial g_1(\lambda)}{\partial \lambda_i},...,\frac{\partial g_m(\lambda)}{\partial \lambda_i}\right)', \tag{3.3.10}$$

is called the *Hessian* matrix of f.

Starting from a given initial point, $\lambda^0 \in \Re^m$, the quasi-Newton method uses the value of the gradient at that point, g^0, to search for a "descent direction" d -- a direction that leads to points where the value of the function is less than the value at λ^0. The direction vector is such that

$$d = - B^{-1} g^0, \tag{3.3.11}$$

where B is a positive definite approximation of the Hessian matrix of the function evaluated at

λ^0.

When a descent direction is found, a line search is conducted to find new point λ^1, where

$$\lambda^1 = \lambda^0 + \theta g^0, \quad \text{for some } \theta \in (0,1] \tag{3.3.12}$$

such that

$$f(\lambda^1) \leq f(\lambda^0) \tag{3.3.13}$$

Once a new point is determined, the algorithm checks for optimality, i.e., it checks

whether the norm of the gradient is approximately equal to zero at that point

$$\|g(\lambda_i)\| = \varepsilon\,, \qquad \varepsilon \approx 0. \tag{3.3.14}$$

If the norm of the gradient is different from zero, the matrix B is updated and a new iteration is performed. Among others, the Broyden-Fletcher, Goldfarb-Shannon (BFGS) formula can be used for such an update

$$B \leftarrow B - \frac{Bss'B}{s'Bs} + \frac{yy'}{y's}, \tag{3.3.15}$$

where $s = \lambda^1 - \lambda^0$ and $y = g^1 - g^0$. An identity matrix can be used as the initial B.

Although this algorithm is designed to solve minimization problems, the problem of maximizing the likelihood function considered in this dissertation can easily be transformed into a minimization problem by simply changing the sign of the objective function.

Zarembka's reference to a "reasonable range" for the values of the transformation parameters of the Box-Cox general form suggests that the problem of maximizing the likelihood function is one of constrained optimization. This can be considered a case of a non-linear objective function with linear inequality constraints, where the latter are the lower and upper bounds for the transformation parameters.

Even though the Quasi-Newton method is a method generally used in unconstrained minimization problems, it can be modified to serve in constrained situations. The constrained problem is of the form

$$\min_{\lambda \in \Re^m} f(\lambda)$$

$$\text{subject to } l \le \lambda \le u \quad , \tag{3.3.16}$$

where $l = (l_1, \ldots, l_m)'$ and $u = (u_1, \ldots, u_m)'$.

The set $\Lambda = \{ \lambda \in \Re : l \le \lambda \le u \}$ is called the feasible region of the problem, and the index set $I = \{ i : \lambda_i = l_i \text{ or } \lambda_i = u_i \}$ (i.e., the set containing the indices of the variables which are at their bounds) is called the active set. Variables not in the active set are called "free" variables.

In the modified Quasi-Newton method, the gradient and the Hessian are computed with respect to the free variables only. The search direction for the variables in I is set to zero. The optimality conditions in this case are

$$\|g(\lambda_i)\| = \varepsilon \qquad l_i < \lambda_i < u_i; \tag{3.3.17}$$

$$g(\lambda_i) < 0, \qquad \lambda_i = u_i; \text{ and} \tag{3.3.18}$$

$$g(\lambda_i) > 0, \qquad \lambda_i = l_i. \tag{3.3.19}$$

That is, that the gradient must be approximately zero for the free variables, negative for the variables at their upper bounds, and positive for the variables at their lower bounds.

The difficulty of using the Quasi-Newton method in this specific application lies in the computation of the gradient of the likelihood function. This problem can be solved by using a finite difference approximation, where the gradient at a given point λ^k is approximated by

$$g(\lambda^k) = \frac{f(\lambda^k + h_i e_i) - f(\lambda^k)}{h_i}, \tag{3.3.20}$$

where h_i is a small positive value and e_i is an m×1 vector where the ith element is equal to one and all other elements are equal to zero.

Attempts to use this method to find the values of the transformation parameters for a generalized Box-Cox equation based on Chang's (1977) data set[8] show that this would be a useful tool in reducing the number of regressions required, since it exhibits super-linear convergence. However, convergence is only local (i.e., the results are not invariant to the choice of the starting point).

3.3.4 A Combination of Grid Search and Quasi-Newton Method for the Estimation of a Generalized Box-Cox Form

The estimation of a generalized Box-Cox form for the functional relationship

[8]See Majano (1991).

expressed by equation (3.2.9) involves the estimation of 4 different transformation parameters. The modified Quasi-Newton method with a finite difference approximation to the gradient offers the best option for this specific application. However a grid search with very wide intervals between grid points can be initially used in order to identify the proper values for the initial point and the bounds on the transformation parameters, as well as to provide a basis for the comparison of the two methods in terms of computing time and accuracy.

FORTRAN programs specifically written for this application are used for the performance of both types of search. In all programs, the DRGIVN subroutine from the IMSL Statistics Library is incorporated whenever regression analyses are necessary. This double-precision subroutine fits a multivariate linear regression by performing an orthogonal reduction of the matrix of regressors to upper triangular form. One of the main advantages ascribed to this method is that it avoids the loss of accuracy resulting from forming the cross product matrix used in the normal equations.[9] Comparisons of the regression parameter estimates and the other statistics produced by this subroutine with those of the widely used statistical package SAS show no significant differences in the results.

The program for the grid search is simply a coding of the algorithm described in section 3.3.2. The code for the gradient method utilizes the DBCONF subroutine from the IMSL Math Library, a double-precision subprogram designed to minimize a function of several variables subject to bounds on the variables using a Quasi-Newton method and an active set strategy like those described in section 3.3.3.[10] The FORTRAN codes for the grid search, the gradient search, and other tasks are presented in Appendix B.

10See IMSL Stat Library Guide, Chapter 2.

[10]See IMSL Math Library Guide, Chapter 8.

3.4 EMPIRICAL FINDINGS

3.4.1 The Data

Annual data from 1963 to 1991 were obtained from statistics collected by the Division of Strategic Planning of CEL. The information provided by CEL includes:

- Total final sales of electricity to the residential sector, in Mwh.
- Number of residential customers.
- Average price for final sales to the residential sector, in current colones per Kwh.
- Consumer Price Index (1978 =100).
- Total number of inhabitants in the country.
- National disposable income, in millions of current colones.
- Number of dwellings in the country.

Publications of other Salvadoran governmental and private agencies, such as the Central Bank of Reserve of El Salvador, the Ministry of Planning, the General Direction of Statistics and Census, and others were used to verify and complete some of the data series.

The following is a description of the way those figures were used to calculate the values for the variables included in the estimations. The units of measurement were changed in some cases to avoid computational problems.

E_t: Per capita residential consumption of electricity, in thousands of Mwh per inhabitant, equals total final sales to the residential sector, in Mwh, multiplied by 100 and divided by the number of inhabitants.

P_t: Real mean price of electricity, in 1978 colones per Kwh, equals mean price for final sales to the residential sector, in current colones, deflated by the Consumer Price Index (1978=100).

Y_t: Real per capita disposable income, in thousands of 1978 colones per inhabitant,

equals National Disposable Income, in millions of current colones, multiplied by 1000, deflated by the Consumer Price Index (1978=100), and divided by the number of inhabitants.

A_t: The proxy for the percentage of dwellings with access to electricity services is equal to the number of residential customers multiplied by 100 and divided by the number of dwellings in the country.

W_t: A dummy variable to account for a shift of the demand curve during the war years. Equals zero (0) for the years prior to 1978 and one (1) for the rest.

3.4.2 The Search for the Optimal Transformation Parameters

The problem of minimizing the negative of the likelihood function L in equation (3.3.7) was initially tackled using the grid search approach. To reduce computation time and effort, the distance between grid points was set to one. Taking into account results from previous works, the search interval for each parameter was initially set to [-2,4], however, the upper limit for λ_2 (the transformation parameter for the income variable) was subsequently changed to 8 because the likelihood function seemed to still be increasing at λ_2=4.

A total of 3,773 regressions were necessary for this four-dimensional search. The results of the search are presented in Table 3.4.1. The optimal transformation parameters for the dependent variable E_t, and for availability are both equal to one, while those for price and income are 4 and 5, respectively. The value of the likelihood function at the optimal point is -1.7823.

A disadvantage of having such wide intervals between grid points is that the search may miss the global minimum. However, constraints in time and resources available make it very difficult, and in some cases impossible, to refine the search by decreasing the distance between grid points to acceptable levels. This is one of the reasons why a guided

Table 3.4.1 Optimal Transformation Parameters and Maximum Value of Objective Function for Grid Search Method

Variable	Parameter	Estimate
E_t and E_{t-1}	λ_0	-1
P_t	λ_1	4
Y_t	λ_2	5
A_t	λ_3	-1
	Maximum L	-1.7823

search method such as the Quasi-Newton method is so attractive. One of the flaws of the gradient method is its general lack of global convergence. Likelihood functions tend to have numerous local maxima, one of which may be the global maximum. If the starting point for the search is too far from the global optimum, and if the step size is too large, the algorithm may identify a local optimum as the global optimum even when that is not the case.

The irregular shape of likelihood surfaces can be illustrated using the two-transformation-parameters case. For illustration purposes only, it was assumed that the transformation parameter is the same for all explanatory variables, and a two-dimensional grid search with a distance of 0.2 between grid points was performed. As a result, 961 observations of the pairs (λ_0,λ_1) and the corresponding value of $L(\lambda_0,\lambda_1)$ were obtained. The three-dimensional graph shown on Figure 3.4.1 was built using these points. The graph shows that more than one local maxima exist.

This work takes advantage of the results from the unrefined four-dimensional grid search to provide a good approximation of the region where the global optimum for $-L(\lambda_0, \ldots, \lambda_3)$ may be located and of the most appropriate starting point. The 50 highest values for the likelihood function and the corresponding sets of transformation parameters were printed in order to get an idea of the intervals where the optimal values of such parameters might lie. The frequencies are shown in Table 3.4.2.

Based on the results from the grid search, the bounds on the variables set as follows

$$\begin{aligned} -2 < \lambda_0 < 2 \\ -2 < \lambda_1 < 4 \\ 2 < \lambda_2 < 8 \\ -2 < \lambda_3 < 2. \end{aligned} \qquad (3.4.1)$$

The set of optimal parameters of the grid search was used as a starting point for the gradient search. After only a few seconds, the quasi-Newton method produced the

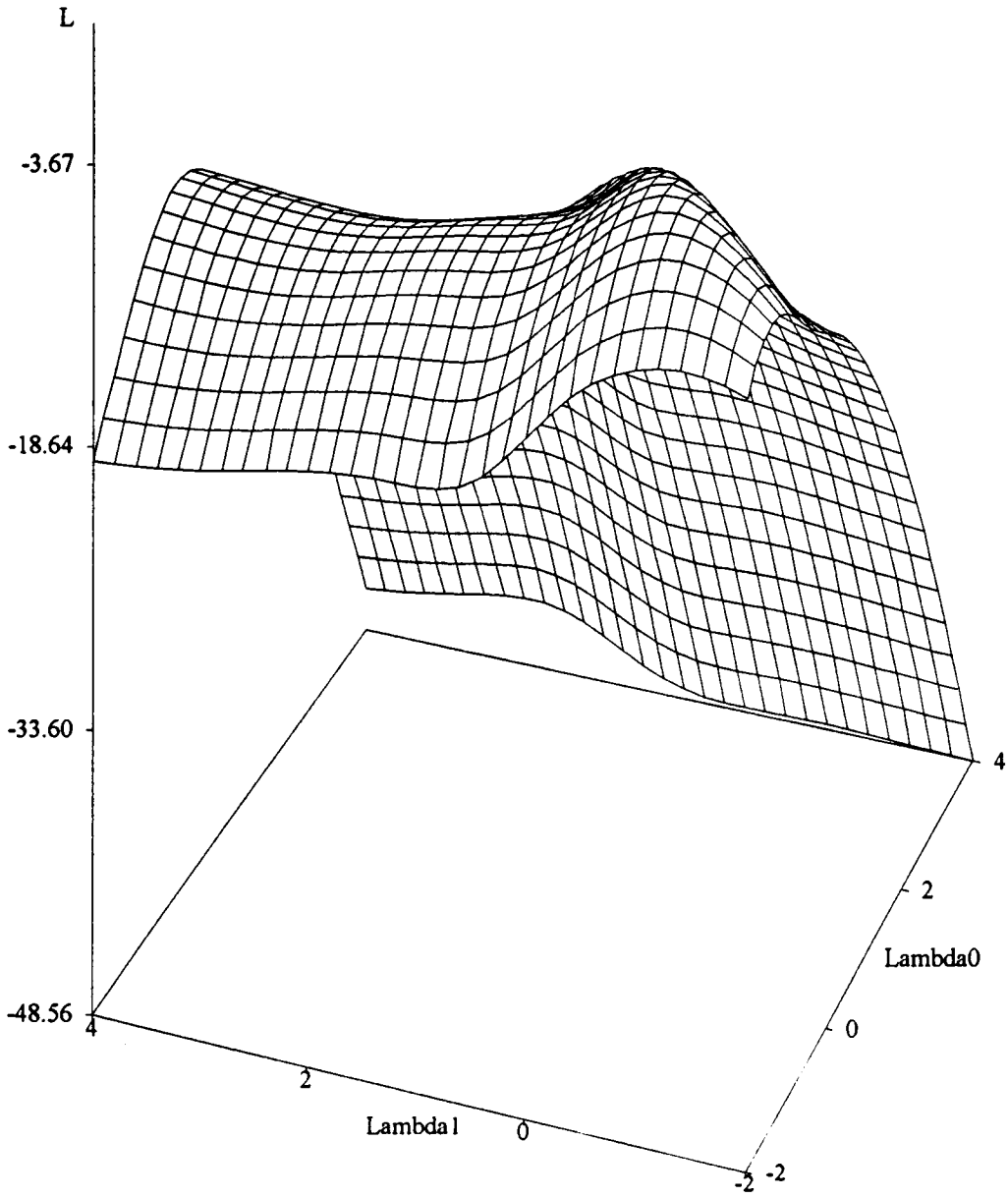


Figure 3.4.1 Likelihood Surface for the Two-Parameter Case

Table 3.4.2 Grid Search: Frequencies of Possible Values of Transformation Parameters in the Fifty Greatest Values of L

	Values										
Parameter	-2	-1	0	1	2	3	4	5	6	7	8
λ_0	0	50	0	0	0	0	0	n/a	n/a	n/a	n/a
λ_1	7	7	7	7	7	7	8	n/a	n/a	n/a	n/a
λ_2	0	0	0	1	7	7	7	7	7	7	7
λ_3	0	50	0	0	0	0	0	n/a	n/a	n/a	n/a

n/a: Does not apply.

results shown in Table 3.4.3. These optimal values, with the exception of λ_1, appear relatively close to those found by the grid search, and the value of the likelihood function is higher in this case.

Within the established search region, several other starting points were used and the same optimal solution was obtained, suggesting that for this specific application, and within the given search region, the quasi-Newton algorithm exhibits global convergence. For this reason, the solution found by the quasi-Newton method was considered optimal and was used for subsequent analyses. The vector of optimal transformation parameters is referred to as $\hat{\lambda}$.

The likelihood ratio statistic was used to test for alternative functional forms. The statistic $2\left[L(\hat{\lambda}_0,...,\hat{\lambda}_4) - L(\lambda_0,...,\lambda_4)\right]$ follows an approximately χ^2 distribution with 4 degrees of freedom. Table 3.4.4 shows the values of the likelihood function, the null hypothesis, and the test statistic for different functional forms. With a significance level of 5 percent, both the hypotheses of linear and double-log functional forms are rejected.

3.4.3 Analysis of Regression Results

Estimated regression parameters for the model in equation (3.2.9) are presented in Table 3.4.5. The F-test shows that, overall, the relationship expressed by the model is significant at the 1 percent level. The OLS regression coefficients have the expected signs. The intercept, and the coefficients for income, availability, and the lagged dependent variable are significantly different from zero at the 1 percent level.

The regression coefficient for price has a negative sign, but the t-test indicates that this coefficient is not significantly different from zero, implying that price variations do not have a significant effect on per capita consumption of electricity in El Salvador's residential sector. All the other variables have a positive effect, which means that electricity consumption in El Salvador will rise with increases in per capita income, and the

Table 3.4.3 Optimal Transformation Parameters and Maximum Value of Objective Function for Quasi-Newton Method

Variable	Parameter	Estimate
E_t and E_{t-1}	λ_0	-0.6870
P_t	λ_1	0.0735
Y_t	λ_2	5.1494
A_t	λ_3	-1.0412
	Maximum L	-1.3775

Table 3.4.4 Values of Likelihood Function and χ^2 Statistic for Alternative Functional Forms of the Model $E_t = f(P_t, Y_t, A_t, E_{t-1}, W_t)$

Form	Assumption	$L(\lambda_0,...,\lambda_4)$	χ^2 *	Decision Concerning $H_0: \lambda = \hat{\lambda}$
General Box-Cox:				
a) From Gradient Search	A different transformation	-1.3775	-	-
b) From Grid Search	parameter for each variable.	-1.7823	0.8096	Fail to reject
Two-Parameter Box-Cox	One transformation parameter for the dependent variable and another for all the independent variables.	-3.6743	4.5936	Fail to reject
Linear	Transformation parameter equals one for all variables.	-6.7953	10.8356	Rejected at α=0.05
Double-Log	Transformation parameter equals zero for all variables.	-12.7656	22.7762	Rejected at α =0.01

* With 4 degrees of freedom.

Table 3.4.5 Box-Cox General Form: Parameter Estimates and Standard Errors for the Model $E_t = f(P_t, Y_t, A_t, E_{t-1}, W_t)$

Variable	Parameter	OLS Estimate	Standard Error
Intercept	β_0	0.4803*	0.0874
$P_t^{(\lambda_1)}$	β_1	-0.0017	0.0015
$Y_t^{(\lambda_2)}$	β_2	0.0023*	0.0007
$A_t^{(\lambda_3)}$	β_3	0.0049*	0.0013
$E_{t-1}^{(\lambda_0)}$	β_4	0.6564*	0.0609
W_t	β_5	0.0007	0.0009

Other Statistics: $R^2 = 0.9989$

Adjusted $R^2 = 0.9986$

F-statistic = 3981.295

*Significant at $\alpha = 0.01$.

availability of the service. The statistical non-significance of the war variable indicates that no significant shift of the demand curve occurred during the war period. The estimated coefficient of the lagged dependent variable lies between zero and one, satisfying the requirements of the model specification.

Since the estimation utilized time-series data, the presence of autocorrelation is a possibility. The popular Durbin-Watson test for autocorrelation cannot be used in this case because the lagged dependent variable is among the explanatory variables. Therefore, the h-test, which is based on the Durbin-Watson statistic, is used instead[11]. In this instance, the computed h equals -0.002, and its contrast with the critical values from the standard normal tables led to the conclusion that no autocorrelation problem exists for this estimation.

The performance of searches for this model, and for other models containing different subsets of the set of explanatory variables, corroborated the strengths of the quasi-Newton algorithm developed for this application, since in all cases the method exhibited global convergence within the search region chosen. In all cases, the hypotheses of linear and double-log and forms could be rejected at the 10 percent level[12].

---

[11] The test statistic h follows an approximately standard normal distribution and is defined as

$$h = \left(1 - \frac{d}{2}\right)\sqrt{\frac{n}{1 - nS_c^2}},$$

where d is the Durbin-Watson statistic, which is computed by the SAS package, and S_c is the standard error of the regression coefficient of the lagged dependent variable.

[12] The regression results for the linear and log-linear form of the full model yield results similar to the generalized Box-Cox form in terms of signs and significance of the explanatory variables, but very different in terms of elasticities. The linear form yields price and income elasticities with absolute values considerably greater than one, which are not consistent with the country's situation. The double-log form yields price and income elasticities of less than 0.01, i.e., much lower than those shown in table 3.4.6 below.

3.4.4 Elasticities and their Behavior

Partial effects, as well as short-and long-run elasticities computed at the mean values of the variables, are presented in Table 3.4.6. The figures corresponding to the short run suggest that, at the means, a 0.10 colones increase in the real price of electricity will decrease per capita consumption by 1.9 Kwh. In elasticity terms, this means that a 1 percent increase in the real price of electricity will result in a 0.0279 percent decrease in the quantity consumed per inhabitant. Also at the means, a one thousand colones increase in per capita disposable income will increase per capita consumption of electricity by 7.07 Kwh or, equivalently, a 1 percent increase in per capita income will increase per capita residential consumption of electricity by 0.1143 percent.

As expected, the magnitude of the elasticities is greater in the long run than in the short run. In the long run, a 1 percent increase in real price will lead to a 0.08 percent decrease in quantity consumed, and a 1 percent increase in per capita disposable income will result in a 0.33 percent increase in quantity demanded. In the long run people have more time to adjust their behavior in response to price and income changes and therefore the proportional changes in quantity demanded are greater than in the short run.

The value of the price elasticity in El Salvador is lower than the values reported for other Latin American countries, while income elasticity falls within the same range as Costa Rica and Paraguay. Given the circumstances exposed in several parts of this dissertation, such as the small share of electricity expenditures in total household expenditures and the absence of substitutes, it was expected that the coefficient for the price variable would be statistically insignificant, and that price elasticity would be very low in both the short and the long run.

The functional form of the demand equation suggests that elasticities will not be constant across different levels of the explanatory variable. The effect of a change in the variable X_{it} on the coefficient of elasticity of E_t with respect to X_{it} is given by

Table 3.4.6 Transformation Parameters, Regression Coefficients, and Elasticities at Mean Values for the Model

$E_t = f(P_t, Y_t, A_t, E_{t-1})$

Variable	Transformation Parameter	Regression Coefficient [a]	Mean Value of the Variable	$\frac{\partial E_t}{\partial X_{it}}$ at the Means	SR Elasticity at Means	LR Elasticity at Means
E_t	-0.6870	-	74.3324	-	-	-
Intercept	n/a	0.4803*	1.0000	-	-	-
P_t	0.0735	-0.0017	0.1086	-19.0735	-0.0279	-0.0811
Y_t	5.1494	0.0023*	1.2016	7.0691	0.1143	0.3326
A_t	-1.0412	0.0049*	0.3556	72.4005	0.2775	0.8076
E_{t-1}	-0.6870	0.6564*	70.6301	-	-	-
W_t	n/a	0.0007	0.4643		-	-

n/a: Does not apply.

* Significant at $\alpha = 0.01$

[a] For the transformed variables

$$\frac{\partial \varepsilon_{X_{it}}}{\partial X_{it}} = \beta_i X_{it}^{\lambda_i - 1} E_t^{-\lambda_0} (\lambda_i - \lambda_0 \varepsilon_{X_{it}}). \qquad (3.4.2)$$

Since the values for both the independent and the dependent variables are nonnegative, the direction of this change ultimately depends on the signs of the estimated regression coefficient for the independent variable and of $(\lambda_i - \lambda_0 \varepsilon_{X_{it}})$.

In the case of price elasticity, the sign of (3.4.2) is negative. This means that an increase in the real price of electricity will decrease the value of the elasticity coefficient. In other words, the absolute value of the coefficient will increase with an increase in real price, which confirms the hypothesis that the responsiveness of electricity consumption to price changes will increase with the price level. However, the value of this expression at the means, -0.0139, indicates that, within the range of prices included in the sample, price changes will have an almost negligible effect on price elasticity.

Regarding income, the sign of (3.4.2) is positive. This result indicates that income elasticity will vary directly with per capita income. The value of the expression at the means indicates that a one thousand colones increase in per capita disposable income will increase income elasticity by 0.4972. This result is contrary to what other researchers have found regarding the behavior of income elasticity of demand in other countries. The works of Pindyck (1979) and Gemmill (1980) suggest that income elasticity should decrease, not increase, as income rises. Their predictions are based on the fact that generally, the share of the electricity bill in household budget decreases as household income goes up. In El Salvador, however, the share of electricity expenditures may be greater in higher income households than in lower income households. This may be the result of the extremely low income of some households who, even if they have electricity connections in their dwelling unit, do not make much use of it because they do not own many electrical appliances. As income level increases, the family acquires a greater stock of appliances and the relative importance of the electricity bill in household expenditures

increases.

3.5 SUMMARY AND CONCLUSIONS

The purpose of this chapter was to estimate a flexible functional form for the equation of residential electricity demand in El Salvador. It was believed that the main determinants of per capita consumption of electricity in that country were the real price of electricity, per capita disposable income, availability of the service, and the stock of household electric appliances. A flow adjustment model was chosen to account for the lack of measurements for the stock of appliances. A dummy variable was included to test whether there had been a shift of the demand curve during the war period.

A Box-Cox equation was chosen to obtain flexibility in the functional form. This form involves the transformation of the variables in the model by a set of transformation parameters which are determined by means of a maximum likelihood estimation. Most works using this form use the simplifying assumptions that the transformation parameter is the same for all variables. However, that assumption is very restrictive, and one of the objectives of this work is to use the most flexible form available. The estimation problem, therefore, involved the search for an optimal transformation parameter for each variable in the model except the intercept and the dummy.

Simultaneous estimation of the regression coefficients and the transformation parameters becomes practically impossible in this case. The standard estimation method for Box-Cox forms with three transformation parameters or less involves a grid search across different sets of transformation parameters. For each set of parameters, the maximum likelihood estimates of the regression coefficients are computed in order to find the value of the likelihood function at that point. The set of transformation parameters that yields the maximum value of the function is then chosen as optimal. The number of regressions required for this search is usually very large.

One of the main contributions of this work was the development of a gradient-based search that reduced the computational effort and improved accuracy relative to the standard grid search. A modified quasi-Newton algorithm for constrained minimization was used to find the set of transformation parameters that minimizes the negative of the likelihood function. Since the computation of partial derivatives becomes very complicated in this case, a finite different approximation was used.

A grid search with very wide intervals between grid points was used to identify the proper search region and initial point. The gradient method was then applied in order to refine the search with less computational effort. The use of the quasi-Newton algorithm for the estimation of several models showed that, for this specific application and within the region established with the help of the grid search, the algorithm exhibits global convergence.

Regression results show that the effect of variations in the real price of electricity on per capita consumption of electricity is not statistically significant. This can be explained by the fact that for political reasons the nominal price of electricity in El Salvador has been kept very low and relatively stable, and as a result, electricity expenditures represent a very small fraction of household expenditures. The estimation results confirm the hypothesis that the responsiveness of demand to price changes would be greater at higher price levels. However, for the range of prices included in the sample, the increase in elasticity due to a price increase is almost zero.

Income and the availability of the service were found to have significant positive effects on per capita consumption of electricity. The war variable proved statistically insignificant, suggesting that the conflict did not significantly affect the position of the demand curve for electricity. These relationships suggest that economic growth, with the resulting increase in per capita income and in consumption of durable goods such as electric appliances, will bring about an increased demand for residential electricity. The

results also indicate that consumption of electricity per inhabitant will increase as rural electrification advances.

An interesting result is that income elasticity seems to increase with income level, contrary to what has been found in other countries. This may be due to the fact that in El Salvador the relative importance of electricity expenditures in the household budget increases with the family's income.

Since both total population and per capita consumption of electricity show increasing trends, the total residential demand of electricity can be expected to grow considerably in the near future. It is the responsibility of the authorities in charge of the provision of electricity services to Salvadoran households to attempt to meet those growing requirements.

CHAPTER 4

ALTERNATIVES FOR THE MANAGEMENT OF RESIDENTIAL DEMAND FOR ELECTRICITY IN EL SALVADOR

4.1 INTRODUCTION

According to the results of the estimations presented in Chapter 3, economic growth and the expansion of electrification projects, with the subsequent increases in per capita income, access to electricity services, and the accumulation of greater stocks of electric household appliances, will bring about considerable increases in residential electricity demand in the foreseeable future.

The Strategic Planning Division of the electric utility in El Salvador, CEL, has formulated plans for the expansion of the electricity generation capacity in the country. Demand projections based on the double-log demand equations described on Section 2.3 have been used in the assessment of capacity requirements. In doing so, PLANICEL follows the traditional approach to public utility planning.

Traditionally, the planning process "has consisted of first, estimating the future demand for electricity, then finding the best set of supply-side options to meet the demand".[1] However, due to the difficulties and high costs associated with expanding supply capacity, as in the case of El Salvador, as well as concerns about the effects of increased energy production and consumption on the environment, planners have been forced to look at ways of shaping demand, rather than considering it as given.

Under current conditions, it would be extremely difficult for CEL to make the

[1] Gellings and Chamberlin (1988), p. 1.

investments necessary to expand generation capacity. It is evident from the description in Chapter 1 that increased prices are necessary to cover production costs. Small price changes, like the ones occurred in the past decade, are not likely to affect residential consumption of electricity. Nevertheless, it is reasonable to believe that large price increases will have a more significant effect on household electricity consumption. International experience shows that an appropriate tariff structure, such as an increasing-block-tariff or a time-of-the-day tariff schedule, should not only affect quantities consumed but also change consumption patterns.

Time-of-the-day and increasing-block tariff schedules are only two options for electricity demand-side management. The purpose of this chapter is to survey the available demand-side management options for the residential sector and to use the results of the analysis of residential demand for electricity in El Salvador to identify the measures that best suit the needs of the country. It is not within the scope of this dissertation to present technical details of the operation of the different measures or to make recommendations as to specific program design, since the demand analysis undertaken here is only one of the inputs in the design of an appropriate demand-side management program. The suggested options should be further explored by utility and government planners within a process of integrated resource management in order to identify the best combination of supply-and demand-side options for the country.

Section 4.2 contains a definition of demand-side management. Section 4.3 presents a survey of demand-side management schemes proposed and used by electric utilities in other countries. Section 4.4 is concerned with the alternatives that best suit El Salvador's residential sector conditions and outlines the steps necessary for the evaluation and implementation of those programs. The contents of this chapter are summarized in Section 4.5.

4.2 DEMAND-SIDE MANAGEMENT

Although instances of demand-shaping actions on the part of electrical utilities can be found as far back as the first part of the first century, the incorporation of those actions into the planning process and the use of the concept of demand management as an approach to utility planning is relatively new.

The term "demand-side management" (DSM) was used until the mid eighties mainly in reference to load-control activities, but its definition has been broadened since. The most accepted definition is that of Gellings (1985):[2]

> DSM is the planning, implementation, and monitoring of those utility activities designed to influence customer use of electricity in ways that will produce desired changes in load shape.

Demand-side activities are not a substitute, but a complement, to the traditional supply-side alternatives. Options on both sides must be consistent with each other. The consideration of the best set of demand-and supply-side alternatives is part of a broader planning process sometimes called "integrated resource planning." This process allows utilities to maintain a balance between supply and demand of electricity.

DSM activities include load control mechanisms, strategic conservation programs, special tariff systems (such as time-of the day or time-of-the year tariffs), interruptible loads, etc. All of these activities are bound by one common thread--"they involve a deliberate intervention by the utility in the marketplace so as to change the configuration of the load shape."[3] Those changes must be associated with specific objectives.

The concept of "load shape" refers to the pattern of electricity consumption in the course of a day. Daily consumption patterns tend to reflect the patterns of human activity having peaks during the daytime and valleys late at night. This fact creates special problems for electric utilities--their generation capacity has to be available to satisfy

---

[2]Gellings and Chamberlin (1993).
[3]Ibid.

demand during peak periods, but much of that capacity has to remain idle during off-peak periods. Due to technical aspects of electricity generation, it is usually more expensive to provide electricity during peak periods than during off-peak periods.[4] Furthermore, in some cases the current generation capacity is hardly sufficient to satisfy peak-load demand, and its expansion is too costly. For these and other reasons, electric utilities are increasingly seeking ways to alter daily consumption patterns.

Different types of changes may be desirable according to the specific circumstances and objectives of the utility. Rabl and Gellings (1988) classify possible changes in load patterns into six categories which are illustrated on Figure 4.2.1. Three of the categories are of special interest for this dissertation--Peak Clipping is directed at reducing peak demand by reducing electricity consumption during peak periods. Load Shifting transfers loads from peak to off-peak periods, and Strategic Conservation refers to an overall reduction of electricity consumption. All these changes are desirable in cases when it is too costly to provide electricity during peak-load periods and/or when the utility wishes to reduce the required installed capacity. Measures oriented to the achievement of these changes are described in the following section.

4.3 DSM OPTIONS FOR THE RESIDENTIAL SECTOR

4.3.1 DSM Alternatives

As explained above, demand management techniques can be used to alter electricity consumption patterns in such a way that the load shape and the load size "are changed in a manner that is beneficial to both the utility and its customers."[5] In cases like that of El Salvador, the main goal of the utility is to manipulate demand so that the demand can be satisfied with an installed capacity which is less than what would be needed

[4]Rabl and Gellings (1991).
[5]Munasinghe (1991), p.68.

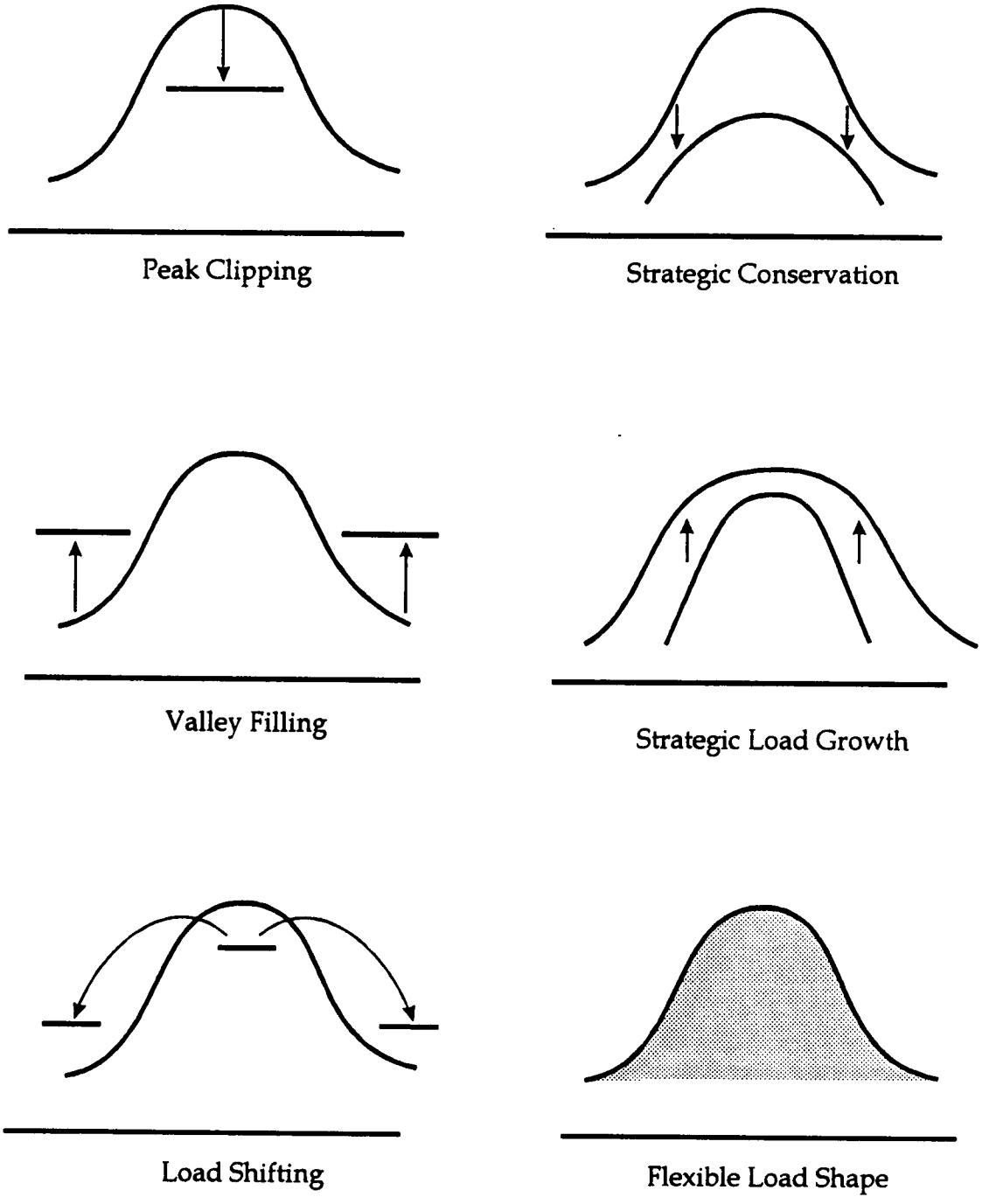


Figure 4.2.1 Load Shape Modification Objectives

if the demand is considered as given. The options to affect demand in this manner include a wide range of price and nonprice tools, the most common of which are described in the following paragraphs.

Time-of-Use Rates. As indicated in Chapter 2, the price of electricity is the main determinant of electricity consumption in some countries. It was also indicated that increasing and decreasing block rate schedules are generally used by electric utilities in order to send "signals" to the consumers as to what patterns of consumption are desired. In the U.S. and other developed countries, rates usually decrease as the level of usage increases. In contrast, El Salvador's rates are designed in such a way that price per unit increased when consumption reaches a higher block.

Recently, rate structures in many countries have been designed to provide incentives for changes in consumption patterns along certain periods of time. The most widely used and recommended is one in which rates vary according to the time of the day. There are also instances of rates that vary according to the time of the year. The idea of time-of-use rates is not new--the first proposals for time of the day pricing date back to the 1890s.[6] However, the majority of the time-of-use rate schedules now in effect in the U.S. were initiated after 1980.

Time-of-use rates are generally designed to reflect cost variations over the year or the hours of the day, and are directed at shifting energy consumption from peak to off-peak periods and to reduce overall electricity use. These rates may be offered to consumers on a voluntary basis or to be imposed in a mandatory manner. In some cases, differentiated rates are designed to give incentives to customers to participate in other demand-side management programs.

---

[6] Gellings and Chamberlin (1988), p.203.

Direct Load Control Mechanisms. This type of tool involves changes in the operation of consumers' user-end equipment in order to change the maximum demand of the appliance and therefore the utility's load requirements[7]. Load control techniques can be categorized into two types: 1) distributed load control and 2) remote load control. Direct load control programs assume the consent of the customers and usually require the provision of financial incentives such as special rates and credits to participating customers.

Distributed load control activities include those activities on the part of consumers aimed at controlling their own loads. This requires changes in the usage of electric equipment and sometimes the use of special devices. Some of the options are as simple as turning off some appliances during certain periods. Others require the use of current limiters, fuses, or circuit breakers that directly limit the user's maximum demand. The alternatives include cyclic control schemes, thermostat control, interlock control, and demand controllers.

Remote load control mechanisms, sometimes called interruptible load mechanisms, entail control of customer loads by the utility. The basic principle is that the utility will interrupt the electricity flow once a maximum level of usage has been reached. Obviously, this type of control mechanism requires the existence of a communication system between the utility and the consumers, both for metering and control of the loads.

Energy Storage Technologies. Energy storage programs are designed to shift electricity consumption from peak to off-peak periods. These programs entail the use of equipment designed to "vary either the quantity or the delivery characteristics of energy input while maintaining the required energy delivery schedule."[8] Cool storage, storage water heating, and storage space heating are among the storage technologies available for demand-side

[7]Gellings and Chamberlin (1988).
[8] Ibid, p.61.

management.

Cool storage devices are designed to shift chiller operation in buildings from peak to off-peak periods -- the chiller operates during off-peak periods to generate and store chilled water or ice that is used for peak-period cooling. In a similar fashion, storage space heating systems use off-peak electricity to heat a storage reservoir, discharging the stored heat as needed to maintain control. In turn, storage water heating technologies are designed to provide daily peak-period hot water with only off-peak heater operation[9]

These programs are effective for peak-clipping, as are load control technologies. But, unlike the latter, energy storage mechanisms do not impair the service to the customers. Users must be informed of the existence of energy storage alternatives, and additional incentives, such as especial rates, are usually necessary.

Energy-Efficient Technologies. A large proportion of demand-side management activities throughout the world are directed at encouraging customers to acquire and use energy efficient appliances and to build or remodel existing buildings to be energy-efficient. The options include the use of better insulation materials in house-building, the improvement of air-conditioning and space-and water-heating technologies, the utilization of energy-efficient household appliances (especially refrigeration devices) and the introduction of more efficient lighting technologies.

The implementation of these programs requires both an information campaign and financial incentives, since the initial cost of energy-efficient appliances is much higher than that of regular appliances. Incentives include special rates, free installations, and the provision of loans and rebates for the purchase of the new appliances.

---

[9] Rabl and Wendland (1991).

4.3.2 Residential Demand Management Experience Around the World.

The majority of electricity DSM programs around the world are directed at commercial and industrial customers. For instance, in many countries time-differentiated rates are only offered to large industrial customers. However, several countries have experimented with instruments to alter residential consumption patterns.

In the United States, survey data show that by 1990 there were 1,022 residential DSM programs in the 485 utilities included in the survey. These programs involved a total of 12,940,736 participants. The majority of the programs are oriented to peak-clipping, the most common being time-of-use rates and load control mechanisms.

In France, measures intended to change residential load shape and size include an optional two time period "double tariff," which has been used by approximately 7 million participants in recent years. In addition, strategic conservation measures, such as establishing energy-efficient standards for electric appliances and promoting good thermal insulation, are in effect.

Time-of-the-day tariffs are used for residential peak-clipping and load shifting in many other European countries, such as England, the Netherlands, and Germany. In Italy, surveys and experiments are being conducted in order to assess the acceptance of time-of-the-day tariffs by residential customers and their impact on residential consumption patterns.[10]

In Norway, there are two kinds of residential tariffs--energy tariff and demand-limit tariff. The former is made up of a fixed annual charge and an energy charge, while the latter is made up of a fixed charge, a demand charge, and an energy charge. Customers using the demand-limit tariffs subscribe to a specific demand limit, and pay higher energy charges for the electricity exceeding the limit.

The use of DSM measures has not been limited to industrialized countries.

[10]Bergamini et al (1991).

Attempts have been made in India to introduce advanced lighting and window technologies to reduce overall electricity consumption and peak demand.[11] In Brazil, the National Energy Conservation Program was created with the sole purpose of planning and promoting the efficient use of electricity. It is expected that energy efficiency will discourage wasteful consumption and reduce costs and the need for new investments.[12]

4.4 FEASIBLE DEMAND-SIDE MANAGEMENT ALTERNATIVES FOR THE RESIDENTIAL SECTOR IN EL SALVADOR

The conditions of electricity supply in El Salvador make peak-clipping and strategic conservation the most desirable changes in consumption patterns for the residential sector. The nature of electricity-consuming activities in Salvadoran households and financial obstacles eliminate some of the options described above. Energy storage programs are not relevant to the residential sector since very few households have air conditioning or water-heating systems, and space heating is unnecessary due to the climatic characteristics of the country.

Remote and local load control devices entail installation expenses and a communication system that are not affordable under current circumstances. Furthermore, load control devices in other countries are mainly utilized for air conditioning, and space- and water-heating, which, as indicated above, are not important residential end-uses of electricity in El Salvador.

Time-of-use tariffs and energy-efficiency programs constitute the best options for residential demand-side management in El Salvador. As pointed out in Chapter 1, tariff changes are necessary to ameliorate the financial problems of CEL. Load management objectives could be achieved at the same time with a proper design for the new tariffs.

---

[11] Gadgil et al (1991)

[12] Gellings and Chamberlin (1993), p.167.

Cost differences between dry and rainy seasons provide the basis for one tariff differentiation scheme--electricity charges per Kwh should be higher during the dry season because the proportion of hydroelectric power available decreases during this period, forcing the producers to utilize the more expensive diesel plants.

Given the characteristics of energy usage in Salvadoran households, it is reasonable to expect that time-of-the-day tariffs would have a strategic conservation effect rather than load shifting. The main uses of electricity in the residential sector are lighting, refrigeration, and entertainment. The scheduling of these activities determines high-loads during evening hours and low-loads during the early morning, as shown in Table 4.4.1. Higher charges during peak-load periods are not likely to shift entertainment and lighting usage to off-peak periods, but to alter consumption patterns as to reduce energy usage during those periods, and consequently, to reduce total energy use.

The use of increasing-block-rate pricing should be maintained, since at proper price levels this structure would discourage wasteful use of electricity. For equity reasons, it may be necessary to keep some subsidized rates for very low levels of consumption, in order to protect those households with extremely low income levels.

Energy efficiency can be promoted through advertising campaigns and financial incentive programs. Customers must be informed of the savings that can be derived from the use of energy efficient electric appliances and lighting devices. Cost-benefit analyses are necessary to explore the possibility of providing loans to low-income consumers for the purchase of energy efficient appliances, especially freezers and refrigerators. Efficiency audits may also be offered together with special rates or discounts for those households that meet specific energy-efficiency standards.

These measures and others should be explored by CEL planners within the context of the search for the best options for satisfying increasing demand given the financial and physical limitations they face. An aggregate demand analysis like the one conducted here is

Table 4.4.1 CEL: Time and Amount of Minimum and Maximum Demand 1980-1991

	Minimum Demand			Maximum Demand		
Year	Date	Hour	Mw	Date	Hour	Mw
1980	May 4	2:30	74.4	Feb. 26	19:00	269.4
1981	May 1	6.00	50.6	Jan. 17	18:30	264.3
1982	May 2	1:00	62.0	Dec. 8	18:00	271.6
1983	Jun. 27	2:30	2.0	Dec. 29	18:30	285.5
1984	May 7	4:00	78.3	Dec. 3	18:30	304.2
1985	Apr. 1	2:30	81.9	Dec. 5	18:00	318.4
1986	Oct.11	4:00	67.0	Dec. 16	18:30	339.5
1987	Apr. 18	2:30	108.3	Dec. 16	18:30	379.9
1988	Jun. 11	2:30	134.0	Dec. 14	18:30	378.6
1989	Aug. 6	4:00	138.0	Oct. 30	18:00	391.4
1990	Jan. 2	3:00	127.0	Dec. 18	18:30	412.3
1991	Nov. 3	4:30	134.8	Nov. 21	18:00	447.7

Source: CEL (1991a).

just one of the inputs in the process of assessing requirements and evaluating alternatives.

An appropriate framework for the design of DSM programs in El Salvador could be the one developed by the Synergic Resources Corporation (SRC) based on research and consulting studies for more than 50 utilities around the world.[13] Figure 4.4.1 depicts the different steps involved in this framework. The first step identifies the utility's goals and objectives based on an understanding of the utility's operation environment, its characteristics and mission, as well as the customers needs and desired benefits.

The second step in the design process is a screening of the different options, which includes a situation analysis that addresses issues such as the most important external factors that determine benefits, costs, and impacts of the DSM options; the internal factors relevant to the design of the programs; strengths and weaknesses of each alternative; and a review of programs implemented by other utilities. The analysis of these factors will lead to the identification and ranking of the most relevant alternatives.

A detailed analysis is then conducted for the highest-ranked options. This analysis includes a thorough definition of the program concept; identification of the target markets and of the relevant end uses and technology options; estimation of market potential and penetration; evaluation of benefit, costs and impacts; and the development of market implementation strategies. Inputs for the different parts of this detailed analysis come from econometric studies, customer surveys, engineering simulations, benefit/cost analyses, etc.

After the most appropriate options are chosen, additional steps must be taken to develop an implementation plan, to conduct the field implementation, and to monitor and evaluate the programs once implemented.

[13]Limaye et al (1991).

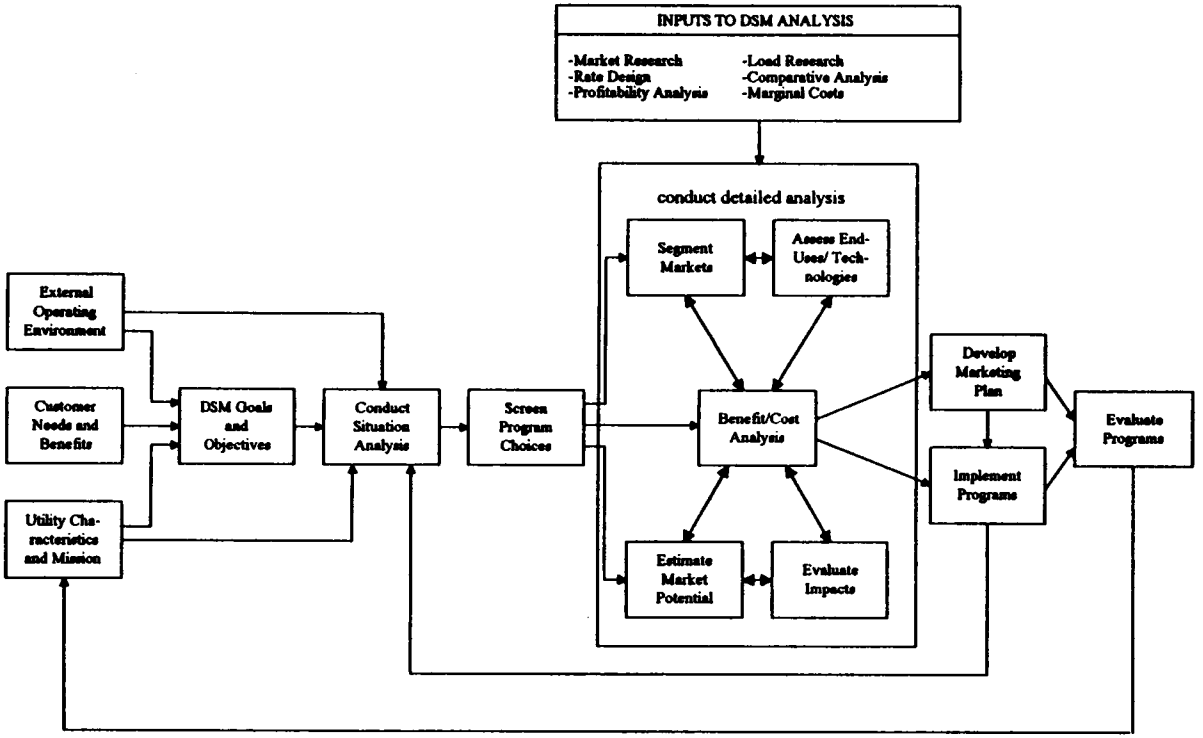


Figure 4.4.1 Planning and Implementation of Demand-Side Management Programs

Source: Limaye et al (1991).

4.5 SUMMARY AND RECOMMENDATIONS

The purpose of this chapter was to describe the options available to electric utilityplanners when attempting to find ways to alter residential consumers' behavior in order to alter the size and shape of electrical loads, and to identify those options that best suit the needs and the situation of electricity producers and consumers in El Salvador.

Peak clipping, load shifting, and strategic conservation were identified as the type of load shape changes most desirable in the case of El Salvador. DSM options available for the achievement of these changes include special tariff structures, direct load control mechanisms, energy storage technologies, and energy-efficiency programs.

Given the characteristics of electricity consumption and production in El Salvador, the best DSM alternatives seem to be the design of time-of-the day and time-of-the year rates combined with the already existent increasing block rates, as well as the promotion of efficiency in the use of electricity through advertising campaigns, rate incentives, and the concession of loans to low income households for the purchase of energy-efficient appliances.

These options must be evaluated and implemented by El Salvador's electric utility using an appropriate planning and monitoring framework, which includes a definition of specific goals and needs, the evaluation of available options on the basis of the analysis of the different factors that determine their positive and negative impacts, the development of implementation plans for the options chosen, and the continuous monitoring and evaluation of the implemented programs.

CHAPTER 5

CONCLUSIONS AND RECOMMENDATIONS

5. 1 OVERVIEW OF THE WORK

The purpose of this dissertation was the analysis of the determinants and the behavior of residential electricity demand in El Salvador and the identification of suitable demand-side management options for that sector. The demand analysis involved the use of a general form for the demand equation in order to allow for flexibility in the functional form of the relationships implicit in the data.

The main hypothesis was that, although under the current conditions price is not a very important determinant of residential consumption of electricity, the responsiveness of quantity demanded to price changes, measured by price elasticity, varies directly with price level. A secondary hypothesis is that the use of arbitrary functional forms such as double-log and linear forms in the demand estimations would introduce specification bias.

The study of the characteristics of electricity consumption and production in El Salvador, presented in Chapter 1, revealed the existence of a crisis caused by environmental, political, and financial problems which hinder El Salvador's electric utility's ability to satisfy growing demand. The most important component of total electricity consumption in the country, and one of the most affected by the crisis, is the residential sector.

The search for solutions to the problems facing the provision of adequate electric services to households requires the knowledge of the main determinants of residential consumption and the nature of the relationship between residential electricity demand and those factors. A review of literature dealing with the most relevant theoretical and

empirical issues to be considered when estimating residential demand equations is contained in Chapter 2.

The works reviewed in Chapter 2 provided the basis for the selection of the variables and the tools that were used for the estimations in Chapter 3. Price, income, availability of electrical connections, and the stock of electric appliances were identified as the main factors influencing per capita household electricity consumption. The lack of appropriate measures for the stock of appliances led to the adoption of a partial adjustment model. A Box-Cox general form with four different transformation parameters was chosen as the most flexible functional form available for the estimations.

A major contribution of this dissertation is the application of gradient-based non-linear programming techniques in the search for the maximum-likelihood estimates of the transformation parameters as an alternative to the standard grid search which makes estimations with more than two transformation parameters extremely laborious. A modified quasi-Newton algorithm with line search, BFGS update, and a finite difference approximation to the gradient was used for that purpose. Computer programs incorporating library subroutines were written specifically for this application, and empirical results show that this method has several advantages relative to the grid search method. Greater accuracy and reduction of computational effort and time can be cited among those advantages.

Estimation results show that price is not a significant determinant of household electricity consumption in El Salvador. Income and availability, on the other hand, have a significant positive effect on per capita residential electricity consumption. Price elasticity varies directly with price, but at the current price levels, the effect of a small price change on price elasticity is extremely small. A surprising result is that income elasticity increases with income levels, while the works of other researchers suggest that it should be the opposite. A reasonable explanation of this disagreement is that in El Salvador, unlike other

countries, the importance of electricity expenditures in household budget is greater for high-income families than for those with low income levels.

The significant positive effect of income and availability on household consumption suggests that the increasing trend of those variables due to economic growth will bring about considerable growth rates of residential electricity demand in the near future. The financial and physical constraints faced by El Salvador's electric utility constitute a serious obstacle to the expansion of generation capacity necessary for the proper satisfaction of current and future demand. A logical complement to supply-expansion plans under these circumstances is the design of programs oriented to change electricity utilization patterns.

A general description of demand-side management alternatives and their utilization by electric utilities around the world is presented in Chapter 4. The results of the demand analysis are then used to identify demand management measures that suit the conditions and the needs of both suppliers and residential consumers in El Salvador. It is recommended that these options be explored in depth by planners and policy-makers as instruments to ameliorate the energy crisis in the country.

5.2 CONCLUSIONS

The results of the empirical estimations and the analysis of the characteristics of residential electricity consumption in El Salvador led to the following conclusions:

- Price is a not a significant determinant of electricity consumption in Salvadoran households. Subsidized prices cause electricity expenditures to be a very small fraction of total household expenditures and, consequently, price elasticity of demand is very close to zero. Estimation results show that, everything else remaining constant, price elasticity will increase slightly with small price increases.
- Income is a very important and significant determinant of electricity consumption. High-income households tend to consume more electricity because

they are able to accumulate a larger stock of electric appliances. In El Salvador, income elasticity is likely to increase with income level because, contrary to what happens in other countries, the share of electricity expenditures in household budgets increases with the family's income level.

- The use of an arbitrarily chosen functional form, such as the double-log form used in previous studies of residential demand for electricity in El Salvador, introduces a specification error, since both the hypotheses of double-log and linear forms were rejected on the basis of statistical tests.

- The utilization of a gradient-based search method, as opposed to the standard grid search method, allows for greater flexibility in the functional form. In addition, the gradient method improves accuracy and reduces the necessary computational effort.

- Peak-clipping and strategic conservation measures, such as time-of-use tariffs and the promotion of energy-efficient household appliance use, are the best alternatives for demand management in El Salvador. Specific programs should be designed and implemented as a complement to supply-side measures for the provision of electricity to Salvadoran households.

5.3 SUGGESTIONS FOR FURTHER RESEARCH

Several issues arose during this dissertation research that may give rise to additional research projects. They were not pursued here either because they lie outside the scope of this work or for lack of appropriate data for the analysis.

The determinants of household consumption of electricity can be further understood by using disaggregated data as the basis for demand estimations. Unfortunately, this type of data was not available for this dissertation research, and the

conduction of a reliable survey involved the use of resources that were not available to the author.

As recommended above, the design of a residential rate structure that incorporates increasing blocks, time-of-the-day, and time-of-the-year tariffs requires further research into the size and shape of residential loads and their determinants, end-use requirements, the potential of different demand management measures, consumer acceptance prospects, and many other related issues. Similar analyses are necessary for energy-efficiency programs.

The planning of electricity provision in El Salvador requires demand studies for the other sectors of the Salvadoran economy and the exploration of demand management alternatives for those sectors.

Concerning the estimation technique, the use of finite difference approximations for the gradient may allow the simultaneous estimation of transformation and regression parameters. However, a larger number of observations would be necessary to compensate for the increase in the number of parameters to be estimated. The algorithm can also be extended to include cases when autocorrelation problems exist.

BIBLIOGRAPHY

BIBLIOGRAPHY

Banco Central de Reserva de El Salvador, BCR (1990). *Revista Trimestral*, April-June. San Salvador.

Bhatia, Ramesh (1987). "Energy Demand Analysis in Developing Countries: A Review." *The Energy Journal* 8 (Special L.D.C. Issue):1-33.

Betancourt, R. R. (1981). "An Econometric Analysis of Peak Electricity Demand in the Short-Run." *Energy Economics* 3(1): 14-29.

Bergamini, M., G.G. Paniale, and R. Poli (1991). "An Experiment to Ascertain the Effects of a Time-of-Day Tariff on Residential Customers' Demand." In *Conference on Advanced Technologies for Electric Demand Management- Proceedings*. Paris: OECD/ International Energy Agency.

Berndt, Ernest R. (1991). *The Practice of Econometrics: Classic and Contemporary*. Reading, Massachusetts: Addison-Wesley Publishing Company, Inc.

Berndt, Ernest and Ricardo Samaniego (1984). "Residential Electricity Demand in Mexico: A Model Distinguishing Access from Consumption." *Land Economics* 60 (3): 268-277.

Box, George E.P. and David R. Cox (1962). "An Analysis of Transformation." *Journal of the Royal Statistical Society*, Series B 26: 211-243.

Burby, R. J., N.M. Didow, M.E. Marshden, C.F. Hanna, M.D. Bunn, and S.A. Johnston (1985). *Electric Utility Load Management: Marketing Strategies and Tactics*. Totowa, New Jersey: Rowman and Allanheld.

Chang, Hui S. (1977). "Functional Form and the Demand for Meat in the United States." *The Review of Economics and Statistics* 59: 355-359.

_____.(1980). "Functional Form and the Demand for Meat in the United States: A Reply." *The Review of Economics and Statistics* 68: 148-150.

Chang, Hui S. and Yu Hsing (1991). "The Demand for Residential Electricity: New Evidence on Time-Varying Elasticities." *Applied Economics* 23: 1251-1256.

_____ (1993). "Demand for Higher Education at Private Institutions: New Evidence." Draft of a paper presented at the 1993 Annual Conference of the American Statistical Association, San Francisco.

Chiang, Alpha C. (1984). *Fundamental Methods of Mathematical Economics*, Third Edition. New York: Mc Graw-Hill Book Company.

Comisión Ejecutiva Hidroeléctrica del Río Lempa, CEL (1988). *Primer Plan Nacional de Desarrollo Energético Integrado 1988-2000.* Gerencia de Planificación Estratégica (PLANICEL), San Salvador.

_____ (1990a). *Balance Energético Nacional 1990.* Gerencia de Planificación Estratégica (PLANICEL), San Salvador.

_____ (1990b). *Estadísticas Seleccionadas 1990.* San Salvador.

_____ (1991a). *El Salvador: Perspectivas de la Demanda de Energía Eléctrica 1991-2010.* Gerencia de Planificación Estratégica (PLANICEL), San Salvador.

_____ (1991b). *Estadísticas Eléctricas, Boletín No. 22.* Centro de Información Energética, Gerencia de Planificación Estratégica (PLANICEL), San Salvador.

_____ (1992). *Resumen - Plan de Expansión Sistema de Generación y Transmisión Eléctrica (1992-2010).* Gerencia de Planificación Estratégica (PLANICEL), San Salvador.

Compañía de Alumbrado Eléctrico de San Salvador, CAESS (1990). *CAESS, Un Siglo de Luz 1890-1990, Revista Conmemorativa.* San Salvador.

Dias-Bandaranaike, R. and M. Munasinghe (1983). "The Demand for Electricity Services and the Quality of Supply." *The Energy Journal* 4 (2): 49-71.

Dunkerley, J., M. Macaulay, M. Naimudia, and P.C. Agarwal (1990). "Consumption of Fuelwood and Other Household Cooking Fuels in Indian Cities." *Energy Policy*, January/February: 92-99.

Dunkerley, J., W. Ramsay, L. Gordon, and E. Cecelski (1981). *Energy Strategies for Developing Nations.* Baltimore: The Johns Hopkins University Press.

Edirisinghe, Chanaka. A FORTRAN Code for a Quasi-Newton Algorithm with BFGS Update and Backtracking Linear Search. (Unpublished).

Fisher, F.M. and C.A. Kaysen (1962). *A Study in Econometrics: The Demand for Electricity in the United States.* Amsterdam: North Holland Publishing Co.

Fundación Salvadoreña para el Desarrollo Económico y Social, FUSADES (1991) *Informe Trimestral de Coyuntura, No. 4, año 1990.* Departamento de Estudios Económicos y Sociales, San Salvador.

Gadgil, A., A. Rosenfeld, D. Arasteh, and E. Ward (1991). "Advanced Lighting and Window Technologies for Reducing Electricity Consumption and Peak Demand: Overseas Manufacturing and Marketing Opportunities." In *Conference on Advanced Technologies for Electric Demand Management- Proceedings.* Paris: OECD/ International Energy Agency.

Garbacz, Christopher (1984). "Residential Electricity Demand: A Suggested Appliance Stock Equation." *The Energy Journal* 5 (2): 151-154.

Gellings, C.W. and J.H. Chamberlin (1988). *Demand-Side Management: Concepts and Methods.* Lilburn, Georgia: The Fairmont Press, Inc.

_____ (1993). *Demand Side Management Planning.* Lilburn, Georgia: The Fairmont Press, Inc.

Gemmill, Gordon (1980). "Using the Box-Cox Form for Estimating Demand: A Comment." *The Review of Economics and Statistics* 62: 147-148.

Glackpe, Emmanuel and Rocco Fazzolare (1985). "Economic Demand Analysis for Electricity in West Africa." *The Energy Journal* 6 (1): 137-144.

Greene, William H. (1993). *Econometric Analysis*, Second Edition. New York: Mc Millan Publishing Co.

Hartman, Raymond S. (1979). "Frontiers in Energy Demand Modeling." *Annual Review of Energy* 4: 433-466.

Heckman, J., and S. Polachek (1974). "Empirical Evidence on the Functional Form of the Earnigs-Schooling Relationship." *Journal of the American Statistical Association* 69 (346): 350-534.

Houthakker, H.S. (1951). "Some Calculations of Electricity Consumption in Great Britain." *Journal of the Royal Statistical Society, Series A* 114 (part III) : 351-371.

Hsing, Yu. (1989). "Testing for the Flexible Employment Elasticity Hypothesis: Application of an Expanded Box-Cox Model to U.S. Manufacturing." *Quarterly Review of Economics and Business* 20 (2): 96-107.

Huang, Cliff J., and Oliver R. Grawe (1980). "Functional Forms and the Demand for Meat in the United States: A Comment." *The Review of Economics and Statistics* 62: 144-145.

Hyman, Eric (1985). "Demand for Woodfuels by Households in the Province of Ilocos Norte, Philippines." *Energy Policy* December: 581-591.

IMSL Problem-Solving Software Systems (1989a). *MATH/LIBRARY User's Manual; FORTRAN Subroutines for Mathematical Applications*, Version 1.1.

_____ (1989b). *STAT/LIBRARY User's Manual; FORTRAN Subroutines for Statistical Analysis*, Version 1.1.

Kmenta, Jan (1986). *Elements of Econometrics*, Second Edition. New York: Mc Millan Publishing Company.

Kouris, George (1983). "Energy Demand Elasticities in Industrialized Countries: A Survey." *The Energy Journal* 4 (3): 73-94.

Limaye, D.R., C. McDonald, and N. Subbakrishna (1991). "Benefits of Utility Programs to Improve Industrial Energy Efficiency: Examples from the U.S., Hungary, and India." In *Conference on Advanced Technologies for Electric Demand Management- Proceedings*. Paris: OECD/International Energy Agency.

Lyman, R.A.(1973). *Price Elasticities in the Electric Power Industry*. Department of Economics, University of Arizona.

Majano, Ana Maria (1991). "Use of the Quasi-Newton Method with BFGS Update and Backtracking Line Search Algorithm in the Estimation of the Maximum-likelihood Values of the Transformation Parameters of the Box-Cox General Form". Application Project for Management Science 651: Nonlinear Optimization, University of Tennessee at Knoxville.

Martinez Montalvo, E.A., J.R. Serrano, M. Campos and V. Campos (1987). *Demanda de Energía por Uso Final en el Sector Residencial, Area Urbana y Rural.* Comisión Ejecutiva Hidroeléctrica del Río Lempa (CEL)/ Banco Interamericano de Desarrollo (BID): Programa de Fortalecimiento de la Capacidad de Planeación en el Campo Energético, Convenio ATN/SF-2369-ES. [CEL/BID Survey].

Munasinghe, Mohan (1990a). *Electric Power Economics: Selected Works*. London: Butterworth & Co. (Publishers) Ltd.

_____ (1990b). *Energy Analysis and Policy: Selected Works*. London: Butterworth & Co. (Publishers) Ltd.

_____ (1991). "Electric Demand-Side Management in Eastern Europe and Developing Countries: Issues and Options." In *Conference on Advanced Technologies for Electric Demand Management- Proceedings.* Paris: OECD/International Energy Agency.

Organización Latinoamericana de Energía, OLADE (1989). *Energía en Cifras 1989.* Sistema de Información Económica Energética (SIEE).

Pindyck, Robert S. (1979). *The Structure of the World Energy Demand.* Cambridge, Massachusetts: MIT Press.

Plourde, A. and D. Ryan (1985). "On the Use of Double-log Forms in Energy Demand Analysis." *The Energy Journal* 6: 105-111.

Pougerami, A., and C.R. von Hirschhausen (1991). "Aggregate Demand for Energy and Dynamics of Energy Demand Elasticities in Non-Oil Developing Countries." *The Journal of Energy and Development* 14 (2): 237-252.

Savin, N.E., and K.J. White (1978). "Estimation and Testing for Functional Form and Autocorrelation: A Simultaneous Approach." *Journal of Econometrics* 8: 1-12.

Sanint, Luis (1982). "Applying Principal Components Regression Analysis to Time Series Demand Estimation." *Agricultural Economics Research* 34 (3): 21-27.

Seaks, T.G., and S.K. Layson (1983). "Box-Cox Estimation with Standard Econometric Problems."*Review of Economics and Statistics* 65 (1): 160-64.

Shin, Jeon-Shik (1985). "Perception of Price When Price Information is Costly: Evidence from Residential Electricity Demand." *Review of Economics and Statistics* 67: 591-598.

Taylor, Lester D. (1975). "The Demand for Electricity: A Survey." *Bell Journal of Economics and Management Science* 6: 74-110.

The World Bank. *World Development Report 1991.*

Tukey, J.W. (1957). "On the Comparative Anatomy of Transformation." *The Annals of Mathematical Statistics* 28: 602-632.

Westley, Glenn D. (1992) *New Directions in Econometric Modeling of Energy Demand/ With Applications to Latin America.* Washington, D.C.: Inter-American Development Bank.

Wilkie, James W. (1990). *Statistical Abstract of Latin America (SALA).* UCLA Latin American Center Publications.

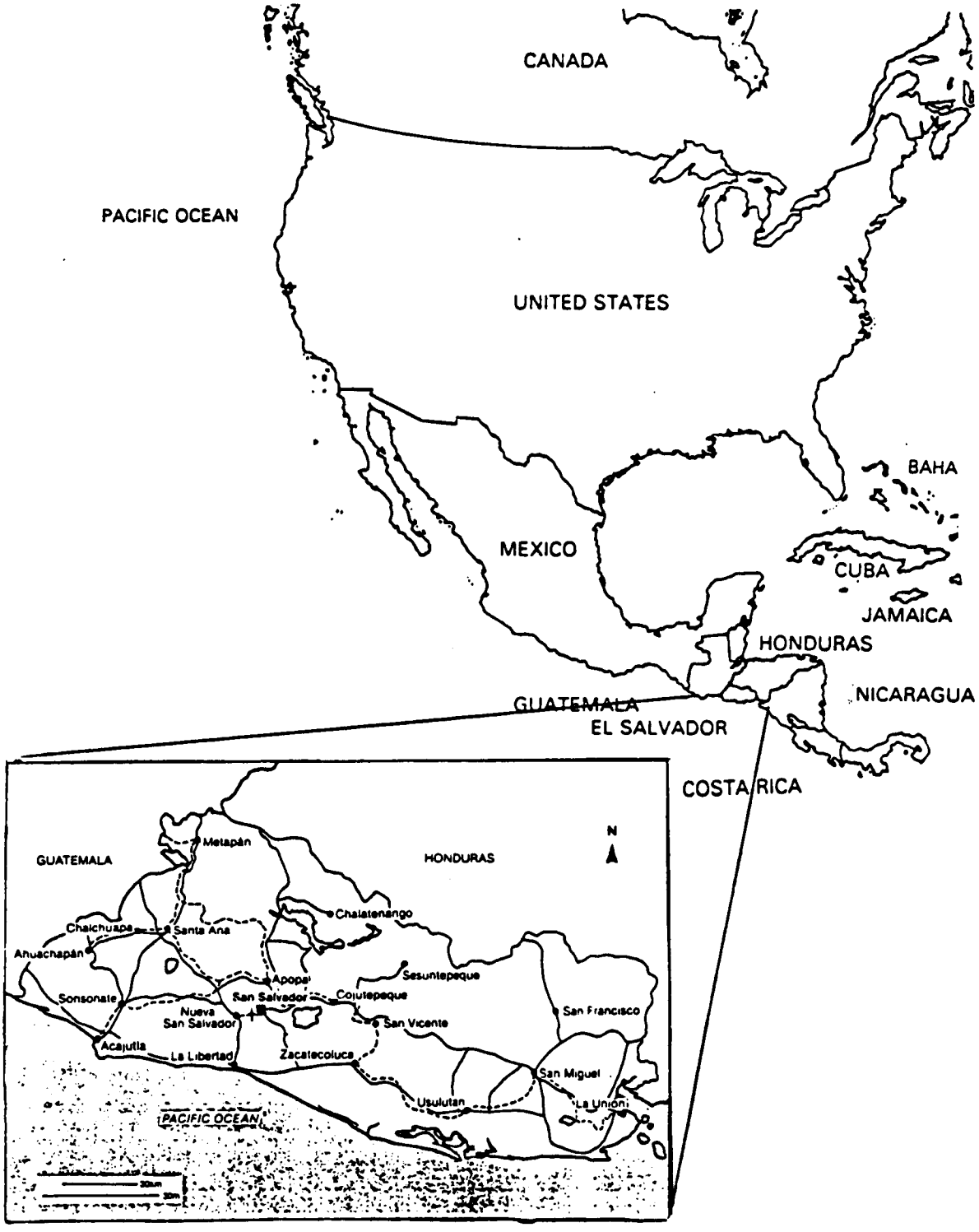
Wilson, John W. (1971). "Residential Demand for Electricity." *Quarterly Review of Economics and Business* 11: 7-22.

Zarembka, Paul (1974). "Transformation of Variables in Econometrics", in *Frontiers in Econometrics*, edited by Paul Zarembka. New York:Academic Press, New York.

APPENDICES

APPENDIX A:

GEOGRAPHIC SITUATION OF EL SALVADOR



APPENDIX B
COMPUTER PROGRAMS

Appendix B.1 FORTRAN Program to Perform Four-Dimensional Grid Search*

```
//GRID JOB ,MAJANO,GROUP=JXXXXXX,USER=PXXXXXX,TIME=5,
// MSGLEVEL=(1,1),
// PASSWORD=XXXXXX
/*ROUTE PRINT UTKVX.MAJANO
/*UTPARM NONEWS
/*JOBPARM LINES=99
//S1 EXEC FORTVCLD,GOREG=5M
//FORT.SYSIN DD *
c       GRID SEARCH
c       n: # observations
c       v: # indep. variables to be transformed
c       d: # dummy variables
c       k= v+d
c       m= k+1
        implicit real*8 (A-H, O-Z)
        integer i,j,n,v,v1,d,k,m,count
        parameter (n=29,v=3,v1=4,d=1,k=4,m=6)
        integer year(n)
        real*8 step,sumlog
        real*8 f, y(n), x(n,k),lam(0:v),lamlb(0:v),lamub(0:v)
        common x,y,sumlog
        external fcn
c
ccccc Read the data
c
        do i=1,n
        read(5,*) year(i), y(i),(x(i,j),j=1,k)
        end do
        read(3,*) (lamlb(i),lamub(i),i=0,v)
```

```
      sumlog=0
      do i=2,n
          sumlog=sumlog+dlog(y(i))
      end do
c
cccc  Create grid Points
c
      step=1
      lam(0) =lamlb(0)
      do while (lam(0).le.lamub(0))
          lam(1)=lamlb(1)
          do while (lam(1).le.lamub(1))
              lam(2)=lamlb(2)
              do while (lam(2).le.lamub(2))
                  lam(3)=lamlb(3)
                  do while (lam(3).le.lamub(3))
                      call fcn(v,lam,f)
                      write (16,*) (lam(i),i=0,v), f
                      lam(3)=lam(3)+step
                  end do
                  lam(2)=lam(2)+step
              end do
              lam(1)=lam(1)+step
          end do
          lam(0)=lam(0)+step
      end do
      end
c
c
c     SUBROUTINE TO CALCULATE THE LIKELIHOOD FUNCTION
c
      Subroutine fcn(v,lam,f)
      implicit real*8 (A-H,O-Z)
      integer i,j,n,v,v1,d,k,m,intcep
      parameter (n=29,v1=4,d=1,k=4,m=6)
```

```
      integer ido,nrow,ncol,lda,iind,idep,ifrq,iwt,isub,ldb,
     1        ldr,irank,ldscpe,nrmiss,indind(1),inddep(1)
      real*8 sigma,f,dfe,tol,x(n,k),x1(n,k),y(n),y1(n),
     1        lam(0:v),b(m,1),a(n-1,m),r(m,m),dx(m),scpe(1,1),xmin(m),xmax(m)
      common x,y,sumlog
      tol=100.d0*dmach(4)
c
ccccc  Box-Cox transformation
c
      do i=1,n
            if (abs(lam(0)).le.tol) then
            y1(i)= dlog(y(i))
            else
                y1(i)=(y(i)**lam(0)-1)/lam(0)
            endif
            do j=1,v
                if (abs(lam(j)).le.tol) then
                    x1(i,j)=dlog(x(i,j))
                else
                    x1(i,j)=(x(i,j)**lam(j)-1)/lam(j)
                endif
            end do
            if (d.gt.0) then
                do j=v1,k
                    x1(i,j)=x(i,j)
                end do
            endif
      end do
c
ccccc  prepare matrix for isml subroutine
c
      do i=2,n
          do j=1,v
            a(i-1,j)=x1(i,j)
          end do
```

```
            a(i-1,v1)=y1(i-1)
            a(i-1,k+1)=x1(i,v1)
            a(i-1,m)=y1(i)
         end do
c
ccccc call regression subroutine
c
         intcep=1
         ido=0
         nrow=n-1
         ncol=m
         lda=n-1
         iind=-(k+1)
         idep=-1
         ifrq=0
         iwt=0
         isub=1
         ldb=m
         ldr=m
         ldscpe=1
         call drgivn (ido,nrow,ncol,a,lda,intcep,iind,indind,idep,inddep,
      1     ifrq,iwt,isub,tol,b,ldb,r,ldr,dx,irank,dfe,scpe, ldscpe,nrmiss,xmin,xmax)
c
ccccc calculate likelihood function
c
         sigma=scpe(1,1)/(n-1) f=((n-1)/2)*dlog(sigma)-(lam(0)-1)*sumlog
         return
         end
```

---

* The first 8 lines contain the JCL commands necessary to execute the program in the MVS System.

Appendix B.2 FORTRAN Program for Quasi-Newton Method

```
c       Quasi-Newton method with bounds using IMSL subroutines.
c       n: # observations
c       v: # indep. variables to be transformed
c       d: # dummy variables
c       k= v+d,v1=v+1
c       m= k+1
        implicit real*8 (A-H, O-Z)
        integer i,j,n,v,v1,d,k,m,ibtype,iparam(7)
        parameter (n=29,v=3,v1=4,d=1,k=4,m=6)
        real*8 fcn,f,fscale,fopt,sumlog, year(n)
        real*8 y(n),x(n,k),lamlb(v1),lamub(v1),lamscale(v1),
       &    rparam(7),lamopt(v1),lamguess(v1)
        common x,y,sumlog
        external fcn
c
ccccc Read the data
c
        open(2, file='elec.dat', status='old')
        read(2,*) (year(i),y(i),(x(i,j),j=1,k),i=1,n)
        open(3,file='minimiz.dat',status='old')
        read(3,*) (lamguess(i),lamlb(i),lamub(i),i=1,v1)
        open(6,file='result.out',status='new')
        write(6,*) 'initial values and bounds'
        do i=1,v1
            write (6,*) 'lam(',i,')=',lamguess(i)
            write (6,*) 'lb(',i,')=',lamlb(i)
            write (6,*) 'ub(',i,')=',lamub(i)
        end do
c
ccccc compute sumlog
c
        sumlog=0
```

```
      do i=2,n
            sumlog=sumlog+dlog(y(i))
      end do
      write (6,*) 'sumlog=', sumlog
c
ccccc Prepare for minimization subroutine
c
      ibtype=0
      do i=1,v1
            lamscale(i)=1.0d0
      end do
      fscale=1.0d0
      tol=dmach(4)
c
ccccc Change parameters in iparam and rparam
c
      call du4inf(iparam,rparam)
      iparam(3)=5000
      iparam(4)=20000
      iparam(5)=20000
      iparam(6)=0
      iparam(7)=100
      rparam(2)=rparam(2)/10000
c
ccccc    Call minimization subroutine
c
      call dbconf(fcn,v1,lamguess,ibtype,lamlb,lamub,lamscale,fscale,
     1      iparam,rparam,lamopt,fopt)
c
cccc Write results
c
      open (7,file='lamda.dat',status='new')
      write (6,*) 'optimal transformation parameters'
      write (6,*) (lamopt(i),i=1,v1)
      write (7,*) (lamopt(i),i=1,v1)
```

```
      write (6,*) 'optimal value function ',fopt
      end
c     Subroutine to calculate the likelihood function
c
      Subroutine fcn(v1,lam,f)
      implicit real*8 (A-H,O-Z)
      integer i,j,n,v,v1,d,k,m,intcep
      parameter (n=29,v=3,d=1,k=4,m=6)
      integer ido,nrow,ncol,lda,iind,idep,ifrq,iwt,isub,ldb,
     1    ldr,irank,ldscpe,nrmiss,indind(1),inddep(1)
      real*8 sigma,sumlog,f,dfe,tol,x(n,k),x1(n,k),y(n),y1(n),
     1    lam(v1),lam1(0:v),b(m,1),a(n1,m),r(m,m),dx(m),scpe(1,1),xmin(m),xmax(m)
      common x,y,sumlog
      do i=1,v1
          j=i-1
          lam1(j)=lam(i)
      end do
      tol=100.d0*dmach(4)
c
ccccc Box-Cox transformation
c
      do i=1,n
          if (abs(lam1(0)).le.tol) then
              y1(i)= dlog(y(i))
          else
              y1(i)=(y(i)**lam1(0)-1)/lam1(0)
          endif
          do j=1,v
              if (abs(lam1(j)).le.tol) then
                  x1(i,j)=dlog(x(i,j))
              else
                  x1(i,j)=(x(i,j)**lam1(j)-1)/lam1(j)
              endif
          end do
          if (d.gt.0) then
```

```
                    do j=v1,k
                        x1(i,j)=x(i,j)
                    end do
                endif
            end do
c
ccccc prepare matrix for isml subroutine
c

            do i=2,n
                do j=1,v
                    a(i-1,j)=x1(i,j)
                end do
                a(i-1,v1)=y1(i-1)
                a(i-1,k+1)=x1(i,v1)
                a(i-1,m)=y1(i)
            end do
c
ccccc call regression subroutine
c
            intcep=1
            ido=0
            nrow=n-1
            ncol=m
            lda=n-1
            iind=-(k+1)
            idep=-1
            ifrq=0
            iwt=0
            isub=1
c           tol=100.d0*dmach(4)
            ldb=m
            ldr=m
            ldscpe=1
          call drgivn (ido,nrow,ncol,a,lda,intcep,iind,indind,idep,inddep,
```

```
     1      ifrq,iwt,isub,tol,b,ldb,r,ldr,dx,irank,dfe,scpe,ldscpe,nrmiss,xmin,xmax)
c
ccccc calculate likelihood function
c
          sigma=scpe(1,1)/(n-1) f=((n-1)/2)*dlog(sigma)-(lam1(0)-1)*sumlog
          return
          end
```

APPENDIX C:
DATA USED IN THE ESTIMATIONS

Year	Total Sales of Electricity to the Residential Sector (Mwh)	Number of Residential Costumers	Avg. Price of Electricity to Residential Customers (Colones)	Consumer Price Index (1978=100)	Number of Inhabitants	Total Disposable Income (Mill. Col)	Number of Dweling Units
1963	77,325.00	79,067.00	0.08	43.88	2,775,700.00	1,434.68	529,179.69
1964	87,084.00	92,360.00	0.08	44.61	2,858,000.00	1,564.51	546,229.88
1965	96,871.00	96,442.00	0.08	44.85	2,942,400.00	1,662.77	563,782.50
1966	107,991.00	102,681.00	0.08	44.35	3,028,900.00	1,782.60	581,844.50
1967	120,946.00	121,681.00	0.07	45.01	3,117,500.00	1,873.16	600,423.81
1968	134,037.00	123,276.00	0.07	46.15	3,208,400.00	1,945.14	619,565.38
1969	143,945.00	130,337.00	0.07	46.05	3,301,700.00	2,006.58	639,293.50
1970	156,675.00	139,203.00	0.07	47.35	3,534,615.00	2,164.39	659,652.63
1971	169,768.00	148,982.00	0.07	47.53	3,637,736.00	2,276.47	680,700.81
1972	186,450.00	160,982.00	0.07	48.29	3,743,866.00	2,419.96	692,275.00
1973	203,183.00	173,503.00	0.07	51.37	3,853,091.00	2,784.53	704,091.81
1974	218,516.00	185,707.00	0.08	60.05	3,965,504.00	3,275.59	716,171.00
1975	240,658.00	200,910.00	0.10	71.51	4,081,196.00	3,703.70	728,553.88
1976	264,574.00	217,537.00	0.11	76.58	4,167,007.00	4,709.76	741,207.69
1977	294,941.00	235,326.00	0.11	85.63	4,254,623.00	5,740.40	754,129.81
1978	331,682.00	256,554.00	0.11	96.97	4,344,080.00	6,298.01	767,305.81
1979	369,479.00	276,017.00	0.12	108.69	4,435,419.00	7,058.50	781,458.13
1980	387,430.00	299,364.00	0.12	127.55	4,528,678.00	7,466.73	791,788.81
1981	383,076.00	314,785.00	0.12	146.44	4,576,430.00	7,181.49	795,991.38
1982	400,146.00	329,219.00	0.12	163.59	4,624,686.00	7,456.55	800,793.38
1983	436,803.00	348,004.00	0.12	185.10	4,673,450.00	8,305.48	805,078.13
1984	461,382.00	368,836.00	0.15	206.70	4,722,729.00	9,508.90	809,453.13
1985	476,916.00	391,876.00	0.17	252.90	4,772,528.00	11,756.58	813,663.31
1986	511,208.00	415,285.00	0.17	333.60	4,845,588.00	15,951.24	821,495.44
1987	551,601.00	432,671.00	0.18	416.60	4,933,835.00	19,115.69	824,802.79
1988	591,805.00	462,182.00	0.19	498.90	5,031,483.00	23,309.09	827,301.91
1989	619,987.00	493,238.00	0.22	586.90	5,137,707.00	27,926.66	828,992.80
1990	651,403.00	544,746.00	0.27	727.76	5,251,678.00	35,470.64	829,875.45
1991	706,939.00	583,328.00	0.31	832.60	5,375,045.00	40,000.00	829,949.87

SOURCES: CEL, Banco Central de Reserva de El Salvador, Ministerio de Planificación, Dirección General de Estadística y Censos.

VITA

Ana Maria Majano Guerrero was born in the town of Berlin, Department of Usulutan, El Salvador, on September 15, 1963. She attended primary schools in Berlin and San Salvador and graduated from the Instituto Nacional "Gral. Francisco Morazán" December of 1980. In January of 1981 she was admitted to the Polytechnical University of El Salvador, where she received the degree of Licenciada en Economia in June of 1987. That year she joined the faculty of both the Polytechnical University and the "Jose Matias Delgado" University.

In July of 1989 she was awarded a Fulbright Scholarship through the Latin American Scholarship Program of American Universities to pursue graduate studies at the University of Tennessee, Knoxville. She received a Master of Arts degree in Economics with a minor in Management Science in December of 1991, and was then awarded a Graduate Teaching Assistantship to continue her studies toward a doctoral degree. In December of 1993 she received a Doctor of Philosophy degree in Economics .

During her graduate studies at the University of Tennessee, she was awarded the UT National Alumni Association Graduate Scholarship, the J. Fred and Wilma D. Holly Fellowship, the McClure Fund for the Study of World Affairs Fellowship, and the Elsie L. Crenshaw International Student Scholarship.

After graduating, Ana Maria returned to El Salvador to resume her work at the Polytechnical University of El Salvador.