# Structural Times Series Modelling of Energy Demand

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A Thesis Submitted to University of Surrey For the Degree of Doctor of Philosophy in Economics

October 2012

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### GLOSSARY

APR	Asymmetric Price Responsiveness
ARDL	Autoregressive Distributed Lag
ARIMA	Autoregressive Integrated Moving Average
ARMA	Autoregressive Moving Average
BOO	Build Own Operate
ВОТ	Build Operate Transfer
COICOP	Classification of Individual Consumption by Purpose
CRDW	Co-integrating Regression Durbin-Watson
ECM	Error Correction Model
EFOM	Energy Flow Optimization Model
EGTSM	Engle and Granger Two Step Method
EG	Engel and Granger Test
EIA	Energy Information Agency
ENPEP	Energy and Power Evaluation Program
EU	European Union
GDP	Gross Domestic Product
GHG	Green House Gas
IEA	International Energy Agency
IPCC	Intergovernmental Panel on Climate Change
Ktoe	Kilo Tonnes of Oil Equivalent
kWh	Kilo Watt Hour
MAED	Model for Analysis of Energy Demand
MENR	Ministry of Energy and Natural Resources
MW	Mega Watt
OECD	Organisation for Economic Co-Operation and Development
OLS	Ordinary Least Squares
PAM	Partial Adjustment Model
PPM	Parts Per Million
PPP	Purchasing Power Parity
SIS	State Institute of Statistics
SPO	State Planning Organization
STSM	Structural Time Series Model

TEDC	Turkish Electricity Distribution Co.
TEGC	Turkish Electricity Generation Co.
TEI	Turkish Electricity Institution
TETC	Turkish Electricity Transmission Co.
TETGTC	Turkish Electricity Generation and Transmission Co.
TOOR	Transfer of Operating Rights
TVP	Time Varying Parameters
TWh	Terra Watt hours
UEDT	Underlying Energy Demand Trend
UNEP	United Nations Environment Program
UNFCCC	United Nations Framework Convention on Climate Change
US	United States
VAR	Vector Autoregressive
WASP	Wien Automatic System Planning
WMO	World Meteorological Organization

#### ABSTRACT

The derived demand for energy comes from the desire to consume energy services such as lighting, heating, and transportation. Consequently, in addition to the economic drivers (income and price), there are number of exogenous factors that drive energy demand. This research therefore uses the Structural Time Series Model to estimate energy demand relationships for Turkish electricity, OECD-Europe natural gas and US per capita gasoline and these relationships are then used to project future demand. The main findings are:

- Estimated long run Turkish industrial energy demand output and price elasticities of 0.15 and -0.16 respectively, with a generally increasing UEDT. Estimated long-run Turkish residential electricity demand income and price elasticities of 1.57 and -0.38 with highly stochastic estimated UEDT with increasing (energy using) and decreasing (energy saving) periods. Estimated Turkish aggregate electricity demand long run income and price elasticities of 0.17 and -0.11 respectively with a generally upward sloping (energy using) estimated UEDT, but at a generally decreasing rate.
  - Based on these estimates it is projected that for Turkey in 2020 industrial electricity demand will be between 97 and 148 TWh; residential electricity demand will be between 48 and 80 TWh; and aggregate electricity demand will be between 259 and 368 TWh.
- Estimated long run OECD-Europe natural gas demand income and price elasticities of 0.95 and -0.18 respectively with an increasing and decreasing an estimated UEDT over the estimation period.
  - Based on this relationship OECD-Europe natural gas demand is projected to be between 442 and 531 mtoe in 2020.
- Estimated long run US per capita gasoline demand income, price maximum, price recovery and price cut elasticities of around 0.42, -0.31, -0.17, and zero respectively with a generally increasing estimated UEDT from 1949 to 1976, but generally declining from 1977 to 1996, and generally increasing from 1997 until 2008.
  - Based on this relationship US per capita gasoline demand is projected to be between 10 and 13 barrels (1590 litres and 2067 litres) in 2020.

### DECLARATION

I declare that, except otherwise stated, this thesis is the result of my own work. No part of this thesis has been submitted in substantially the same form for the award of a higher degree elsewhere.

Zafer Dilaver

October 2012

#### ACKNOWLEDGEMENTS

I would like to express my thanks to a number of people who have supported me during my PhD studies.

I would like to express my deep gratitude to my PhD supervisors, Lester Hunt and Neil Rickman for all their guidance and support and for facilitating the process to enable to attain my PhD from the University of Surrey. Above all, I would like to thank them for believing in me enough to allow me to work independently and for encouraging me to be ambitious. I am most grateful for all the time they spent reading my numerous drafts that progressively created this thesis over the last five years.

I would like to thank my wife Emine Dilaver for her incredible support and encouragement over these past years. I also would like to thank my parents Sebahattin and Mehruz Dilaver for their commitment to my academic progress and in particular for all their support during my fieldwork in Turkey and my sister Özge Dilaver Kalkan for her enthusiastic encouragement and useful critiques and for not leaving me alone in this process.

I also thank the Republic of Turkey Prime Ministry and the people of Turkish Republic for their financial support during my PhD.

I would like to thank Dr. Vasco Gabriel and Prof. Sjur Westguaard for examining this thesis, for the challenging but inspiring discussions during the viva and their constructive comments to help improve the thesis.

Finally, my special thanks are extended to all staff in the School of Economics at the University of Surrey.

#### **CHAPTER 1: INTRODUCTION**

#### **1.1 Introduction**

Energy is vitally important for modern economies. It enables the use of daily appliances (such as computers, medical devices, telecommunication appliances, and transport vehicles) that increase people's quality of life. Most appliances used in daily life are powered by energy and it is generally regarded at least in the developed world to be almost impossible to live without them. As a result, energy is seen as a necessity for social and economic welfare; it is essential to maintain economic activity in modern industrialized nations and social development. Moreover, one of the main reasons for low social and economic progress in developing nations is the limited access to modern energy services given appliances that require electricity (such as computers, televisions and radios) provide access to information that accelerates social progress of societies (Medlock, 2009).

Over centuries, humans have changed their lifestyles along with technological progress and innovation. According to Medlock (2009), the exceptional economic growth and major improvements in standards of living over the last two decades have mainly come about because of the replacement of manpower with mechanical power through technological progress (Medlock, 2009). Energy consumption and technology have developed through history and modern societies' lifestyles became more energy dependent. These energy dependent lifestyles make energy indispensable for life; societies want uninterrupted light, hot water, warm houses, to travel freely and to power industries. Humans have become accustomed to the benefits that are provided by energy consuming appliances and arguably, it is impossible today to think about life without these appliances. The above highlight the advantages of the energy dependent lifestyles of modern societies but this also emphasises the importance for the need for modern societies to tackle energy security. However, this key energy policy objective is now coupled with the need to tackle the problem of climate change. Since the beginning of the industrial revolution, consumption of fossil fuels has substantially increased Green House Gas (GHG) emissions into the atmosphere, which is generally regarded as the cause of climate change (IEA, 2010a). However, as discussed above, energy is important for social and economic progress and simply just reducing energy consumption in order to help solve the climate problem is not an option since modern societies' given lifestyles are heavily dependent on energy. Moreover, it is commonly expected that this dependency will increase in the foreseeable future. Furthermore, there are a significant number of studies that illustrate the strong negative relationship between energy prices and macroeconomic performance, which is the main concern related to energy security (Medlock, 2009). In order to sustain economic and social progress societies arguably need to secure access to energy resources at a reasonable price.

Given energy is generally accepted as being an important driver of economic growth, countries that focus on sustainable economic growth try to find ways to secure their future energy needs at a reasonable price. At the time of writing, the emerging economies of Asia (led by India and China) are recovering from the late 2000s global economic crisis faster than developed economies. According to IEA (2010b), the share of global energy consumption of OECD economies and non-OECD economies was about 50% each in 2007 but project that by 2035 the share will be 38% and 62% respectively. This is based on IEA (2010b) projections for 2008 to 2035 of average annual increases of 0.5% and 2.2% in OECD and non-OECD energy consumption respectively. The rapid increase in demand from emerging economies, competition between nations to access energy resources, along with environmental problems,

arouses another concern: whether or not there will be enough energy supply to meet future demand at reasonable cost. Arguably, this can be solved by long-term planning by developing scenarios for the future evolution of energy demand and the possibilities of meeting that demand in different ways. This can be achieved by a proper understanding of current and past energy demand and possible changes in terms of efficiency and structure, possible supply alternatives, possible technological change, etc. (Bhattacharyya, 2011). Consequently, energy demand analysis and forecasts are vitally important for long term planning and energy security.

In order to develop successful policies to tackle the issues of energy security and climate change it is important that energy demand is analysed and examined carefully. Income and price are the two main economic drivers of energy demand and the response of demand to these drivers are usually analysed in terms of income and price elasticises. However, energy is a derived demand rather than being a demand for its own sake, a demand for the services it produces with the capital stock at a certain time. The amount of energy consumed is connected to the technology level of the energy appliances to assure the required level of services. Therefore, the energy efficiency levels of these capital and appliance stocks considerably affect energy consumption. Furthermore, there are other factors, besides technological progress, which have an impact on energy consumption, such as, changes in consumer tastes, the rebound effect<sup>1</sup>, change in regulations, economic structure, and other exogenous factors.

<sup>&</sup>lt;sup>1</sup> The rebound effect results from the behavioural, or other systemic, responses that offset the benefits of implementation of new technologies that increase energy efficiency. In other words, it results from increased consumption of energy services following a technical improvement in producing the services; consequently, the increased consumption offsets the energy savings that might have otherwise been achieved (Sorrell and Dimitropoulos, 2008).

The typical focus of energy demand analysis is to identify the main economic drivers of energy demand (income and price) but also other factors that might explain energy demand in the past and shape it in the future. However, these other (exogenous) factors are often unobserved components of energy demand, so difficult to capture with traditional statistical and econometric techniques, despite their potential importance in driving energy demand. Moreover, an understanding of their relative importance is arguably vital for policy implementation and policy evaluation.

Although there are number of approaches to modelling energy demand, the econometric modelling approach is thought to have a significant advantage in terms of identifying price responsiveness of energy demand and forecasting (discussed in more detail later). Therefore, in this thesis, a particular econometric modelling approach is utilized to undertake energy demand modelling for a number of different sectors, energy types, and countries. As indicated above, the estimated elasticities and the impact of other exogenous factors are also essential for determining future energy needs. Forecasting is important for many institutions: governments and local authorities use them in order to develop sensible policies; private sector corporations use forecasts for their strategic outlook and investment strategies; and public utilities use demand projections to develop and rationalize plans to regulatory bodies to accomplish public service responsibilities (Medlock, 2009). Having better information about the structure of energy demand, future energy needs, underlying trends and impacts of the policies on energy consumption enables these bodies to tackle the problems related with uncertainty about the future. Therefore, the econometric analysis of the energy demand and the forecasts that are based on these analyses are important for governments, energy companies, and regulatory bodies.

As also indicated above, energy security, in terms of accessing energy supplies, is necessary for a nation's welfare and sustainable development. With increasing demand and finite resources energy security has become an important issue and a difficult goal for most countries. The increasing demand for energy also increases competition between nations for the access to energy resources; given energy is a major factor of economic growth. Different economies have different types of priorities, opportunities, and threats in terms of security of supply so the policies that are developed for these needs may vary. However, there is one thing that does not change, which is the necessity of having a better understanding about the future. This enables the design and implementation of more successful policies to maintain energy security. Consequently, one of the aims of this research is to better understand past energy demand behaviour and therefore be able to project future energy demand.

As stated above, another serious global problem is climate change, which is very closely related with energy consumption. Although climate change has some natural components (dynamics of atmosphere, orientation of planet around the sun), the human race arguably impacts on the climate change by changing the existing structure of the atmosphere. The level of  $CO_2$  in the atmosphere was 280 parts per million (ppm) before the industrial revolution, but with its continuous increase it reached to 385 ppm in 2008 and consumption of fossil fuels has played an important role in this growth (US National Oceanic and Atmospheric Administration, 2009). Therefore, this problem has been considered by national governments around the world and international organizations in recent years.

Since the 1980s, various international negotiations took place in order to try to prevent global warming. The United Nation Environment Programme (UNEP) together with The World Meteorological Organization (WMO) established the Intergovernmental Panel on Climate

Change (IPCC). The United Nations Framework Convention on Climate Change (UNFCCC) was accepted by the congress in 1992. Following that on 11 December 1997, the Kyoto Protocol was accepted and entered into force on 16 February 2005. As of November 2009, it was signed and ratified by 187 countries. The 37 developed countries, which are listed as "Annex I" countries, committed to reduce their collective greenhouse gas emissions by 5.2% from the 1990 level by the year 2012. The Copenhagen Summit in 2009 that was held in order to discuss and approve the framework for climate change mitigation beyond 2012 was not successful. It failed to approve any legally binding agreement to reduce GHG emissions. This was followed by the Cancun Summit in 2010. Although the Cancun Summit also did not result in any legal obligations, it sets out a process for legally binding agreement and adopts a Green Climate Fund that will provide financial aid for poorer nations to tackle with the problems caused by climate change. Moreover, the Cancun Summit provides funding for low carbon technology transfer such as solar panels and wind turbines for developing countries. The last United Nations Climate Change Conference took place in Durban in 28 November 2011 (UNFCCC; 2011). At the Durban Summit, the negotiations advanced, in a balanced fashion for the implementation of the Convention and the Kyoto Protocol, the Bali Action Plan, and the Cancun Agreements. One of the most noteworthy outcome of the summit is the decision that has taken by Parties in order to adopt a universal legal agreement on climate change until 2015 (UNFCCC; 2012).

There are different policy options currently under discussion to reduce the primary and secondary (such as power generation) fossil fuel consumption and consequently GHG emissions. One of the main sources of GHG emissions is the consumption of fossil fuels in power generation. Thus, in order to implement successful polices that will help to reduce fossil fuel demand, the structure of fossil fuel demand and electricity demand need to be

understood. In order to choose the right policy option between policies such as investment incentives for renewable technologies, carbon taxation, improvements in energy efficiency standards, carbon trading schemes or personal carbon allowances, the main characteristics of energy demand including price responses, income responses and underlying trends should be taken into account. In environmental terms, time is not an ally for the planet; consequently, policies implemented without taking into account the main characteristics of energy demand might not be able to meet expectations. The policies that have less chance of being successful are arguably as dangerous as  $CO_2$  emissions since they consume valuable time.

As discussed above, by providing valuable information energy demand modelling is a vital tool in order to develop policies aiming to help solve problems such as energy security and climate change. Moreover, as suggested it is important to understand the economic drivers of income and price, but also other factors; hence, in this research, the appropriate way to model these unobserved components is investigated. Consequently, Harvey's (1989) Structural Time Series Model (STSM) is employed along with Hunt et al.'s (2003a and 2003b) concept of the Underlying Energy Demand Trend (UEDT). Therefore, this thesis aims to investigate the best way to identify the energy demand and its structure by taking into account above mentioned dimensions in the literature.

In this thesis, three different cases are considered: namely Turkey's electricity demand (for aggregated and disaggregated sectors), OECD-Europe aggregate natural gas demand, and US aggregate gasoline demand per capita. Turkey's electricity demand is investigated because previous forecasts have performed poorly and created a risk for Turkey's energy security.<sup>2</sup> OECD-Europe's natural gas demand is investigated since natural gas supply security and new

<sup>&</sup>lt;sup>2</sup> In addition, I am Turkish and therefore wanted to apply my research, at least in part, to my home country.

infrastructures to maintain this supply security is high on Europe's Energy Security agenda. Finally, US gasoline demand is investigated since the US transport sector has a significant impact on global GHG emissions and hence climate change.

In all cases, the STSM is utilized. For Turkish electricity, the standard STSM is utilised. Whereas, for OECD-Europe natural gas the STSM is extended by decomposing and comparing the relative estimated effects of income, price and the UEDT. Furthermore, for US per-capita gasoline, the STSM is extended to include asymmetric price responsiveness and time varying parameters. This thesis therefore covers many aspects of energy demand modelling and different dimension in the literature. It examines different types of energy demands for countries or group of countries and arguably provides valuable information for these specific groups; different information that should be taken into account by the policy makers, consultancy companies, energy companies and other market forces. In the next section, the research questions will therefore be introduced.

#### **1.2 Research Questions**

Given the focus of this research outlined above, the focus of this thesis can be summarized by the following main research questions:

-What are the advantages of using the STSM approach when estimating energy demand functions?

-What are the implications of the estimated UEDTs, and the price and income elasticities for future energy demand and policy analysis?

Moreover, through the research this thesis also answers the following sub-questions for various sectors in Turkey, OECD-Europe and the US.

i) For Turkey:

-What are the shapes and directions of the UEDTs for Turkish aggregate, residential and industrial electricity demand? Do they indicate any structural changes in electricity demand behaviour for the investigated sectors?

-What are the best estimates of the price and income elasticities for Turkish aggregate, residential, and industrial electricity demand?

-How is future Turkish electricity demand likely to evolve?

#### ii) For OECD-Europe:

-What is the shape and direction of the UEDT for OECD-Europe natural gas demand? Does it indicate any structural changes in OECD-Europe natural gas demand behaviour?

-What are the best estimates of the price and income elasticities for OECD-Europe natural gas demand?

- How is future OECD-Europe natural gas demand likely to evolve?

-What are the relative contributions of income, price, and the UEDT in driving OECD-Europe natural gas demand?

iii) For the US:

-What is the shape and direction of the UEDT for US gasoline demand per capita? Does it indicate any structural changes in US gasoline demand behaviour?

-What are the best estimates of the price and income elasticities for US gasoline demand per capita?

-How is the future US gasoline demand per capita likely to evolve?

- Are Asymmetric Price Responses important in driving US gasoline demand per capita?

- Is there evidence of time varying elasticities for US gasoline demand per capita?

#### **1.3 Structure of the Thesis**

The structure of the thesis is as follows. The general energy demand modelling literature is reviewed in the next chapter and the methodology utilized in the research for this thesis detailed in Chapter 3. This is followed by Chapters 4, 5 and 6 that estimate and forecast Turkish electricity demand, OECD-Europe Natural Gas demand, and US Gasoline per capita demand respectively. The final chapter summarises and concludes.

#### **CHAPTER 2: Literature Review**

#### **2.1 Introduction**

This chapter reviews the different approaches to energy demand modelling. The focus is on the econometric modelling approach given this is what is used in this thesis. The more specific literature related to the areas investigated in the later chapters of this thesis, are reviewed within the appropriate chapters.

#### 2.2 Energy Demand Modelling

Since the first oil shock in early 1970s, there has been a significant increase in the number of research studies of energy demand in order to attempt to understand the nature of energy demand and demand response generated by external shocks of that time (Pindyck, 1979). According to Wirl and Szirucsek (1990), the debate between engineers and economists of that era guided the important methodological development in energy demand modelling and helped a wide variety of models to be developed for analysing and forecasting energy demand. Ryan and Plourde (2009) argues that computing power, data availability and the training of energy analysts developed over time and as a consequence demand modelling has advanced to a great extent that the early studies in energy demand modelling are identified as simplistic in today's terms.

According to Hartman (1979) and Bhattacharya and Timilsina (2009) energy is a derived demand rather than a demand for its own sake; it is derived from the demand for the end use services that utilize energy resources with the capital stock that uses energy resources to provide these end-use services (such as lighting, heating, motive power, etc.). Therefore, analysis of energy demand should explicitly or implicitly, accommodate the fact that energy resources and energy consuming appliances are combined in different ways to provide these services.

Hartman (1979) summarizes energy demand behaviour in three steps. Firstly, the energy demander/consumer or user decides whether to buy energy consuming durable goods that will provide a particular service. Secondly, the consumer makes a choice about the technical and economic characteristics of the appliances such as the technology embodied, the fuel type it uses, etc. Thirdly, the consumer's preferences about the intensity and the frequency of use of that appliance (capital utilization) will influence the level of use or demand. In the short run, the capital stock and its characteristics are generally assumed to be fixed, therefore the energy demand behaviour might differ in the short run from that in the long run. As an example, the households' decision to buy a new residential appliance depends upon household income, the climate in which he lives, the cost of purchasing (capital cost) and operating cost (energy costs) the appliance and the general socioeconomic trends that affect the popularity of such appliances. The choice of economic and technological characteristics of appliances depends upon the comparison of capital and operating costs, reliability, size and efficiency of alternatives. Moreover, the climate or the region where the appliance is used might affect the choice of fuel and other characteristics of the appliances; once the decision about the residential appliance has been made, the capital stock is fixed in the short run. Therefore, the capital utilization of these appliances depends upon the cost of the fuel used by the appliance, income and the other characteristics of the household (Hartman, 1979; Bhattacharyya and Timilsina, 2009).

Hartman (1979) argues that an energy demand model should analyse three sets of decision discussed above by taking into account the characteristics of the energy user, the technical

and economic characteristics of the energy source and the capital stock, and the characteristics of the environment that the capital stock is used. As the policy implications of energy demand models are important, Hartman (1979) furthermore states that the variables subject to policy control or that might affect or guide the energy user decisions should be included. However, there are number of different approaches to model energy demand. According to Ryan and Plourde (2009) there is no single 'right' approach to modelling energy demand, the modelling strategy might differ according to a range of conditions and here are different approaches and studies in the literature aiming to model energy demand that can be categorized into three main groups: i) end-use modelling; ii) input-output modelling; iii) econometric modelling. The remainder of this chapter presents a general review of these approaches with, a special focus on econometric modelling of energy demand.

#### 2.3 The End-Use Modelling Approach

End-use approach was developed to identify the role of each end-use towards the aggregate energy consumption. One of the earliest studies using the end-use modelling approach or engineering-economy approach (also known as the bottom up approach) was Chateau and Lapillonne (1978). This approach is based on estimating the energy demand in different sectors or industries using the technical relationship between output and energy use. The data needed for end-use modelling approach is collected through energy surveys, technical studies, and energy audits and focuses on dividing the sectoral demand into homogeneous parts, so that the energy demand for each part can be easily related to the technical and economic factors - the key factors that determine the energy demand for each sector. The general process of end-use modelling is summarized by Bhattacharyya and Timilsina (2009) as follows:

-Total energy demand is disaggregated into homogenous end use categories;

-The evaluation process of social, economic, and technological factors in order to identify the interrelationships and long term development;

-The determinants are organized into a hierarchical structure;

-The mathematical formulization of the hierarchical structure according to the identified relations;

-A snap-shot view of reference year;

-Different scenarios are designed for the future based on a variety of assumptions about the determinants; and

-Forecasting takes place according to scenarios and the mathematical relationship between the determinants.

Furthermore Bhattacharyya and Timilsina (2009) and Swisher et al. (1997) summarises the structure of the end-use modelling of electricity demand as follows:

A wide variety of models have been developed regarding the level of disaggregation, technology selection, technology representation, model target and the level of macroeconomic integration (Worrel et al., 2004). Therefore, a number of models have been produced; such as MARKAL, MARKAL MACRO, EFOM, MAED that all use the general end-use modelling approach but differ from each other in terms of the structure of chosen determinants.

**Figure 2.1: End Use Modelling Approach** 



In reviewing a range of energy demand models for policy formulation, Bhattacharyya and Timilsina (2009) point out that most end-use demand models do not rely on neo-classical economic theory. Moreover, they do not focus on history; instead, they identify recent structural changes and technological developments, which is arguably the main strength of this approach (Bhattacharyya and Timilsina, 2009). Another strength is that these models search for the optimal level of aggregation of sectors by categories that generate satisfactory homogenous consumer groups; for example the rural-urban divide. However, the level of disaggregation in the end-use approach is often not supported by available data in most of the cases; therefore, the data limitation is seen by Pesaran et al, 1998 and others as a major weakness of this approach. Another weakness of this approach, described by Bhattacharyya and Timilsina (2009), is that the accounting type end-use models are unable to identify the price induced effects. However, price effects are important for policy makes for assessing policy options such as carbon tax.

#### **2.4 Input-Output Models**

Wassily Leontief developed the input-output approach in the late 1920s and early 1930s. This systematically quantifies the interrelationships between ranges of sectors in a complex economic system and based on a fully determined general equilibrium model (Arbex and Perobelli, 2010). This analyses the process in which inputs from one industry produce output for consumption or input for another industry. From an input-output table it is possible to identify the change in demand for inputs from a change in production of a final good. The application of this approach to energy demand enables the estimation of the direct energy demand as well as indirect energy demand via inter-industry transactions (Bhattacharyya and Timilsina, 2009).

The value of output relations in a group of inter-industry can be defined as<sup>3</sup>:

$$X_{i} = \sum_{j=1}^{n} X_{i,j} + \sum_{k=1}^{r} F_{i,k} ; i = 1, 2, \dots n$$
(2.1)

where;

 $X_i$  = is the value of total energy output;

 $X_{i,j}$  = is the value of energy demand of industry j; and

 $F_{i,k}$  = is the value of energy for final consumption.

The final energy demand occurs from a number of sources as illustrated below;

$$\sum_{k=1}^{r} F_{i,k} = C_i + \Delta V_i + I_i + G_i + E_i - M_{Fi}$$
(2.2)

<sup>&</sup>lt;sup>3</sup> The specification that is used here is based on the Macro-Demand Analysis of Codoni et al. (1985), as also stated in Bhattacharyya and Timilsina (2009).

where;

 $C_i$  = is the private consumer demand for energy output;  $\Delta V_i$  = is the value of inventory investment demand for energy output;  $I_i$  = is the value of private fixed investment demand for energy output;  $G_i$  = is the value of government demand for energy output;  $E_i$  = is the value of export demand for energy output; and  $M_{Fi}$  = is the value of imports of energy output.

Furthermore, it is assumed that input requirements are a constant proportion of total output, which is identified by:

$$a_{ij} = \frac{x_{ij}}{x_j} \tag{2.3}$$

 $a_{ii}$  = is the fixed input-output coefficient or technical ratio of production.

Although input-output models provide valuable information about the direct and indirect use of energy sources, this approach needs a huge amount of data and very well described input and output relations, which are often not generally available. Another perceived weakness of this approach is the assumption of a fixed input-output ratio however, economic policy induce changes in these input-output coefficients. This assumption therefore excludes the probability of inter-fuel substitution and substitution of non-energy inputs. In addition, the time invariant nature of this assumption cannot adequately capture technological progress (Bhattacharyya and Timilsina, 2009; Arbex and Perobelli, 2010). Technological progress is an important driver of energy demand (this will be discussed in the Methodology section) therefore ignoring technological progress might lead to biased outcomes.

#### **2.5 The Econometric Modelling Approach**

The econometric modelling approach of energy demand is a quantitative approach that generally aims to analyse statistically relationships usually based on econometric theory or intuition between a dependent variable and independent variables using historical data. The identified relationships can be used for analysing the past, estimating the effect of changes of the independent variables on the dependent variable and for prediction over the future.

The econometric modelling approach has been widely used for energy demand modelling because of the availability of historical observations. It can be applied with sufficiently long historical observations on energy consumption, and explanatory variables such as population, income, and prices. For the end-use and input-output modelling approaches, the main strategy is the homogenous grouping of consumers in order to model common characteristics of the energy demand of these homogenous consumer groups (industrial, residential etc.). Although this strategy is utilized by the econometric modelling approach, the main difference between this and the two other approaches is that the econometric modelling approach statistically estimates energy demand relationships; the end-use and input-output approaches rely on energy surveys and technical studies which are not always available.

One of the reasons that the econometric approach is arguably more attractive than the other approaches is that the econometric approach has a strong theoretical background consistent with economic theory (in particular consumer and production theory). A group of potentially significant variables from economic theory is selected and, then by using a statistical process, their effects on the dependent variable is estimated and evaluated. In the econometrics literature there are several functional forms which have been developed for energy demand modelling such as the trans-log model (most often applied to a demand system) and the loglinear model (most often applied to a single equation model). Moreover, the log-linear model has been extensively used and given a single equation approach is adopted in this thesis, the remainder of this chapter focuses on this functional form and its applications in the literature.<sup>4</sup>

#### 2.6 The Log Linear Models and Their Applications

The demand for energy is not a final demand; the energy demand is generated because of the demand for goods and services which needs energy in order to be utilized; such as heat, light, transport, etc. (Nordhaus, 1977). Therefore, the stock of appliances and its capacity usage are important factors that contribute to determining energy demand. This relationship can be shown as follows (Bohi, 1981; Bohi and Zimerman, 1984):

$$E_t = F(A_t, R_t) \tag{2.4}$$

#### Where;

 $E_t$  = total demand for aggregated energy;  $A_t$  = stock of appliance for aggregated energy;  $R_t$  = capacity usage rate of the appliances; and t = time period t.

According to Bohi and Zimmerman (1984) and Bohi (1981), A and R can be also represented by the following functional forms:

$$A_t = h(P_t, P_{at}, Y_{nt}, Z_A); (2.5)$$

<sup>&</sup>lt;sup>4</sup> Furthermore, according to Pesaran et al. (1998) the log-linear model of energy demand generally performs better than other specifications and is a more convenient specification for forecasting purposes (p. 84).
$$R_t = g(P_t, Y_{nt}, Z_R)$$

where;

 $P_t$  = nominal price of aggregated energy in time t;

 $P_{at}$  = nominal price of all other goods in time *t*;

- $Y_{nt}$  = nominal income in time t;
- $Z_A$  = vector of other variables (e.g. household size) in time *t*; and

 $Z_R$  = vector of other variables (e.g. temperature, energy efficiency) in time *t*.

Substituting Equation (2.5) and (2.6) into (2.4) the following functional form for energy demand can be obtained:

$$E_t = k (P_t, P_{at} Y_{nt}, Z_{A_t}, Z_{R_t})^5$$
(2.7)

In order to estimate Equation (2.7) it needs a mathematical form and the log linear form is chosen given its convenience in terms of the constant estimated elasticities. Furthermore, a substantial majority of econometric energy demand studies have employed log linear models. Houthakker's (1951) being generally regarded as the first application of this model. The log linear specification of Equation (2.7) is given by:

$$ln E_{i,t} = a + \psi ln P_{a,t} + \tau ln P_{i,t} + \pi ln Y_{n,t} + \partial ln Z_t + \varepsilon_t$$
(2.8)

Equation (2.8) contains nominal prices and income and therefore might suffer from money illusion by taking into account nominal prices instead of real prices in that it is not reflecting

<sup>&</sup>lt;sup>5</sup> For simplicity, the vectors  $Z_A$  and  $Z_R$  will be illustrated as a single vector Z for the following equations.

the purchasing power of the currency. In order to overcome the money illusion problem, the constraint  $\psi + \tau + \pi = 0$  is applied to Equation (2.8) yielding (Weyman-Jones, 1986 p.18):  $ln E_t = a + \psi (lnP_t - lnP_{at}) + \tau (lnY_{nt} - lnP_{at}) + \partial lnZ_t + \varepsilon_t$  (2.9)

Where;

 $ln \frac{(P_t)}{(P_{at})}$  is the natural log of energy prices with respect to all other prices, which can be regarded as real energy prices.

 $ln \frac{(Y_{nt})}{(P_{at})}$  is the natural log of income with respect to all other prices, which can be regarded as the natural log of real income.

Equation (2.9) can therefore be written as:

$$ln E_t = a + \psi ln P_t + \tau ln Y_t + \partial ln Z_t + \varepsilon_t$$
(2.10)

where;

 $P_t$  = the real price of energy;

 $Y_t$  = real income;

 $\psi$  = the price elasticity of energy demand;<sup>6</sup>

 $\tau$  = the income elasticity of energy demand;<sup>7</sup> and

 $\partial$  = the other variable(s) elasticity of energy demand.

<sup>&</sup>lt;sup>6</sup> The price elasticity gives the percentage change in quantity demanded as a response to one percent change in real price (holding constant all other determinant of demand).

<sup>&</sup>lt;sup>7</sup> The income elasticity gives the percentage change in quantity demanded as a response to one percent change in real income (holding constant all other determinant of demand).

Equation (2.10) is a static log linear energy demand model in reduced form and assumes that there is no distinction between the short term and the long term. However, when the price or income changes the capital or appliance stock is fixed in the short run therefore the short run adjustment might be limited. However, in the long run consumers and producers might also change the capital or appliance stock in which case there would be generally be a distinction between the short run and long run impacts. Therefore, it is often argued that instead of the static expression (2.10) a general specification should be utilised that allows for the possibility of this distinction, with the long term impact being different to the short term. To do this a number of dynamic specifications can be found in the literature, including the Partial Adjustment Method, the Autoregressive Distributed Lag Model, and the Error Correction Model, all of which are discussed in the following sections.

# 2.6.1 Partial Adjustment Model and Autoregressive Distributed Lag Model

One of the early methods widely employed to attempt to capture the dynamic process, is the partial adjustment method (PAM). The theoretical base of this method is that the stock of appliance and capital is not very flexible so that it cannot adjust to a new equilibrium in the short run so that the adjustment process of energy demand can be shown as:

$$lnE_t - lnE_{t-1} = \lambda(lnE_t^* - lnE_{t-1})$$
(2.11)

where;

 $E_t^*$  = unobservable equilibrium (or desired) level of demand;  $\lambda$  = speed of adjustment, 0< $\lambda$ ≤1; and

t = time period t.

If  $\lambda$  is near to 0, the adjustment speed is low when it is near to 1, the adjustment speed is fast and when it is equal to one the adjustment completes in one period. The equilibrium energy demand relationship in levels, Equation (2.11), can therefore be re-written as follows:

$$\ln E_t^* = a + \alpha \ln P_t + \delta \ln Y_t \tag{2.12}^8$$

and substituting Equation (2.11) into (2.12) yields:

$$lnE_t = \lambda a + \lambda \alpha \, lnP_t + \lambda \delta \, lnY_t + (1 - \lambda)E_{t-1}$$
(2.13)

For simplicity let  $\beta_0 = \lambda a$ ;  $\beta_1 = \lambda \alpha$ ;  $\beta_2 = \lambda \delta$ ;  $\beta_3 = (1 - \lambda)$  so that Equation (2.13) can be rearranged as follows (see for example, Common, 1981):

$$lnE_{t} = \beta_{0} + \beta_{1} lnP_{t} + \beta_{2} lnY_{t} + \beta_{3} E_{t-1}$$
(2.14)

where;  $\beta_1$  is the impact/short term price elasticity and  $\beta_2$  is the impact/short term income elasticity. Given  $\lambda = 1 - \beta_3$ , the long run price and income elasticity are given by  $\alpha = \frac{\beta_1}{\lambda}$  and  $\delta = \frac{\beta_2}{\lambda}$  respectively.

An alternative more general way to consider the dynamics is by generalizing Equation (2.14) to a  $k^{th}$  order Autoregressive Distributed Lag (ARDL) model:

 $lnE_t = \varphi_0 + \varphi_1E_{t-1} + \dots + \varphi_kE_{t-k} + \alpha_1lnP_t + \alpha_2lnP_{t-1} + \dots + \alpha_klnP_{t-k} + \delta_1lnY_t + \beta_1lnY_t  

<sup>&</sup>lt;sup>8</sup> Note that Z has been omitted for simplicity.

$$\delta_2 ln Y_{t-1} + \dots + \delta_k ln Y_{t-k} \tag{2.15}$$

Where  $\alpha_{1,2,3,\dots,k}$  and  $\delta_{1,2,3,\dots,k}$  are short run price and income elasticities of the related period respectively. In order to determine the long run elasticities it is assumed that in the long run:

 $ln E^{*} = ln E_{t} = ln E_{t-1} = ln E_{t-2} = ....$  $ln P^{*} = ln P_{t} = ln P_{t-1} = ln P_{t-2} = ....$  $ln Y^{*} = ln Y_{t} = ln Y_{t-1} = ln Y_{t-2} = ....^{9}$ 

So substitution these into Equation (2.15) yields:

$$lnE_{t}^{*} = \varphi_{0} + \varphi_{1}lnE_{t}^{*} + ... + \varphi_{k}lnE_{t}^{*} + \alpha_{1}lnP_{t}^{*} + \alpha_{2}lnP_{t}^{*} + ... + \alpha_{k}lnP_{t}^{*} + \delta_{1}lnY_{t}^{*} + \delta_{2}lnY_{t}^{*} + ... + \delta_{k}lnY_{t}^{*}$$
(2.16)

and re-arranging Equation (2.16) gives:

$$(1 - \varphi_1 - \dots - \varphi_k) \ln E_t^* = \varphi_0 + (\alpha_1 + \alpha_2 + \dots + \alpha_k) \ln P_t^* + (\delta_1 + \delta_2 + \dots + \delta_k) \ln Y_t^*$$
(2.17)

And rearranging further gives:

$$\ln E_t^* = \frac{\varphi_0}{(1-\varphi_1 - \dots - \varphi_k)} + \frac{(\alpha_1 + \alpha_2 + \dots + \alpha_k)}{(1-\varphi_1 - \dots - \varphi_k)} \ln P_t^* + \frac{(\delta_1 + \delta_2 + \dots + \delta_k)}{(1-\varphi_1 - \dots - \varphi_k)} \ln Y_t^*$$
(2.18)

<sup>&</sup>lt;sup>9</sup> This implicitly assumes that all variables have reached their long run steady state equilibrium values.

where 
$$\frac{(\alpha_1 + \alpha_2 + \dots + \alpha_k)}{(1 - \varphi_1 - \dots - \varphi_k)}$$
 and  $\frac{(\delta_1 + \delta_2 + \dots + \delta_k)}{(1 - \varphi_1 - \dots - \varphi_k)}$  long run price and income elasticity.

Thus, this dynamic log-linear model can be used as a general specification and a restricted version estimated if accepted by the data.<sup>10</sup> Both this and the PAM are usually estimated via OLS; however, there is the potential problem of spurious regression with this, as discussed in the next section.

# 2.6.2 Non-Stationarity and the Co-integration Technique

Most economic variables such as energy consumption, energy prices and income are trended and therefore these series are likely to be 'non-stationary'. Series that are 'stationary' and 'non-stationary' have some important differences. Shocks will be temporary in stationary time series and the series will be pushed to return to their long-run equilibrium. On the other hand, a shock to a non-stationary series will have some permanent impact; therefore, the mean and/or the variance of a non-stationary time series will depend on time. (Asteriou and Hall; 2006). Moreover, it has been shown that the existence of non-stationary time series variables can produce OLS regression results with spuriously significant regression coefficients (Thomas, 1993). In order to overcome this, the unit root/co-integration technique has developed and been widely employed in energy demand modelling studies. The first applications of the technique to the energy demand modelling were Nachane et al. (1988) and Hunt and Manning (1989). Both studies employed the log linear model and the unit root/cointegration technique was adopted since it was argued that classical regression techniques might not have been producing reliable results when applied to non-stationary time series variables in energy demand studies.

<sup>&</sup>lt;sup>10</sup>The PAM being one restricted version of the general ARDL.

Letting  $e_t = lnE_t$ ,  $y_t = lnY_t$ , and  $p_t = lnP_t$ , and using energy demand as the example, a non-stationary time series variable,  $e_t$ , can be represented as follows:

$$e_t = \phi e_{t-1} + \varepsilon_t \qquad \qquad \varepsilon_t \sim iid \ (0, \sigma^2) \tag{2.19}$$

If  $|\phi|\geq 1$ , then  $e_t$  is non-stationary and known as a random walk model. A series  $e_t$  is integrated order d if  $e_t$  is non-stationary but  $\Delta^d e_t$  is stationary. After differencing d times a series might convert to being stationary, in that case the series is said to integrated of order d and represented as I(d) (Engle and Granger, 1987). For simplicity only the values of d=0 and d=1 will be explained as examples. For equation (2.19), if d=0 then the  $e_t$  will be stationary and if d=1 then the first difference of  $e_t$  is stationary. Consequently,  $e_t$ , which is assumed autoregressive, is also said to have a unit root or is integrated order one, I(1). Therefore an integrated of order one variable, Equation (2.19), can be rearranged in order to reach stationary series as follows:

$$\Delta e_t = e_t - e_{t-1} = \varepsilon_t \tag{2.20}$$

In order to test for the stationarity of time series data the most common tests are the Augmented Dickey Fuller (ADF) and Phillips-Perron (PP) tests can (see for example, Asteriou and Hall, 2006)

When non-stationarity is discovered, a careful approach is required. For example, if  $e_t$ ,  $y_t$ , and  $p_t$  are three non-stationary variables that are integrated of order one, then the long run equilibrium energy demand relationship could be represented as follows in an OLS regression:

$$e_t = a + \alpha p_t + \delta y_t + \varepsilon_t \qquad \varepsilon_t \sim iid \ (0, \sigma^2) \tag{2.21}$$

Granger and Newbold (1974) illustrate, by simulation methods, that this regression is expected to be spurious, with high  $R^2$  and significant estimate of  $\alpha$  and  $\delta$  with a very low DW value. Therefore, if the error term  $\varepsilon_t$  has a stationary process, then  $e_t$ ,  $p_t$  and  $y_t$  are said to be co-integrated and the estimation is no longer spurious. In order to understand if the three non-stationary variables do co-integrate, the ADF and PP tests can be employed as discussed above.

Dickey and Fuller (1979, 1981) first developed a procedure in order to test for nonstationarity (known as the Dickey-Fuller (DF) test). This procedure is based on the assumption that testing for non-stationarity is equal to testing for a unit root. Assuming that Equation (2.19) represents a simple AR(1) process, it can be re-arranged by substituting  $e_{t-1}$ from both sides as follows:

$$e_t - e_{t-1} = \phi e_{t-1} - e_{t-1} + \varepsilon_t \tag{2.22}$$

$$\Delta e_{t-1} = (\phi - 1)e_{t-1} + \varepsilon_t \tag{2.23}$$

$$\Delta e_{t-1} = \omega e_{t-1} + \varepsilon_t \tag{2.24}$$

where  $\omega = (\phi - 1)$ 

The DF tests for whether  $\phi=1$  or  $\phi<1$  in Equation (2.19). The null hypothesis is H<sub>0</sub>:  $\phi=1$ , that the series has a unit root. For equation (2.24), the H<sub>0</sub>:  $\omega=0$  (pure random walk model) and the alternative is  $\omega<0$ . The DF test is based on the normal t test on  $\phi$ , however the t-statistic does not have a conventional t-distribution. The critical values are computed by Dickey and Fuller (1979, 1981) and MacKinnon (1991).

The original DF test was further developed, thus becoming the ADF. This includes lagged terms of the dependent variable in order to avoid autocorrelation. The necessary lag length can be determined by Akaike Information Criterion (AIC) or Schwartz Bayesian Criterion (SBC). Alternatively lag length can be determined by testing the lag length necessary to whiten the residuals by the Lagrange Multiplier serial correlation test. Equation (2.24) can therefore be re-arranged by including lagged terms of the dependent variable as follows:

$$\Delta e_t = \omega e_{t-1} + \sum_{i=1}^p \beta_i \Delta e_{t-i} + \varepsilon_t \tag{2.25}$$

The ADF Test therefore corrects for higher order autoregressive process by adding lagged dependent variable on the right hand side. The critical values for the ADF tests are the same as DF tests as is the null hypothesis,  $\omega = 0$  for Equation (2.24). Therefore, the ADF is a more general test and the DF is a special test when no lagged dependent variables are included in the test – hence it can generally be given as the ADF test.

The DF test is based on the assumption that the error term is statistically independent and has a constant variance. Philips and Perron (1988) therefore developed a generalization of the ADF testing procedure related to the distribution of errors. The PP tests make a correction to the t statistics of the  $\omega$  to take account of the serial correlation in  $\varepsilon_t$ . The expression is complex to derive however in general the PP statistics are basically modifications of the ADF statistics, which allows for a less restrictive nature of the error process (see, Asteriou and Hall; 2006).

As stated above the integrated order of d series might lead to spurious regressions. If the variables included are non-stationary, then the error term  $\varepsilon_t$  in Equation (2.21) can be interpreted as a combination of the cumulated error process. It is generally expected that this cumulated error process will produce another non-stationary process. However in special cases these two variables are closely related and it is possible that a linear combination of these two variables eliminates the non-stationary, in which case the variables are co-integrated (see, Asteriou and Hall; 2006).

Co-integration is important for economic models using non-stationary variables. If the variables do not co-integrate then because of the spurious regression problem, the econometric approach becomes meaningless. For example, if  $e_t$ ,  $p_t$  and  $y_t$  and all I(1) then estimating Equation (2.21) above by OLS might result in unsatisfactory estimates of  $\alpha$  and  $\delta$ . One way of resolving this problem, is to make the variables stationary by differencing as follows:

$$\Delta e_t = a + \alpha \Delta y_t + \delta \Delta p_t + \Delta \varepsilon_t \tag{2.26}$$

If estimated by OLS, this will provide estimates of  $\alpha$  and  $\delta$  that are not affected by the spurious regression problem, given the first differenced variables are stationary. However, Equation (2.26) only gives the short run relationship between the variables, whereas information on and the long run relationship between the variables is very important for

energy economists and energy policy analysis. Nevertheless, the long term relationship can be identified by different approaches based on the co-integration methods such as the Engle and Granger Two Step Procedure and the Johansen multivariate approach, which are discussed in the following sections.

#### 2.6.3 Engle and Granger Two Step Procedure and the Error Correction Mechanism

One of the approaches to identify the long run relationship between co-integrating variables is the Engle and Granger (1987) Two-Step Method (EGTSM). This involves a first step where the long run relationship is determined followed by the second step whereby the disequilibrium errors from this long run relationship are used as an error correcting term in a short run dynamic equation, often referred to as Error Correction Mechanism (ECM).

To illustrate, if  $e_t$ ,  $p_t$  and  $y_t$  are found to be I(1) then an attempt can be made to see if these variables co-integrate by estimating Equation (2.21) (which is re-written here as Equation (2.27):

$$e_t = \beta_0 + \beta_1 p_t + \beta_2 y_t + \varepsilon_t \tag{2.27}$$

The estimated version of Equation (2.31) is given by:

$$e_{t} = \hat{\beta}_{0} + \hat{\beta}_{1}p_{t} + \hat{\beta}_{2}y_{t} + \hat{\varepsilon}_{t}$$
(2.28)

$$\hat{e}_t = \hat{\beta}_0 + \hat{\beta}_1 p_t + \hat{\beta}_2 y_t \tag{2.29}$$

where;

 $\hat{\beta}_1 =$ long-run price elasticity;

- $\hat{\beta}_2 =$ long-run income elasticity;
- $e_t$  = actual energy demand; and
- $\hat{e}_t$  = predicted energy demand.

Therefore, in order to determine whether Equation (2.27) represents a valid long-run relationship, (i.e. there is co-integration) the estimated residuals ( $\hat{\varepsilon}_t$ ) are tested to see if they are stationary using such tests as the ADF and PP outlined above. If they are found to be stationary, (i.e.  $\hat{\varepsilon}_t \sim I(0)$ ) then co-integration is accepted and it can be said that there exists a valid long run energy demand relationship.

The estimated residuals may then be used in the second step of the procedure given the difference between actual  $(e_t)$  and predicted  $(\hat{e}_t)$  energy demand represents the disequilibrium and so the error correction term is defined as:

$$EC_t = e_t - \hat{e}_t = \hat{\varepsilon}_t \tag{2.30}$$

Moreover, in the second step the EC term (which is stationary, I(0)) can be included in a short run dynamic equation (the ECM) given by:

$$lnE_{t} = \eta_{0} + \eta_{1}\Delta lnE_{t-1} + \dots + \eta_{k}\Delta lnE_{t-k} + \pi_{1}\widehat{\pi_{1}}\Delta lnP_{t} + \dots + \pi_{k}lnP_{t-k} + \theta_{1}\Delta lnY_{t} + \dots + \theta_{k}\Delta lnY_{t-k} + \lambda EC_{t-1}$$
(2.31)
where:

where;

 $\pi_1$  = Short run price elasticity;

 $\theta_1$  = Short run income elasticity; and

 $\lambda$  = speed of adjustment (-1< $\lambda \leq 0$ ).

The ECM provides some advantages. Firstly, as explained it estimates the correction from disequilibrium of the previous period. Secondly, it overcomes the problem of spurious regression. Thirdly, it fits into the general to specific approach that will help to determine the most parsimonious model. Finally, since the error term is the disequilibrium and is stationary it implies that there is an adjustment process that avoids errors becoming larger in the long term (see, Asteriou and Hall; 2006).

A disadvantage of the EGTSM and the ECM is that it assumes that there is only one cointegrating relationship (or vector). However, it is possible to have a number co-integrating vectors. Therefore the co-integration method has developed further to allow for the possibility of, and testing for, more than one co-integrating vector. This is known as the multivariate co-integrating approach and is discussed in the next section.

#### 2.6.4 Multivariate Co-integration System (Johansen Approach)

One issue with the two-step method is that when more than two variables are included it is assumed that only one co-integration long run equilibrium relationship exists. Johansen (1988 and 1991), Johansen, and Juselius (1990) therefore introduced a framework considering the possibility of multiple co-integrating vectors by utilizing the multivariate maximum likelihood approach to co-integration. The Johansen procedure analyses the co-integration relationship based on a vector autoregressive (VAR) model.

Given a VAR model of a set of variables X as:

$$X_{t} = \Pi_{1} X_{t-1} + \dots + \Pi_{k} X_{t-k} + \varepsilon_{k} \qquad t = 1, 2, \dots \dots \dots T \qquad (2.32)$$

Where  $X_t$  is a (N x 1) vector of integrated order one variables. As an example in a three dimensional VAR model,  $X_t = (e_t, y_t, \text{ and } p_t)$ 

 $\Pi_1, \ldots, \Pi_k$  (N x N) coefficient matrices, k is the maximum lag length,  $u_t$  is a (N x 1) vector of error terms under the classical assumption. All three variables, namely  $e_t$ ,  $y_t$ , and  $p_t$  are assumed to be endogenous.

Equation (2.32) can be transformed to a vector error correction form (VECM) as follows:

$$\Delta X_t = \Gamma_1 \Delta X_{t-1} + \dots + \Gamma_{k-1} \Delta X_{t-k+1} + \Pi X_{t-k} + \varepsilon_t$$
(2.33)

where;

 $\Gamma_i = -I + \Pi_1 + \dots + \Pi_I$  for all  $i=1,\dots,k-1$ ;  $\Pi = -I + \Pi_1 + \dots + \Pi_k$ ; and

I= the identity matrix.

The rank of  $\Pi$  will be zero, if there is no co-integration within the system, but if cointegration exists, the correlation between the variables in X<sub>t</sub>, reduced rank of  $\Pi$ , r, will be equal to the number of co-integrating vectors in the system. Then the matrix  $\Pi$  can be reduced into two matrices  $\alpha(Nxr)$  and  $\beta'(Nxr)$  these matrices can be shown as follows.

$$\Pi = \alpha \beta' \tag{2.34}$$

Where  $\beta'$  is the co-integration vector, representing the long run relationships, and  $\alpha$  represents the error correction parameters. There are two different likelihood ratio tests that can be employed for obtaining maximum likelihood estimation of co-integrating vectors  $\delta$  where r is the number of possible co-integrating vectors. The first way is to test of null hypothesis of r co-integrating vectors against the alternative of r+1 co-integrating vectors which comes from trace statistics and the second way is the same hypothesis test based on maximal Eigenvalue statistics; however, the maximal Eigenvalue test is accepted to be more powerful (see, Asteriou and Hall; 2006).

The Johansen multivariate approach is a powerful way of analysing co-integrated systems. It allows a complex modelling of causality and structure in energy demand modelling. However, one perceived drawback with this approach (and all the co-integration techniques discussed above) is the specification of the vector Z included in Equation (2.9) above. If data is available for the other exogenous variables then there is not a problem, however, quite often this is not the case and a trend is required as a proxy (see further arguments about this in a later section). Moreover, traditional OLS estimation and the various co-integration techniques can only allow for a simple deterministic trend. However, as discussed below this is likely to be an unreasonable assumption and instead a non-linear stochastic trend might be a more appropriate proxy for the other non-measurable exogenous impacts. As discussed above, energy is a derived demand; therefore, there are a number of exogenous factors that might affect demand (discussed more below). However, it is often not possible to measure these factors adequately in order to include in the energy demand models discussed thus far, thus a suitable proxy is required. As stated in the models discussed so far the only way to do this is by adding a deterministic linear trend; but it is arguably not realistic to expect that exogenous factors will affect energy demand in a unidirectional way as given by a linear

trend. However, the STSM does provide a stochastic framework that arguably allows a better way of modelling the exogenous factors and consequently modelling energy demand. A brief overview of the STSM approach and the associated UEDT is therefore examined in the next section.<sup>11</sup>

# 2.6.5 The Underlying Energy Demand Trend (UEDT) and the Structural Time Series Model (STSM)

In this section, firstly, the technological progress debate and UEDT concept will be reviewed and secondly the STSM will be examined outlining its advantages in terms of modelling exogenous factors, including technological progress.

# 2.6.5.1 Technological Progress Debate and the UEDT Concept

Technological progress of the capital stock is an important factor that influences energy demand. Energy is a derived demand rather than being demanded for its own sake; it is the demand for the services it produces with the capital stock in place at a certain time. The amount of energy demand is therefore connected to the technology level of the energy appliances to assure the demanded level of services. Beenstock and Willcocks (1981) therefore argued that technological progress should be taken into account in energy modelling studies and used a simple deterministic trend in their study. However, Kouris (1983a, 1983b) criticized this, arguing that although technology is an important determinant of energy demand, there is no sufficient way to identify its effect on energy demand unless a sufficient way to measure it can be addressed. Moreover, in the absence of the appropriate measure, Kouris argued that the effect of technological progress could therefore be observed via the

<sup>&</sup>lt;sup>11</sup> However, please note that given this is the methodology adopted in this thesis, the details of this methodology are given in the next chapter.

response to energy price changes, the price elasticity. In response, Beenstock and Willcocks (1983) argued that it is important to attempt to capture the exogenous effect of technological progress and, although using a linear trend is not an adequate way, it is better than just ignoring it.

Hunt et al. (2003a and 2003b) agreed that technical progress should be captured in energy demand models arguing that it is important to distinguish between the exogenous impact and the endogenous price (and income) effects. Furthermore, Hunt et al. (2003a and 2003b) argued that in addition to technical change and the change in energy efficiency of the capital stock there are a number of additional exogenous factors that will also affect the demand for energy. These include changes in such factors as consumer tastes and preferences, demographic and social structure, environmental regulations, economic structure, etc. Hunt et al. (2003a and 2003b) therefore introduced the wider concept of the UEDT that encompasses technical change of the capital stock and other exogenous factors.<sup>12</sup> However, Hunt et al. (2003a and 2003b) argued that given the way technical progress is introduced and the likely 'lumpiness' of other exogenous factors, it is unlikely that the UEDT would be linear - as given by incorporating a deterministic time trend in an estimated energy demand function. Instead, they argue that the UEDT is likely to be non-linear and could incorporate periods where it is downward sloping (energy saving) and periods where it might be upward sloping (energy using). Thus, according to Hunt et al. (2003a and 2003b) it is important to model the UEDT in the most general and flexible way possible, and therefore recommended the use of the STSM introduced by Harvey et al. (1986), Harvey (1989), Harvey and Shephard (1993), Harvey and Scott (1994) and Harvey (1997).

<sup>&</sup>lt;sup>12</sup> Hunt et al. (2003a) also argued that if the UEDT is not included (or incorrectly modelled) then this could lead to biases in the estimated price and income elasticities; for example, if the true UEDT is downward sloping then the income elasticity will be underestimated by not taking account of the UEDT.

#### 2.6.5.2 The Structural Time Series Model (STSM)

Harvey's (1989) STSM decomposes a time series into different components that have direct interpretations. The basic form of structural time series models is where the dependent variable is formulated as a regression of a time trend and a set of seasonal dummies. This can be interpreted as a univariate time series model where the explanatory variable is a function of time and the parameters of the model are time varying. The extension of the univariate model by adding observable explanatory variables produces a multivariate structural time series model (Harvey and Shephard, 1993; Harvey, 1989).

The main tool to estimate structural time series models is the state space form, which represents the state of the system by various unobserved components such as trends and seasonals. As new observations become available, the estimates of the unobservable components are updated by means of a filtering process while a smoothing algorithm provides the best estimate of the state at any point within the sample (Harvey and Shephard, 1993).

The classical time series analysis is based on analysis of time series data obtained from observations that are assumed to be realization of random variables as a result of a stochastic process. The stationarity of the series is identified by the properties of this stochastic process. The theory of stochastic processes is used to construct conventional time series models. The non-stationarity in the series is dealt with by differencing, which is the underlying assumption of the ARIMA methodology of Box and Jenkins (1976) type models. As discussed in the previous chapter, the co-integration approach is often utilized to deal with non-stationarity of variables in energy demand modelling literature. Expansion of unit root tests coupled with co-integration technique lead to so called the "unit root revolution". Because of this so-called

revolution, time series econometric modelling became widely dominated by the cointegration technique.

As in other fields of economics, researchers working in energy economics focused on discovering a co-integrating vector for energy demand relationships. However, the co-integration technique has been questioned (for example, see Maddala and Kim, 1998; Hunt et al., 2003a and 2003b). Harvey and Shephard (1993) argued that most of the economic time series are non-stationary and there is no good reason to expect that they will be stationary by differencing. Moreover, Harvey (1997) criticizes the co-integration approach because of its "poor" statistical properties and argues that co-integration technique is misleading. In STSM, stationarity of time series do not have a fundamental role, therefore the STSM approach combines the flexibility of time series with the direct interpretation of regression, reflecting that it is possible to utilize a model selection methodology that is consistent with the standard econometric literature (Harvey and Shephard, 1993; Harvey, 1997). Furthermore, in their studies, Hunt et al. (2000, 2003a and 2003b) suggest that the structural time series approach is the ideal way to model the UEDT. The major reason being that the STSM permits a stochastically changing unobservable trend that can be combined with a distributed autoregressive lag ARDL as follows (Hunt et al., 2003a and 2003b):

$$A(L)e_{t} = \mu_{t} + \gamma_{t} + B(L)y_{t} + C(L)p_{t}$$
(2.35)

where;

 $e_t$ ,  $y_t$  and  $p_t$  are as defined above;  $A(L) = 1 - \lambda_1 L - \lambda_2 L^2 - \lambda_3 L^3 - \lambda_4 L^4$  (the polynomial lag operator);  $B(L) = 1 + \alpha_1 L + \alpha_2 L^2 + \alpha_3 L^3 + \alpha_4 L^4$  (another polynomial lag operator);  $C(L) = 1 + \varphi_1 L + \varphi_2 L^2 + \varphi_3 L^3 + \varphi_4 L^4 \text{ (the final polynomial lag operator);}$   $\frac{B(L)}{A(L)} = \text{long run activity elasticity;}$   $\frac{C(L)}{A(L)} = \text{long run price elasticity;}$   $\mu_t = \text{is the stochastic trend;}$   $\gamma_t = \text{is the stochastic seasonal variation; and}$   $u_t = \text{is a random white noise disturbance form.}$ 

$$\mu_t = \mu_{t-1} + s_{t-1} + \eta_t \tag{2.36}$$

$$s_t = s_{t-1} + \xi_t \tag{2.37}$$

where 
$$\eta_t \sim NID(0, \sigma_{\eta}^2)$$
 and  $\xi \sim NID(0, \sigma_{\xi}^2)$ .

As stated, the main advantage of structural time series analysis of energy demand is to introduce a stochastic trend (the UEDT) that is defined in Equation (2.36) and (2.37). This enables the identification of structural changes over time. Given this, the STSM is the chosen methodology employed in the research for this thesis. Therefore, a general overview of the method is given below; however, in the methodology section the structural time series method and its application to energy demand studies will be illustrated in detail.

#### 2.6.5.3 The STSM in Energy Demand Studies

There are only a few applications of the STSM to energy demand (see Table 2.1). Harvey and Koopman (1993) within the context of STSM and by using time varying splines examined hourly electricity demand for northwest US. Hunt et al. (2000) was the first attempt to use the

STSM to estimate a UEDT for UK final consumption of coal, gas, oil, petroleum, electricity, and total energy by using quarterly data over period 1972 to 1995. They concluded that the UEDT has a stochastic, rather than deterministic, form as previously used in conventional models. Furthermore, the estimated UEDT was found to be fluctuating over time, illustrating that energy demand is affected by exogenous unobserved influences in a non-systematic (non-linear) way. Hunt et al. (2003a and 2003b) investigated UK aggregate energy demand using the STSM for various sectors of the UK using quarterly data for the period 1972 to 1997 and concluded that stochastic trends and seasonals are better when modelling UK energy demand. Similarly, Dimitropoulos et al. (2005) demonstrated again that the STSM approach is superior by implementing the stochastic rather than deterministic trend when investigating sectoral aggregate energy demand using annual UK data for the period 1967 to 2002. Hunt and Ninomiya (2003) investigated transportation oil demand for the UK and Japan by using the STSM with quarterly data over the period 1971 and 1997, testing their results against conventional deterministic trend models and argue that the stochastic trend from the STSM is more appropriate than a deterministic one. Amarawickrama and Hunt (2008) estimated Sri Lankan electricity demand functions by using six different methods including the STSM approach over the period 1970-2003 and showed that the technique performed equally as well compared to co-integration econometric approaches; but implicitly showed that the STSM was the only technique that allowed an exogenous non-linear trend to be identified. Doornat et al. (2008) investigated French hourly electricity load by employing a multivariate periodic state space model over the period 1995-2004 that included a stochastic trend and concluded that their model gives satisfactory prediction results for one, two and three day ahead but some improvements can be made for longer prediction periods. Broadstock and Hunt (2010) estimated a UK transport oil demand function over the period 1960-2007 by using the STSM but included a proxy for fuel efficiency in their model, finding a highly non-linear UEDT. Agnolucci (2010) estimated UK domestic and industrial energy demand functions by the STSM and OLS with the inclusion of asymmetric price responses for these two approaches for data spanning the period 1973 and 2005 and concluded that the STSM is an effective approach in the estimation of the energy demand.

Study	Sector/Area	Data Used	Conclusion
	Covered		
Harvey and	US Aggregate	07.11.1990-	A time varying periodic spline
Koopman (1993)	Hourly and Weekly	31.03.1991	component provide a good way
	Electricity Demand	hourly data	of modelling changing
			electricity load pattern within
			week.
Hunt and Ninomiya	UK and Japan	1971-1997	STSM is superior to other
(2003)	Transport Sector	quarterly	conventional techniques for
	Oil Demand	data	estimating transportation oil
			demand.
Hunt et al. (2000,	UK Aggregate and	1971-1997	The STSM perform better than
2003a, and 2003b)	Sectoral Energy	quarterly	co-integration approach.
	Demand	data	
Dimitropoulos et al.	UK Aggregate and	1967-2002	The STSM is superior to
(2005)	Sectoral Energy	annual data	traditional regression methods
	Demand		by introducing stochastic trend
			rather than deterministic.
Amarawickrama	Sri Lanka	1970-2003	STSM performed equally as well
and Hunt (2008)	electricity demand	annual data	compared to co-integration
			approaches.
Doornat et al.	French Electricity	01.09.1995-	STSM is successful in terms of
(2008)	Demand	31.08.2004	short term load forecasting.
		hourly data	
Broadstock and	UK Transport Oil	1960-2007	The contribution of UEDT that
Hunt (2010)	Demand	annual data	is estimated by STSM is highly
			significant.
Agnolucci (2010)	UK Domestic and	1973-2005	STSM is an effective approach
,	Industrial Energy	quarterly	for estimating energy demand.
	Demand	data	

 Table 2.1: Summary of Energy Demand Studies with STSM

#### 2.7 Other Modelling Issues in Energy Demand

As justified above the STSM coupled with the UEDT concept is employed in this research and is initially applied to Turkish electricity demand in Chapter 4 below. However, the analysis is extended in Chapter 5 for OECD-Europe gas demand by considering the relative contributions of economic and non-economic factors in driving demand and in Chapter 6 for US gasoline per-capita demand by considering asymmetric price responses and time varying parameters. These extensions are therefore briefly surveyed here but discussed in detail in Chapter 5 and Chapter 6.

# 2.7.1 Estimating the Relative Contribution of Demand Drivers

As mentioned above, Broadstock and Hunt (2010) estimated a transport oil demand function for the UK using the STSM. From this, they decomposed the demand drivers in an attempt to find the relative importance of the economic drivers (price and income) and the noneconomic drivers (fuel efficiency and the UEDT) and found that the UEDT was relatively very important in determining UK transport oil demand. Similarly, Chitnis and Hunt (2012) estimated UK 'transport' and 'housing' energy expenditure equations for 1964-2009 and again found that the relative contribution from the non-economic factors was non-trivial.<sup>13</sup>

Similar attempts to decompose demand drivers using the STSM have also been undertaken by Chitnis and Hunt (2011 and 2012). Chitnis and Hunt (2011) estimated consumer expenditure relationships for 12 UK 'Classification of Individual Consumption by Purpose (COICOP)' categories over the period 1964Q1 to 2006Q1 and found that for the majority of

<sup>&</sup>lt;sup>13</sup>Another, non-energy demand example is Chitnis and Hunt (2011). They estimated consumer expenditure relationships for 12 UK COICOP categories over the period 1964Q1 to 2006Q1 and found that for the majority of the UK12 COICOP categories, the relative contribution from the non-economic factors is estimated to be very high.

the UK12 COICOP categories, the relative contribution from the non-economic factors is estimated to be very high.

#### 2.7.2 Asymmetric Price Responses

A basic asymmetric price response is where a consumer responds differently to a price rise than a price fall. The origins of this approach in the economics literature can be traced back to Wolffram (1971) and Traill, et al. (1978). Both studies investigated asymmetric price responses in agricultural supply. This idea was later taken up by energy demand modellers and energy economists with a number of papers investigating the imperfect price reversibility concept in energy demand.

There are a number of examples. Dargay (1992) investigates the demand for motor fuels for road transport in France, Germany, and UK. Gately (1992) explores vehicle miles per driver, miles per gallon and gasoline demand per driver for the US. Dargay and Gately (1994) examines the oil and energy demand for OECD as a whole and according to regions with in the OECD. Dargay and Gately (1995b) consider the price reversibility of OECD non-transport oil demand. Gately and Huntington (2002) investigates the response of energy and oil demand to income and price change for 96 of the world's largest countries. Haas and Schipper (1998) explore residential energy demand for a panel of 15 OECD countries. Manzan and Zerom (2008) examine US gasoline demand and the impact of the price using a panel of US households. Huntington (2010) investigates total oil, other petroleum products, gasoline, and residual fuel oil demand for the US. All these studies found some evidence of asymmetric price responses and they are reviewed in detail in Chapter 6.

Dargay and Gately (1995a) investigates world energy and oil demand and found mixed results. They concluded that in industrialized countries the price responses are asymmetric, whereas in less developed countries there is less evidence for imperfect price reversibility. Gately and Streifel (1997) investigates the demand for oil products in 37 developing countries. The price responses of the countries differ; some petroleum products in some countries are found to be symmetric whereas others are found to be asymmetric. As far as is known, the only study that does not support the finding of asymmetric price responses is Griffin and Schulman (2005). However, their findings are criticized by Huntington (2006) for their econometric approach, which again will be explained in detail in Chapter 6.

In summary, a significant number of studies suggest that energy demand responds differently depending on whether prices fall, rise or rise above some previous maximum.

#### 2.7.3 Time Varying Parameters (TVP)

A further area of development, which has not been fully investigated in energy demand is the idea of time varying parameters (TVP). In fact, as far as is known, Park and Zhao (2010) is the only energy demand application. Park and Zhao (2010) estimate a US gasoline demand function using monthly aggregate data over the period 1976 to 2008 and their results suggest that the price elasticity increased from 1976 to 1980, decreased from 1980 to 1986, increased from 1986 to 1994, decreased from 1995 to 2005, and decreased from 2005 to 2008. The estimated time varying income elasticity followed a similar pattern, but with a much smaller size and variation. Park and Zhao (2010) therefore argue that the TVP can be explained by variations in the degree of necessity and the proportions of gasoline demand to the total disposable income. Their price elasticity estimate fluctuates between -0.35 to -0.10 over the estimation period, which is consistent with the current literature. However, the estimated

income elasticity fluctuates between 0.02 and 0.10, which appears to be rather low (lower than the price elasticities, in absolute terms) and inconsistent with current literature.<sup>14</sup>

Furthermore, although the study utilises tests for unit roots and model specification for the TVP model, there are no diagnostics tests for the overall assessment of the model; including normality of residuals, goodness of fit and serial correlation. In addition, although the TVP approach is employed a fixed level is used (i.e. equivalent to a constant but with no trend) which arguably does not allow sufficient flexibility in terms of capturing structural changes over time.

# 2.8 Summary

This chapter has reviewed the main approaches to energy demand modelling with a particular focus on the econometric modelling approach. Econometric modelling of energy behaviour helps understand the past, thus better preparing policy makers for possible future outcomes and opportunities, such as the financing of the development of necessary natural resources, the utilization of new technologies, evaluation of energy generating capacity, etc. (McVeigh and Mordue, 1999). Arguably, econometric modelling has a number of advantages when compared with end-use and input-output energy demand modelling approaches. Firstly, end-use and input-output models need detailed information based on surveys about energy consuming assets and their utilization rates that are not always available; therefore, the application of the econometric modelling approach is more practical. Secondly, the

<sup>&</sup>lt;sup>14</sup>Other non-energy demand examples of where the TVP model has been applied include: Kim (1993) for analysing US monetary growth; Brown et al. (1997) for analysing UK house price movements; Song et al. (1998) for analysing UK non-durable consumption expenditure; and Song and Wong (2003) for analysing Hong-Kong tourism demand. Furthermore, for many of these studies, when compared to constant parameter (CP) models (such as Error Correction Mechanism (ECM), Vector Autoregressive (VAR), and Autoregressive Time Series Regressions) the TVP model appeared to perform better.

economic factors such as income and price based on economic theory; thus assisting the implementation and evaluation of price induced policies.

It has been shown that the early attempts of econometric modelling employed static equation models. These static models were then extended by allowing for lags in the models and thus introducing a dynamic adjustment process. Finally, the existence of other exogenous factors rather than income and price that affect energy demand lead the researchers in that field to model energy demand by taking into account these exogenous factors. The lumpiness of the exogenous factors needs to be treated in the most flexible way, which the STSM estimation process provides the preferred flexibility. Therefore, in the next chapter the STSM approach coupled with the UEDT concept and their application to energy demand modelling is explained in detail; along with the extensions applied in later chapters, that of analysing the relative importance of economic and non-economic factors, asymmetric price responses, and TVP.

#### **CHAPTER 3: Methodology**

# **3.1 Introduction**

As stated in the previous chapter Hunt et al.'s (2003a and 2003b) concept of the UEDT estimated by Harvey's (1989) STSM is employed as the core methodology for the research presented in this thesis. This chapter therefore introduces the details of the UEDT and STSM and detail how it is utilised in the later chapters.

#### **3.2 Statistical and Econometric Framework**

This section details the statistical and econometric framework utilized for the different modelling and forecasting exercises undertaken for this thesis.

# 3.2.1 The STSM and UEDT

The STSM for quarterly observations in general can consist of trend, cycle, seasonal and irregular components that for the natural log of energy demand  $(e_t)^{15}$  can be formulated as follows:

$$e_t = \mu_t + \psi_t + \gamma_t + \varepsilon_t, \quad t = 1, \dots, T$$
(3.1)

where  $\mu_t$  is the trend,  $\psi_t$  is the cycle,  $\gamma_t$  is the seasonal and  $\varepsilon_t$  is the irregular and all four components are assumed to be stochastic with the disturbances driving them mutually uncorrelated. The trend, seasonal and cycle are all derived from deterministic functions of time and the irregular is white noise. Nevertheless, the research for this thesis uses annual data so the seasonal component can be omitted. Furthermore, the cyclical movement is also omitted since, as is explained later in this chapter, an economic activity variable (GDP,

<sup>&</sup>lt;sup>15</sup> The formal definitions of all variables in the research are presented in detail in the appropriate chapters.

Industrial output, etc.) is included as one of the key explanatory variables that drives each energy demand considered. Thus any cyclical effects should be captured this leaving all other exogenous factors that affect energy demand captured by the stochastic trend component; consequently, Equation (3.1) can be re-written as follows:

$$e_t = \mu_t + \varepsilon_t$$
,  $t = 1, \dots, T$  (3.2)<sup>16</sup>

Focussing on the trend component  $(\mu_t)$ , in classical regression analysis, a deterministic trend is identified as follows:

$$\mu_t = a + st \tag{3.3}$$

However, a more general specification is possible since  $\mu_t$  can be obtained recursively from the following:

$$\mu_t = \mu_{t-1} + s \tag{3.4}$$

where  $\mu_0 = a$ , so that the linear trend can be converted to a stochastic trend by introducing the stochastic terms as follows:

$$\mu_t = \mu_{t-1} + s_{t-1} + \eta_t \qquad \eta_t \sim NID \ (0, \sigma_\eta^2) \tag{3.5}$$

$$s_t = s_{t-1} + \xi_t$$
  $\xi_t \sim NID \ (0, \sigma_{\xi}^2)$  (3.6)

<sup>&</sup>lt;sup>16</sup> Note, that at this stage, equation (3.2) does not contain any explanatory variable (i.e. income, price etc), it is just the trend component. The explanatory variables are added and explained below.

where  $\eta_t$  and  $\xi_t$  are mutually uncorrelated white noise disturbances with zero means and variances  $\sigma_{ij}$  and  $\sigma_{\zeta}$  respectively. The term  $\eta_t$  lets the level of trend to shift up and down whereas the term  $\xi_t$  allows the slope to vary. The larger are the variances the greater is the stochastic movements in the trend component. In the case of  $\sigma_{ij} = \sigma_{\zeta} = 0$  the Equation (3.4) collapses to Equation (3.2) confirming that the deterministic trend is the restricted form of stochastic trend. The hyperparameters of the model  $\sigma_{ij}$  and  $\sigma_{\zeta}$  can be estimated by maximum likelihood and once the hyperparameters are estimated the state space form can be used in order to construct the estimators of unobserved components. The estimated hyper-parameters can lead to different types of trend component that are classified in the Table 3.1 below (Harvey and Shephard, 1993).

	Fixed Level	Stochastic Level
No Slope	i. Conventional regression model	iv. Local Level
	with fixed level no time trend	
Fixed Slope	ii. Conventional regression	v. Local Level with a Drift
	model with a deterministic trend	Model
Stochastic Slope	iii. Smooth Trend Model	vi. Local Trend Model

Source: Hunt et al, (2003a).

- *i*. Conventional regression Model with fixed level no time trend: This model is similar to an estimation of OLS with a constant level where  $\mu_t = a$  (t=1,...,T) and  $s_t = 0$  (t=1,...,T).
- *ii.* Conventional regression Model with deterministic trend: This model is also similar to an estimation of OLS with a constant time trend where  $\mu_t \neq a$ ,  $\sigma_{ij} = 0$  and  $s_t \neq 0$ ,  $\sigma_{\zeta} = 0$ .
- *iii.* Smooth Trend Model: This model is a restricted form of the local trend model where  $\mu_t = a$  ( $t = 1, \dots, T$ ) and  $s_t \neq 0, \sigma_{\zeta} \neq 0$ .

- *iv.* Local Level Model: This model is the restricted form of the local trend model where  $\mu_t \neq 0$ ,  $\sigma_{ij} \neq 0$  and  $s_t = 0$  (t = 1,...,T).
- *v*. Local Level with a Drift Model: This model is again a restricted form of the local trend model where  $\mu_t \neq 0$ ,  $\sigma_{\eta} \neq 0$  and  $s_t = b$  (t = 1,...,T).
- *vi.* Local Trend Model: This model has the most general form of the trend component. Both the slope and the level component of the trend vary over the time where  $\mu_t \neq 0$ ,  $\sigma_{ij} \neq 0$  and  $s_t \neq 0$ ,  $\sigma_{\zeta} \neq 0$ .

The shape of the underlying trend is determined by the hyper-parameters including the variance of the slope  $(\sigma_{\xi}^2)$ , the level  $(\sigma_{\eta}^2)$  and the irregular residuals  $(\sigma_{\varepsilon}^2)$ . The hyper-parameters and other parameters of the model are estimated by a combination of maximum likelihood and the Kalman filter. Equation residuals and a set of auxiliary residuals are also estimated in order to evaluate the model. The auxiliary residuals consist of smoothed estimates of model disturbances (the 'irregular residuals'), smoothed estimates of the level disturbances (the 'level residuals'), smoothed estimates of the slope disturbances (the 'slope residuals').

In order to maintain the normality of the auxiliary residuals, some irregular, slope and level interventions can be identified (Koopman et al. 2007). These interventions generally give information about important breaks and structural changes at certain dates during the estimation period. The irregular intervention can be described as a pulse effect since it has only a temporary effect on the trend; it is therefore a short run response normally used to account for an unexpected one off event or shock. However, level and slope interventions do have a permanent effect on the estimated trend; hence, these effects are longer lasting. In energy demand modelling, these interventions normally illustrate a 'structural change' that

might arise because of a number of factors, captured by the estimated trend, as discussed above. If there are no interventions then the estimated trend is given by  $\mu_t$ ; however, when there are interventions it is given by:

 $UEDT = \mu_t + \text{ irregular interventions} + \text{ level interventions} + \text{ slope interventions}$  (3.7)

#### **3.2.2 Estimation Process with Kalman Filter**

As discussed above the STSM consists of decomposing the dependent variable (energy demand) into the impact of the explanatory variables (such as price and income/output) plus trend and irregular components. Although it is possible to establish a model based on a deterministic trend, as discussed above the preferred flexibility can be achieved by letting the trend change over time and therefore being stochastic (at least in the initial general model). The statistical framework for the unobserved components model is the state space form, which refers to the space whose axes are the state variables and the state of a system can be represented as a vector within that space. It consists of a measurement equation and a transition equation such as:

$$e_{t} = K_{t}\alpha_{t} + G_{t}\epsilon_{t} t = 1, 2,...,T$$
 (Measurement Equation) (3.8)  

$$\alpha_{t+1} = T_{t}\alpha_{t} + H_{t}\epsilon_{t}$$
 (Transition Equation) (3.9)

The system  $K_t$ ,  $G_t$ ,  $T_t$  and  $H_t$  is allowed to change over time. In a deterministic fashion, these system matrices are constant. The measurement equation connect the unobservable state vector to the observable scalar values of the dependent variable;  $e_t$ . The explanatory variables  $K_t$  provide additional information to explain the change in the dependent variable. If the changes in the dependent variable were explained only by the explanatory variables then the trend component would reduce to a constant term. Moreover, the transition equation identifies the dynamics in the time domain and estimates unobservable variables. The Kalman Filter (Kalman, 1960) is the main algorithm to estimate dynamic systems in state-space form. This filter consists of a group of mathematical equations that provides an optimal recursive solution by applying least squares method in order to compute a linear, unbiased and optimal estimator of a system's state at time t, based on information available at t-1 and update these estimators, with the additional information at time t (Kalman, 1960).

Recursive solution means that the filtering process re-computes the optimal solution each time a new observation is included into the system. By introducing new observations to the system, the estimate of unobservable components can be updated by means of a filtering procedure (Harvey and Shephard, 1993; Commandeur and Koopman, 2007; Harvey et al. 2005).

The state space representation of the system is identified by a group of state variables. The state contains all information about the system at a given time. This information allows the modelling of the past behaviour of the system in order to forecast the future state of the system. The most interesting feature of the Kalman filter is its capability to predict the past, present and future of a system even if the exact characteristics of the modelled system are unknown. The parameters and the hyper-parameters of a dynamic system cannot be exactly identified through a direct measurement; therefore, their measurements contain some degree of uncertainty through a stochastic process (Jalles, 2009).

After the model is defined, the filtering and smoothing algorithms are related to the statespace form and can be applied to the states and the systems of matrices of known errors. The unknown values in these matrices are considered as parameters to be estimated. The parameter estimation is done by maximum likelihood methods. The recursive estimation takes into account the initial observation and gradually updates the estimates as the new observations are included into the system, which suggest that the most recent estimates are affected by the distant history of the series. However, in the presence of a structural change the deterministic approach could end up biased. One of the advantages of the Kalman filter is that it aims to estimate the stochastic path of the coefficients rather than deterministic by using recursive methods. This approach solves the problem of estimation bias in the presence of structural breaks and changes (Jalles; 2009).

# 3.2.3 Application of STSM and UEDT to Energy Demand

Above discusses the general statistical framework of the STSM without explicitly specifying any economic demand relationship. Given that the aim of this research is to estimate, not only a stochastic UEDT, but also the income and price elasticities for different countries, sectors and energy types, it is assumed that energy demand function<sup>17</sup> is generally characterized by:

$$E_t = f(Y_t, P_t, UEDT_t) \tag{3.10}$$

where;

 $E_t$  = Energy Demand;

 $Y_t =$  Income;

 $P_t$  = Price; and

 $UEDT_t$  = Underlying Energy Demand Trend.

<sup>&</sup>lt;sup>17</sup> Note for now energy is used as a generic term with the different energy types that this model is applied to detailed in subsequent chapters.

As discussed in previous chapters, the oft-used log-linear energy demand functional form is utilized for the research in this thesis. Furthermore, the possibility of a distinction between short run and long run elasticities is allowed for by using an ARDL specification of equation (3.10) for the estimated general model. This constant elasticity specification is given by:

$$A(L) e_{t} = B (L)y_{t} + C (L)p_{t} + UEDT_{t} + u_{t}$$
(3.11)

where;

A(L) is the polynomial lag operator  $1 - \lambda_1 L - \lambda_2 L^2 - \lambda_3 L^3 - \lambda_4 L^4$ ; B(L) is the polynomial lag operator  $1 + \alpha_1 L + \alpha_2 L^2 + \alpha_3 L^3 + \alpha_4 L^4$ ; C(L) is the polynomial lag operator  $1 + \varphi_1 L + \varphi_2 L^2 + \varphi_3 L^3 + \varphi_4 L^4$ ;<sup>18</sup>  $e_t =$  the natural log of energy demand  $(E_t)$ ;  $y_t =$  the natural log of income variable  $(Y_t)$ ;  $p_t =$  the natural log of price variable  $(P_t)$ ; B(L)/A(L) = the long run income elasticity; C(L)/A(L) = the long run price elasticity;  $UEDT_t =$  the value of the UEDT at period t; and  $u_t =$  is a random error term.

For the level  $(\mu_t)$  and the slope  $(s_t)$  of UEDT, the following stochastic process is identified for all Chapters:

$$\mu_t = \mu_{t-1} + s_t + \eta_t ; \qquad \eta_t \sim NID \ (0, \sigma_\eta^2)$$
(3.12)

$$s_t = s_{t-1} + \xi_t$$
;  $\xi_t \sim NID(0, \sigma_{\xi}^2)$  (3.13)

<sup>&</sup>lt;sup>18</sup> A four-year lag is assumed since it is believed this is long enough to capture any possible dynamics.

where  $\mu_t$  and  $s_t$  represent the UEDT level and slope respectively. As discussed above, in the absence of interventions the estimated UEDT is given by  $\mu_t$ , however when there are interventions it is given by:

 $UEDT = \mu_t + \text{ irregular interventions} + \text{ level interventions} + \text{ slope interventions}$  (3.14)

This framework is utilized in Chapter 4 in order to estimate Turkish industrial, residential and aggregate electricity demand function for Turkey and in Chapter 5 to estimate OECD-Europe Natural gas demand function and finally in Chapter 6 to estimate US per capita gasoline demand.

# **3.2.4 Decomposing the Estimated Relative Contributions of Price, Income and UEDT to Driving Energy Demand**

As indicated above, in Chapter 5 the analysis is extended by decomposing the estimated relative contributions of price, income and UEDT to driving OECD-Europe Natural Gas demand; thus allowing a comparison of the contribution of the different influences. Once the preferred model is obtained by the framework detailed in the previous section the relative contribution of income, price and the UEDT to the annual change in energy demand is estimated in a similar way to Broadstock and Hunt (2010) and Chitnis and Hunt (2011 and 2012) as follows:

$$\widehat{\Delta e_t} = \widehat{\kappa_Y} \Delta y_{t-1} + \widehat{\kappa_P} \Delta p_{t-1} + \Delta \widehat{UEDT_t}$$
(3.15)<sup>19</sup>

<sup>&</sup>lt;sup>19</sup> Note this formulation is based upon the preferred specification obtained in Chapter 5. A more general specification is explained in Chitnis and Hunt (2011 and 2012).
where  $\widehat{\kappa_{Y}}$ , and  $\widehat{\kappa_{P}}$  are the estimated income and price elasticities respectively and  $\Delta \widehat{UEDT}_{t}$ the estimated UEDT, so that  $\widehat{\kappa_{Y}}\Delta y_{t}$ ,  $\widehat{\kappa_{P}}\Delta p_{t}$  and  $\Delta \widehat{UEDT}_{t}$  represent the estimated contributions to the change in energy demand (in logs) from income, price and the UEDT respectively.

#### **3.2.5.** Time Varying Parameters (TVP)

As also indicated above, a couple of alternative methodological extensions are introduced in Chapter 6 for analysing US gasoline per-capita demand. The first extension is the introduction of time varying parameters (TVP) order to investigate whether or not the price and income elasticities of US per capita gasoline demand change over time. This is based upon a very similar framework described above but with the time varying parameters given by:

$$e_t = \lambda_{1,t} y_t + \lambda_{2,t} p_t + UEDT_t + u_t \tag{3.16}$$

$$\lambda_{i,t} = \lambda_{i,t-1} + v_{i,t} \qquad \text{where } i=1,2 \tag{3.17}$$

where:

 $\lambda_{1,t}$  = the income elasticity at time *t*;

 $\lambda_{2,t}$  = price elasticity at time *t*;

 $UEDT_t$  = level of underlying energy demand trend (UEDT)<sup>20</sup>;

 $u_t$  = a random error term with  $u_t \sim NID(0, \sigma_{\eta}^2)$ ;and

 $v_t$  = a random error term with  $v_t \sim NID(0, \sigma_{\eta}^2)$ .

 $<sup>^{20}</sup>$  Note this specification assumes that there is no interventions; in the presence of interventions the UEDT is given by Equation (3.14) above.

However, before estimating a TVP model it is necessary to determine which variables to include in the US gasoline demand function. A two-step process is therefore followed, whereby, in the first step the coefficients are restricted to be fixed in order to determine the significant variables at the end of the period and in the second step the TVPs are estimated based upon the variables chosen in the first step. Therefore, in order to choose the significant variables that affect energy demand<sup>21</sup>, Equation (3.16) is initially estimated with fixed coefficients, i.e. with the parameter coefficients restricted in the first stage as follows:

$$\lambda_{i,t} = \lambda_{i,t-1} = \lambda_{i,t-2} = \lambda_{i,t-3} \dots \dots = \lambda_{i,t-n}$$
(3.18)

In both of the stages the level  $(\mu_t)$  and the slope  $(s_t)$  of UEDT have the following process:

$$\mu_t = \mu_{t-1} + s_{t-1} + \eta_t \quad ; \qquad \eta_t \sim NID \ (0, \sigma_\eta^2) \tag{3.19}$$

$$s_t = s_{t-1} + \xi_t$$
;  $\xi_t \sim NID(0, \sigma_{\xi}^2)$  (3.20)

## **3.2.6** Asymmetric Price Responsiveness

The second methodological extension in Chapter 6 is to allow for asymmetric price responses in order to identify whether US per-capita gasoline demand responds differently to the different change in prices. This is achieved by decomposing the (log of the) price variable in Equation (3.10) into three variables: price-max, price-recovery, and price-cut. Accordingly, the energy demand function is identified by:

$$E_t = f(Y_t, p_t^{max}, p_t^{rec}, p_t^{cut}, UEDT_t)$$
(3.21)

<sup>&</sup>lt;sup>21</sup>Which is actually US per-capita gasoline demand in chapter 5.

With the explicit mathematical specification given by:

$$e_t = \lambda_{1,t} y_t + \lambda_{2,t} p_t^{max} + \lambda_{3,t} p_t^{rec} + \lambda_{4,t} p_t^{cut} + UEDT_t + u_t$$
(3.22)

where, in addition to the definitions for Equation (3.16) and (3.14) above:

 $p_t^{max}$ =cumulative increase in the natural logarithm of maximum historical real energy prices;  $p_t^{rec}$ =cumulative sub-maximum increase in the natural logarithm of historical real energy prices;

 $p_t^{cut}$ =cumulative decrease in the natural logarithm of historical real energy prices;

 $\lambda_{2,t}$  =price max elasticity at time *t*;

 $\lambda_{3,t}$  = price recovery elasticity at time *t*; and

 $\lambda_{4,t}$  = price cut elasticity at time *t*.

#### 3.3 Model Selection Criteria

Model selection is one of the most problematical phases of time series analysis (Harvey and Shephard, 1993). However, the structural time series approach enables the formulation of a model that captures the main characteristics of the data in the beginning of the process. After the model has been estimated, the suitability of the model should be assessed by both applying a series of diagnostic tests and checking the consistency of the estimated parameters and hyper-parameters with the economic theory and prior intelligence. Therefore, the estimated parameters, hyper-parameters and the interventions should be consistent with the economic history of the investigated subject (Harvey and Shephard, 1993).

Therefore, in addition to identifying appropriate interventions, the estimation strategy involves estimating Equations (3.11) or (3.22) together with (3.12) and (3.13) and testing

down to the preferred specification ensuring, as advocated by Thomas (1993) that it satisfies a number of model selection criteria including:

- *Data Coherency*: The normality of residuals should be maintained. The residuals should be entirely random white noise disturbance terms that exempt autocorrelation and heteroscedasticity.
- *Consistency with theory*: The model should present consistent results with the economic theory and economic history.
- *Parsimony*: The preferred model should be at its possible most simplest form.
- *Encompassing*: The model should present the data better than its rival models.

Furthermore, the estimated model should pass an array of diagnostic tests such as:

- Bowman –Shenton Test; is a normality test statistics; approximately distributed as  $\chi^2$ .
- Heteroscedasticity Test distributed as F distribution with (k,k) degrees of freedom.
- Serial Correlation Test; coefficients at the equivalent residual lags, approximately normally distributed.
- DW is the Durbin-Watson statistic for the first order autocorrelation.
- Box Ljung is an autocorrelation Test; which is distributed as  $\chi^2$ .
- Failure is a predictive failure statistic distributed as  $\chi^2$ .
- Cusum is a mean stability statistic distributed as the Student-t distribution.

### **3.4 Forecasting**

In chapters 4, 5 and 6, once the preferred energy demand models (with the estimated income elasticity, price elasticity, and UEDT) are determined, forecast scenarios are constructed. Future energy demand depends upon a number of factors, such as the future path of the key drivers (income, price and the UEDT); hence, the uncertainty of future projections produced

in this way depend upon the uncertainty around the future paths of these driers. Another uncertainty comes from the variation in the point estimates for the key parameters and elasticities (indicated by their standard errors) in the preferred energy demand models. One approach therefore, would be to produce a 'reference' scenario based upon an assumption about the key drivers and produce 'low' and 'high' versions around this based on the variation indicated by point estimate's standard errors. However, an alternative approach, more akin with Scenario Planning,<sup>22</sup> is adopted here, whereby for the 'reference scenario' assumptions seen as the 'most probable' outcome for the economic variables and the UEDTs are assumed ('business as usual'). Whereas for the 'low' and 'high' scenarios, variations of the economic variables and UEDTs are chosen to produce sensible lower and upper bound forecasts for future energy demand respectively. Thus, these assumptions are applied to the preferred estimated equations and the various future energy demands for the three cases computed accordingly. The detailed information about the assumptions and forecast scenarios are provided in the relevant chapters.

## 3.4.1 Forecasting the Turkish 'Residual' Sector

For Turkish electricity demand, forecast scenarios are constructed for the industrial and residential sectors as well as the whole economy based upon the estimated demand relationships. However, for Chapter 4 (only) it is also possible to construct forecast scenarios for the Turkish 'residual' sector given the constructed forecast scenarios industrial, residential, and aggregate electricity demand.

<sup>&</sup>lt;sup>22</sup> According to scenariothinking.org (2012), scenario planning or scenario thinking is a strategic planning tool used to think about and anticipate the unknown future to enable the development of flexible long-term plans; the objective being to examine possible future developments that could affect organizations or societies to try to assist decision-making. Therefore, the uncertainty in the analysis undertaken here is implicitly encompassed by the built in uncertainty of the economic drivers.

The 'residual' sector is therefore defined by subtracting the residential and industrial sectors from the aggregate/whole economy sector. Thus, the Turkish forecast scenarios for the 'residual' sector are determined by the following:

#### **3.5 Summary and Conclusion**

Although co-integration has been used by the majority of time series energy demand studies, the co-integration methodology is arguably too inflexible for the complexities of modelling energy demand since it is not possible to estimate a non-linear UEDT (Hunt et al. 2000, 2003a and 2003b). Moreover, Harvey (1997) strongly advocates the use of the STSM, and criticises unit root tests and the co-integration methodology as unnecessary and/or a misleading procedure due to, amongst other things, its poor statistical properties. The STSM methodology is arguably a better approach given that it enables to estimate a stochastic UEDT. Furthermore, by identifying a stochastic path for the estimated parameters the STSM approach copes with structural changes and provides estimates that are arguably more robust. Last, but not least, the estimated stochastic UEDT by the STSM approach provides information about how underlying energy demand behaviour evolves over time. The changes in the estimated stochastic UEDT produce valuable information about the impact of exogenous factors on energy demand behaviour.

Therefore, for the research in this thesis the STSM approach consistent with the UEDT concept is employed for estimating and forecasting Turkish electricity demand for different sectors, OECD-Europe aggregate natural gas demand, and estimating US per-capita gasoline demand. Therefore, in the next chapter, Turkish residential, industrial and aggregate

electricity demand functions are estimated and, by using the relationships that is identified by the STSM estimation process, forecast scenarios are produced up to 2020. In Chapter 5, an OECD-Europe natural gas demand function is estimated using a similar procedure, again producing forecast scenarios up to 2020, but also an analysis of the relative demand drivers is undertaken. In chapter 6, US per-capita gasoline demand is analysed; again the STSM framework is employed but is extended by utilizing time varying parameters and a price decomposition within the STSM framework.

# **CHAPTER 4: Turkish Electricity Demand**\*

# 4.1 Introduction

This Chapter investigates the relationship between:

- Turkish industrial electricity consumption, industrial value added (output) and electricity prices;
- ii) Turkish residential electricity consumption, household total final consumption expenditure and residential electricity prices; and
- iii) Turkish aggregate electricity consumption, GDP, and average real electricity prices.

To achieve this, electricity demand functions for these Turkish sectors are estimated by applying the STSM outlined in the previous chapter using annual data for the period 1960 to 2008. These relationships are then used to produce forecast scenarios for Turkish industrial, residential, and aggregate electricity demand (and the 'residual' sector).

- 2<sup>nd</sup>International Workshop on Empirical Methods in Energy Economics (EMEE2009) Organised by CBEEDAC-SEEC-CEPE, Jasper, Alberta, Canada 28-29 August 2009;
- 10<sup>th</sup>International Association for Energy Economics (IAEE) European Conference 'Energy Policies and Technologies for Sustainable Economies', Vienna, Austria, 7-10 September 2009. *where the paper was given a Best Student Paper Award;* and

The results from this chapter have been published in:

- 'Industrial Electricity for Turkey: A Structural Time Series Analysis', *Energy Economics*, 33, 426-436, 2011 (with L. C. Hunt);
- 'Modelling and Forecasting Turkish Residential Electricity Demand', *Energy Policy*, 39, 3117-3127, 2011 (with L. C. Hunt);and
- 'Turkish Aggregate Electricity Demand: An Outlook to 2020', *Energy*, 36, 6686-6696, 2011 (with L. C. Hunt).

<sup>\*</sup>Earlier preliminary work for this chapter was presented at the following:

<sup>•</sup> The Young Energy Engineers and Energy Economists Workshop, University of Cambridge, Cambridge 8-9 April 2010.

As discussed in the chapters above, for sustainable economic growth, robust reliable demand forecasts of Turkish electricity demand are vital for the development of appropriate Turkish energy policies. The aim of this chapter therefore is to investigate how the structural time series methodology performs in terms of modelling Turkish electricity demand, estimating the key elasticities, and forecasting future electricity demand.

The motivation and justification for this chapter is twofold. Firstly, the STSM approach is utilised since this allows for a focus on the economic and exogenous factors of different electricity demand functions by investigating the relationship between electricity consumption, economic variables, and a UEDT. This work is therefore, as far is known, the first that allows for a stochastic the UEDT when modelling Turkish electricity demand. Secondly, the estimated models are used to produce forecasts of Turkish electricity demand, which are compared to past Turkish electricity demand projections, since it is hypothesised that a model estimated using the structural time series methodology will outperform these previous forecasts. That is, using the STSM to underpin the forecast arguably provides one explanation for the shortcomings of previous 'unsuccessful' forecasts; these forecasts being essential for evaluating policies and strategies in order to achieve Energy Security and to decrease CO<sub>2</sub> emissions. Therefore, given the importance of electricity demand, this work contributes to the development of Turkish energy policy and the strategy to ensure future Turkish energy security. Additionally, reliable forecasts are vital for Turkish electricity generating and distribution companies in order to establish their long-term investment decisions. However, before investigating the electricity demand functions, it is important to understand the history and development of the Turkish energy, which is discussed in the next section.

#### 4.2 Overview of Energy Situations in Turkey

Turkey covers an area of just over 780 thousand km<sup>2</sup>, straddling South Eastern Europe and South Western Asia with an estimated population of just under 72 million people in 2007 (FCO, 2010). Turkey's economy consists of modern industries, the commercial sector, and the traditional agricultural sector. Although the Turkish economy experienced a period of transformation from agriculture to industrial followed by a rapid urbanization, especially after 1982, the agriculture sector still accounts for 25% of total employment. The major industrial sectors are textiles and clothing, which employ about a third of total industrial employment. Turkey's GDP in 2011was1.053 trillion US dollars (constant 2011PPP prices) accounting for just over 1% of the world's total GDP (World Fact Book, 2012; IEA, 2010b).

#### 4.2.1 Turkish Energy History

In this section, Turkey's energy balances are reviewed in two sub-sections. Firstly, energy demand, production, sectoral energy consumptions development over time are reviewed and secondly the more recent situation is analysed.

#### 4.2.1.1 Historical Development of Turkish Energy 1960-2008

In 1960, Turkey's total indigenous energy production was 9371 ktoe of which 5878 ktoe (63%) was combustible renewable and waste production, 3036 ktoe (32%) was coal and coal products production, 370 ktoe (4%) was petroleum production, and 86 ktoe (1%) was hydro production. In 1960, there was no natural gas, geothermal, solar & wind and other energy sources production (Figure 4.1) (IEA, 2010c).

Turkey's domestic primary energy production reached its peak in 1998 with 29,071 ktoe. Of this, 13943 ktoe (48%) was coal and coal products, 6980 ktoe (24%) was combustible

renewable and waste, 3632 ktoe (12%) was hydro, 3185 ktoe (11%) was petroleum production, 655 ktoe (2%) was geothermal energy, 465 ktoe (2%) was natural gas, 210 ktoe (1%) was solar & wind and other sources (Figure 4.1) (IEA, 2010c). However, by 2008 this had decreased to 28,979 ktoe; made up of 16675 ktoe (58%) of coal and coal products, 4828 ktoe (17%) of combustible renewable and waste production, 2861 ktoe (10%) of hydro, 2134 ktoe (7%) of petroleum 1151 ktoe (4%) of geothermal, 837 ktoe (3%) of natural gas, and 493 ktoe (2%) of solar & wind and other renewables (Figure 4.1) (IEA, 2010c). The decrease from 1998 to 2008 coming mainly from the decrease in coal and coal products, petroleum and combustible renewable and waste productions.



Figure 4.1: Indigenous Primary Energy Production 1960-2008 (ktoe)

Since Turkey's indigenous production has not been sufficient to meet demand, the majority of the Turkish primary demand has been met by imports. Turkey imported only 1175 ktoe of petroleum products back in 1960 and was self-sufficient in other types of fuels. However,

Source: IEA, 2010

between 1960 and 2008 Turkey's net energy imports increased to a net 69523 ktoe of energy; made up of 21570 ktoe (31%) of crude oil, 30244 ktoe (43%) of natural gas, 12856 ktoe (18%) of coal and coal products, and 5924 ktoe (8%) of petroleum products (Figure 4.2) (IEA, 2010c).



Figure 4.2: Net Energy imports 1960-2008 (ktoe)

In 1960, total final energy consumption of Turkey was 9748 ktoe, which consisted of 5878 ktoe (60%) of combustible renewable and waste, 2249 ktoe (23%) of coal and coal products, 1405 ktoe (14%) of petroleum products, 184 ktoe (2%) of electricity, and 31 ktoe (0.3%) of natural gas. Final energy consumption increased continuously until 1978 reaching 26864 ktoe; however, following the 1978 economic crisis. Turkey's total final consumption slightly decreased to 25539 ktoe in 1979. After 1979, total final energy consumption continued to increase until 1993 when it reached 45818 ktoe but decreased again in 1994 to 43603 ktoe at the same time as the economic problems of that year. From 1994, Turkey's total final consumption increase was

Source: IEA, 2010

halted in 1999 following the economic problems, with Turkey's total final consumption falling to 52551 ktoe in 1999. As the economy recovered again, energy consumption increased to 58447 ktoe in 2000, but falling again in 2001 to 52716.84 ktoe as economic problems emerged again. From then Turkey's total final energy consumption increased continuously from1960 to 2007 when it reached 75450 and fell slightly in 2008 to 73365 ktoe (Figure 4.3). In 2008,Turkey's final energy consumption reached 73365 ktoe, consisting of 27445 ktoe (37%) of petroleum products, 13710 ktoe (19%) of electricity, 12776 ktoe (17%) of coal and coal products, 13233 ktoe (18%) of natural gas, 4770 ktoe (7%) of combustible renewable and waste, 1011 ktoe (1,4%) of geothermal energy, and 420 ktoe (0,6%) of solar & wind and other energy sources (Figure 4.3) (IEA, 2010c).



Figure 4.3: Turkish Energy Consumption by Fuel 1960-2008 (ktoe)

Turkey's aggregate energy intensity did not change appreciably over the period 1960 to 2008. In order to create 1000 \$ (2000 constant PPP) of GDP in 1960, 0.11 toe was needed where in 2008 it was 0.12 (Figure 4.4). One possible reason might be that Turkey failed to implement

Source: IEA, 2010

effectively energy efficiency measures or possibly from the transformation of the Turkish economy from less energy intensive to more energy intensive activities by using machinery and other equipment instead of manpower.



Figure 4.4: Energy Intensity 1960-2008

In terms of population, energy consumption per capita increased somewhat over the period 1960 to 2008. In 1960 an average Turkish citizen was consuming 0.39 toe annually, however this figure increased by just above 3.5 times to 1.39 toe in 2008 (Figure 4.5); consistent with the development of energy dependent life styles as income increased.

The historical evolvement of the energy balances is reviewed above. However, recent energy balances will be important when analysing Turkish energy markets. Therefore, in the next section the recent energy balances in Turkey (for the year 2008) will be analysed.

Source: IEA, 2010



Figure 4.5: Energy Consumption per Person 1960-2008

Source: IEA, 2010

# 4.2.1.2 Turkey's 2008 Energy Balance

As stated above, Turkey is a net energy importer with rapid energy demand growth. In 2008, Turkey's total primary energy demand had reached 99384 ktoe, where the indigenous production can only cover 28979 ktoe of this demand and the rest is met by imports (Table 4.1).

Furthermore, in 2008, Turkey covered only 29% of total primary demand by production. Moreover, Turkey produced; 56% of coal and coal products demand, 9% of petroleum demand, and 3% of natural gas demand (Fig 4.6) (IEA 2010). When increasing prices of natural gas and petroleum are considered, Turkey has significant vulnerabilities in the field of natural gas and petroleum import dependency.

# Table 4.1: Turkey's 2008 Energy Balance (ktoe)

Source	Coal and Coal Products	Crude, NGL, Feed Stocks	Petroleum Products	Natural Gas	Hydro	Geothermal	Solar Wind Other	Combustible Renewables and Waste	Electricity	Total
Indigenous Production	16674.70	2134.31	0	837.36	2861.22	1150.49	492.75	4827.86	0	28978.60
Imports	12856.20	21570.40	14406.00	30603.30	0	0	0	0	67.85	79503.40
Exports	0	0	-6526.81	-359.01	0	0	0	0	-96.49	-6982.31
International Marine Bunkers	0	0	-652.69	0	0	0	0	0	0	-652.69
International Aviation Bunkers	0	0	-1302.28	0	0	0	0	0	0	-1302.28
Stock Changes	-70.26	-140.80	65.89	-897.83	0	0	0	0	0	-1043
Total Primary Energy Supply	29460.60	23563.90	5989.78	30183.80	2861.22	1150.49	492.75	4827.86	-28.64	98501.70
Statistical Difference	202.68	700.77	-20.68	0	0	0	0	0	0	882.76
Primary Demand	29663.20	24264.70	5969.09	30183.80	2861.22	1150.49	492.75	4827.86	-28.64	99384.50
Transfers				0	0	0	0	0	0	0
Transformation	-16233.80	-24264.70	22735.20	-16452.40	-2861.22	-139.67	-72.84	-57.93	17063.90	- 20283.30
Energy Industry Use	-598.23	0	-1259.28	-442.42	0	0	0	0	-962.00	-3261.92
Losses	-54.88	0	0	-56.13	0	0	0	0	-2363.37	-2474.38
Total Final Consumption	12776.30	0	27445.10	13232.90	0	1010.82	419.91	4769.92	13709.90	73364.90
Non Energy Use	0	0	5106.70	262.26	0	0	0	0	0	5368.96
Final Energy Consumption by Sector	12776.30	0	22338.40	12970.60	0	1010.82	419.91	4769.92	13709.90	67995.90
Industry	6120.93	0	1334.19	3194.40	0	0	125.97	0	6219.52	16995
Transport	0	0	14786.60	183.05	0	0	0	15.25	82.56	15067.40
Residential	4930.08	0	1685.73	6524.02	0	1010.82	293.94	4754.68	3404.22	22603.50
Other Final Consumers	1725.33	0	4531.87	3069.14		0	0	0	4003.64	13330

Source: IEA, 2010

Turkey's total primary energy demand was 99385 ktoe in 2008. 20283 ktoe (20%) was transfers and transformation, 3262 ktoe (3%) was energy industries own consumption, 2474

ktoe (3%) was lost during the distribution and transportation process, and 73365 ktoe (74%) went to final consumption (Figure 4.7) (IEA, 2010c). Of this total final consumption the industrial sector consumed 16995 ktoe (25%), the transport sector consumed 15067 ktoe (22%), the residential sector consumed 22604 ktoe (33%), and the other sectors consumed 13330 ktoe (20%) in 2008 (IEA, 2010c).



Figure 4.6: Turkey's Energy Demand, Production, and Net Imports 2008 (ktoe)

Source: IEA, 2010



Figure 4.7: The Allocation of Primary Energy Demand 2008

Source: IEA, 2010

Furthermore, Turkey's total final energy consumption of 73365 ktoe in 2008 was made up of the following energy types: petroleum products 27445 ktoe (33%); electricity 13710 ktoe (20%); coal and coal products 12776 ktoe (19%); natural gas 13233 ktoe (19%); combustible renewable and waste 4770 ktoe (7%); geothermal energy 1011 ktoe (1%); solar & wind 420 ktoe (1%); and other source of energy (Figure 4.8) (IEA, 2010c). However, the distribution of different energy types differs somewhat in the different sectors. Out of a total of 16695 ktoe of energy in 2008 consumed by the Turkish industrial sector, 6121 (36%) ktoe was coal and coal products, 6220 ktoe (36%) was electricity, 1334 (8%) ktoe was petroleum products, 3194 ktoe (19%) was natural gas, and 126 ktoe (1%) was solar & wind and other sources (Figure 4.9) (IEA, 2010c).





Source: IEA, 2010



Figure 4.9: Industry Sector Energy Consumption by Fuel 2008

Source: IEA, 2010

For the Turkish residential sector, which consumed a total 22604 ktoe in 2008, 4755 ktoe (21%) was combustible renewable and waste, 6524 ktoe (29%) was natural gas, 1686 ktoe (7%) was petroleum products, 3404 ktoe (15%) was electricity, 4930 ktoe (22%) was coal and coal products, 1011 (5%) was geothermal energy, and 294 (1%) was solar & wind and other energy sources (Figure 4.10) (IEA, 2010c).Whereas for the Turkish transport sector, which consumed 15067 ktoe energy in 2008, 14787 ktoe (98%) was petroleum products, 83 ktoe (1%) was electricity, and 183 ktoe (1%) was natural gas (IEA, 2010c).

The other sector (i.e. the total less industrial, residential and transport) consumed a total of 13330 ktoe energy in 2008, of which 4532 ktoe (34%) was petroleum products, 4004 ktoe (30%) was electricity, 1725 ktoe (13%) was coal and coal products and 3069 ktoe (23%) was natural gas (IEA, 2010c).



Figure 4.10: Residential Sector Energy Consumption by Fuel 2008

Source: IEA, 2010

The above has given an overview of the history and current energy situation in Turkey before focussing the energy source that is modelled in this chapter, Electricity. The next section therefore discusses the historical development of Turkish electricity.

# 4.3 Development of Turkish Electricity Markets

The first attempt to produce electricity in Turkey was during the Ottoman Empire era at the beginning of the 20<sup>th</sup> century. In 1902, electricity was first generated and distributed to households by connecting a 2 KW dynamo to a watermill. Technical knowledge at that time was limited; therefore, the Ottoman Empire targeted foreign investment in order to finance electricity generation. To help facilitate this, the 'Privileges for Public Wealth' law was introduced in 1910, giving privileges to electricity generation companies such as the Hungarian Ganz Partnership that, with a Hungarian and Belgium bank, established the 'Ottoman Electricity Stock Company'. As a result, in 1913 the first large scale electricity

power plant (13.4 MW) was built in Silahtaraga, Istanbul. This was followed by construction of further power plants in Anatolia (Dolun, 2002 and TEK, 1972).

When the Turkish Republic was founded in 1923, the installed electricity capacity for Turkey was 33 MW with production around 50 million kWh. The privileged contracts for foreign electricity generation companies were approved by the new Turkish Republic Administration, but only for a temporary period, acknowledging the lack of technological knowledge within Turkey at that time. The privilege contracts were designed to favour generation companies by indexing the electricity prices to gold prices. Given this, electricity prices were high in the early republican era leading to some electricity intensive industrial factories building their own power generation facilities. This allowed them to produce electricity for their own use and to supply to local households located nearby these facilities<sup>23</sup> (Dolun, 2002 and TEK, 1972).

Given that the foreign private firms involved in the Turkish electricity industry at this time aimed at maximising profits, they were reluctant to invest in rural areas, thus slowing down both the increase in electricity generation and electrification. Therefore, the Etibank (a governmental entrepreneurship) was established in 1935 to operate in the electricity generation and mining sectors. In the same year the Electric Power Resources and Survey Administration was also established with the remit to examine electricity generation opportunities from hydro and other fuels. In addition, starting in 1938 thru 1944 the power plants operating under the control of the foreign concessionary private companies were bought by the Turkish government and were given to the municipal administrations for

<sup>&</sup>lt;sup>23</sup> For example, the Karbuk Iron and Metal Factory and the Izmit Seka and Sumerbank were also known as autoproducers (Dolun, 2002 and TEK, 1972).

management. Furthermore, in 1957, the Turkish government established a new organization namely the Energy and Natural Resources Department, responsible for coordinating the activities of electricity generation and distribution companies and the Ministry of Energy and Natural Resources was founded in 1963 to administer Turkish energy policies (Dolun, 2002 and TEK, 1972).

In 1970, the Turkish Electricity Institution (TEI)<sup>24</sup> was established with the main aim of coordinating electricity generation across the country. <sup>25</sup> Consequently, the TEI had a monopoly in the generation and transmission of electricity, with distribution undertaken by municipal administrations. However, following the introduction of Law No 2705 in 1982, the distribution function of the municipal administrations was transferred to the TEI giving Turkey a fully vertically integrated state owned monopoly (Dolun, 2002). In 1993, Law no. 513 was introduced, with the stated aim to privatize the TEI. Following this, the TEI was divided into two state owned enterprises, the 'Turkish Electricity Generation and Transmission Co. (TEGTC)<sup>26</sup>, and the 'Turkish Electricity Distribution Co. (TEDC)<sup>27</sup>, but their relationship with the Ministry of Energy and Natural Resources was maintained as before (Dolun, 2002).

In 2001, the Electricity Market Law No. 4628 was introduced, with the aim of regulating the electricity market with the establishment of the Regulatory Body of Electricity Market in the

<sup>&</sup>lt;sup>24</sup> In Turkish this is known as, TEK (Turk Elektrik Kurumu) translated by author.

<sup>&</sup>lt;sup>25</sup> Although at different times, similar developments occurred across Western Europe (although often for similar reasons) resulting in the establishment of centralised electricity industries and institutions, coupled with nationalization. For example, Electricite de France in France in the mid 1940s, the Central Electricity Generating Board in the UK in the late 1950s and the Ente Nazionale per l'Energia Elettrica (ENEL) in Italy in the early 1960s.

<sup>&</sup>lt;sup>26</sup> In Turkish this is known as TEAS (Turkiye Elektrik Anonim Sirketi) translated by author.

<sup>&</sup>lt;sup>27</sup> In Turkish this is known as TEDAS (Turkiye Elektrik Dagitim Anonim Sirketi) translated by author.

same year. Furthermore, the TEGTC was restructured, being divided into three state owned public enterprises, the 'Turkish Electricity Transmission Co. (TETC)<sup>28</sup>, the 'Turkish Electricity Generation Co. (TEGC)<sup>29</sup>, and the 'Turkish Electricity Trading Co. (TETC)<sup>30,</sup>. Within this new structure TEGC took over and operated the public power plants, TETC was given responsibility for wholesale operations and became the holder of all pervious Build-Own-Operate (BOO), Build-Operate-Transfer (BOT) and Transfer of Operating Rights (TOOR) agreements and long term power purchase agreement with Treasury guaranties. TETC was assigned responsibility for transmission and balancing and settlement procedure in order to balance power operation between parties, covering both the physical and financial aspects of transmission operation; hence, TETC became the transmission system operator for Turkey (Dolun, 2002).

The history and development of the Turkish electricity industry, discussed above, has been driven by past governments' concerns with meeting the growth in electricity demand in order to maintain economic growth and raise the living standards of the Turkish people. This remains true for the present Turkish government. Therefore, given that the Turkish electricity industry remains under state control, with only, limited genuine market activity, it is vital that Turkish policy makers understand the main characteristics and the key drivers of both past and future of electricity demand. This is therefore one of the key motivations for undertaking the research for this thesis; it aims to identify and forecast Turkish electricity demand. However, before this is undertaken, Turkish Economy and Electricity consumption over the period 1960-2008 will be analysed in the next section.

<sup>&</sup>lt;sup>28</sup> In Turkish this is known as TEIAS (Turkiye Elektrik Iletim Anonim Sirketi) translated by author.

<sup>&</sup>lt;sup>29</sup> In Turkish this is known as EUAS (Elektrik Uretim Anonim Sirketi) translated by author.

<sup>&</sup>lt;sup>30</sup> In Turkish this is known as TETAS (Turk Elektrik Ticaret ve Taahut Anonim Sirketi) translated by author.

#### 4.4 Turkish Economy and Electricity Consumption 1960-2008

The Turkish economy experienced a number of economic crises and economic policy changes during the period 1960-2008. In particular, there were four serious and long lasting economic crises in 1978-1981, 1988-1989, 1994 and 1998-2002; in addition to the three mid-size, and relatively short lasting, economic crises in 1969, 1982, and 1991 (Kazgan, 2002).

As part of the response to these continuing problems, the Turkish government responded in the 1960s and 1970s by implementing an industrialization strategy based upon import substitution. This resulted in significantly higher and more stable growth rates until the late 1970s. However, the Turkish government's decision not to allow the increase in the cost of oil imports due to the oil price hikes of the early and late 1970s to permeate through the economy and hence shoulder the true economic 'burden' of high oil prices resulted in balance of payments problems and an increase in the budget deficit. This led to the worst political instability in Turkish history, when inflation reached 64% with a balance of payments 'crisis' in 1979, with GDP declining in both 1979 and 1980. It was following this period that Turkey adopted export-oriented industrialization policies (Taymaz and Yilmaz, 2007).

Not surprisingly, these crises and policy changes affected both industrial output and industrial electricity consumption. As highlighted above, before 1980 the Turkish economy was inward looking with an import-substituting industrialization strategy; whereas, after 1980 this changed to an export oriented industrialization strategy. Therefore, before 1980 the Turkish industrial sector was more vulnerable to domestic shocks whereas after 1980 it became more vulnerable to external shocks such as the Gulf War and the global economic crisis. However despite this volatility, Turkish industrial electricity consumption increased by an average of about 8½% per year from about 1½ TWh to just over 72 TWh over the period 1960 to 2008

(IEA, 2010c). This high growth rate of industrial electricity consumption would appear, according to Bakirtas et al. (2000) to be mainly a result of the increasing number of applications of energy intensive technologies in the Turkish industrial sector.

Although Turkish industrial electricity consumption generally followed an upward trend over the period 1960 to 2008 some falls did occur; consistent with the economic crises, namely just under 4% in 1991, just under 2.4% in 2001, and a very marginal fall in 1994 (IEA, 2010c). In 2008, industrial electricity consumption accounted for 45% of total Turkish electricity consumption, down from just above two thirds in 1960. Although the share of industrial electricity consumption in total electricity consumption diminished, it still has a significant weight in overall electricity consumption (IEA, 2010c). On the other hand industrial value added increased from just under 9 billion (2005 constant YTL) to just under 175 billion (2005 constant YTL) representing an average annual increase of just under 6½% for the period 1960 to 2008 as illustrated in Figure 4.11 (World Bank, 2010). As discussed above, the effect of the changing international oil price and energy prices in general were not felt directly throughout the economy, including the industrial sector, given the regulation of energy prices by the Turkish government.

In 1970 just over 50% of the Turkish population benefited from accessing electricity but by 1987 it had almost reached 100% (Altas et. al., 1994). In the early part of this period, electricity was generally used for lightening but use expanded for a range of other household energy services in the latter part with the installation of new appliances such as TVs, refrigerators, etc. It is commonly expected that higher household income and expenditure will result in higher demand for the services emanating from these kinds of appliances, which use electricity. In the short term, this is likely to boost electricity consumption but in the longer

term, higher income is likely to result also in households replacing appliances that use old technologies with new more efficient ones that might have a lessening effect on electricity consumption. It is therefore important for policy makers and planners to have some idea of the short and long run income and expenditure elasticities.

Figure 4.11: Industrial Value Added, Industrial Electricity Consumption, Industrial Electricity Prices Growth Rates 1960-2008



From 1960 to 2008, Turkish residential electricity consumption increased by an average of about 10% per year, from 0.5 TWh to 39.5 TWh (IEA, 2010c). Whereas from 1960 to 2008 household total final expenditure increased on average by just under 5% per year, from about 53 billion YTL (2005 Constant YTL) to just over 500 billion YTL (2005 constant YTL) (World Bank, 2010). Furthermore, over the period 1960 to 2008 electricity prices were mostly controlled by successive Turkish governments despite the Electricity Market Law No. 4628 introduced in 2001 with the aim of creating a liberalized market structure, as discussed above; hence, real electricity prices decreased by an average of about 1% per annum over the

estimation period. Figure 4.12 illustrates the annual changes in residential electricity prices along with the annual changes in electricity consumption and total household expenditure.





In 2008, residential electricity consumption accounted for 25% of total Turkish electricity consumption (IEA, 2010c). Therefore, it is increasingly important to investigate the key drivers of Turkish residential energy demand and be able to construct sensible future scenarios. The success or otherwise of these can have a significant impact on the welfare of the Turkish economy and is essential for Turkish sustainable economic development.

Between 1960 and 2008, total electricity consumption in Turkey increased by an average of 9.4% per year from 2.1 TWh to 159.4 TWh (IEA, 2010c). The high growth rate of electricity consumption would appear to reflect the increasing number of applications of energy intensive technologies both in the daily life of Turkish households and Turkish manufacturing sector. Whereas real Turkish electricity prices decreased by an average of 0.6% per annum

over the period 1960 to 2008. On the other hand GDP increased by an average of a 5% annum from just over 63 to just below 717 billion YTL over the period (Figure 4.13).

Figure 4.13: Annual Change in Turkish Total Electricity Consumption, Real Average Electicity Prices and Real GDP over the period 1960 to 2008



In terms of energy security, the Turkish electricity market became increasingly more dependent on imported primary energy resources as illustrated in Figure 4.14. Since the 1990s, the share of natural gas in power generation increased continually reaching 48% by 2009 whereas the share of renewable energy sources decreased (IEA, 2010c). This has resulted in Turkey becoming more dependent on imported primary energy resources (see Figure 4.15) making Turkey vulnerable to natural gas price volatility.

Electricity consumption is also important in terms of the associated  $CO_2$  emissions. Turkish  $CO_2$  emissions from energy consumption more than doubled from 1990 to 2010. Turkey is a party to United Nations Framework Convention on Climate Change (UNFCCC) and Kyoto Protocol but is the only Annex-I country that has not put any mitigation targets in place for the post 2012 period. Moreover, among the OECD countries Turkey is the only country that

does not have a national emission target for 2020 (IAE, 2010). Consequently, Turkey might well face future international pressure to set emission targets. In the short term, the Turkish government's priority is to meet growing energy demand, but in the long term, ignoring these global trends might be costly both politically and economically. However, in order to reach a balance between securing electricity supply to meet demand and transforming the power generation to a more sustainable level, the Turkish government requires sound and reliable electricity demand projections to underpin their planning activities. However, as stated above, this has not always been the case, so that given electricity consumption has been increasing significantly, it is important that Turkish policy makers understand what drives electricity demand and more importantly how it will evolve over the next 10 years or so.





Source: IEA 2010



**Figure 4.15: Self Sufficiency Vs Import Dependency** 

Source: IEA, 2010

In order to investigate the key drivers of Turkish industrial, residential, and aggregate electricity demand and be able to construct sensible future scenarios, these demand functions are estimated by utilizing STSM. In the next section, previous Turkish electricity demand studies are reviewed in the next section.

# 4.5 Previous Turkish Electricity Demand Forecast Studies

Studies before the 1970s that directly focused on analysing Turkish electricity demand are very limited, being generally carried out by governmental institutions with their own approaches, namely the State Planning Organization (SPO), the State Institute of Statistics (SIS) and the Ministry of Energy and Natural Resources (MENR). Although some research in those institutions tried to apply mathematical modelling techniques to analyse energy demand in the late 1970s, these methods were not used in official energy planning until 1984. Before 1984, national energy policy was shaped by the forecasts of the SPO in which they employed various simple best-fit curves (Ediger and Tatlidil, 2002).

The MENR utilized different models in order to determine energy demand functions and to make future projections. For instance, 'Balance' models that are non-linear equilibrium models that match the energy demand with available resources and technologies and 'Impact' models that focus on the relation between energy consumption and its interaction with the environment were employed in the framework of Energy and Power Evaluation Program (ENPEP). Both models were used for the long-term supply and demand projections between 1981 and 1985. The MENR began to use the simulation models namely MAED, WASP III, and EFOM-12 C Mark. MAED (Model for Analysis of Energy Demand) and WASP III (Wien Automatic System Planning) were originally developed by the International Atomic Energy Agency (IAEA) and the energy demand model EFOM-12 C Mark (Energy Flow Optimization Model) was developed by the commission of the European Union starting from 1984 (Ediger and Tatlidil, 2002).

At the same time, SPO also developed its own models based on sectoral energy demand for different consumer groups, subgroups and finally the mathematical models were developed for each sub group by regression. On the other hand, the SIS explored the relationship between demographic factors and economic parameters with energy demand in its models. Both of the models explored by SIS and SPO verified the relationship between energy demand and GDP (Ediger and Tatlidil, 2002).

The previous forecast and energy modelling studies above used different kinds of approaches, but the main motivation of all those studies was to provide better energy and electricity planning tools for policy makers for sustainable economic growth. However, the previous forecast studies such as those produced from MAED, WASP III, and EFOM-12 C Mark, always predicted much higher demand levels than the actual outturn. As an example the official total electricity demand projections for 2003 produced in 1987, 1990, 1993, 1996 and 2000 (utilizing the MAED) are illustrated in Figure 4.16, which demonstrates the 'over forecasts' (TETC, 2009). According to Keleş (2005), this is mainly due to "technical deficiencies of the models used, lack of ability of the relevant authorities in creating precise assumptions and not having transparency and accountability in the relevant processes" (p. vi). Moreover, Keleş (2005) argues that the policies adopted based upon these unsuccessful forecasts resulted in a significant proportion of electricity generation capacity remaining idle, transformed the Turkish economy to be more dependent on imported primary energy resources, prevented energy markets liberalization, and resulted in high electricity prices. Furthermore, Ediger and Tatlidil (2002) stated that the values of the future predictions of demographic and economic variables used in the MAED models by SPO were significantly manipulated by government policies in line with high economic growth targets rather than reliable forecasts.

In summary, the above has illustrated how previous projections of Turkish electricity demand generally proved to be above that actually observed (i.e. they 'over-forecast'). This mislead Turkish policy makers, causing them to implement projects to meet this perceived demand that later proved to be incorrect. This resulted in 'short-term' policy decisions with the installation of gas fuelled power plants rather than 'longer-term' policy decisions such as to install power plants fuelled by renewable energy. As a result, the share of natural gas in power generation and dependency to imported natural gas gradually increased.

Hence, as explained above, a key motivation for this chapter is to develop a more robust model of Turkish energy demand in order to produce more reliable forecasts and scenarios for future electricity demand, which is undertaken below but it is important beforehand to consider previous academic (and other) work on Turkish electricity demand. The next section therefore reviews these past studies.



Figure 4.16: Official Turkish Energy Demand Projections for the year 2003

Source: TETC (2009)

#### 4.6 Previous Turkish Energy Demand Studies

There was a large increase in the number of Turkish energy modelling studies after the late 1990s and they can be divided into three main groups. In the first group, the focus is on investigating the causality between energy consumption and economic variables (termed 'Causality Studies' below). In the second group, the focus is on identifying the relationship and the magnitude of the key relationships (mainly the elasticities) between economic variables and energy demand (termed 'Relationship Studies' below). Moreover, in the third group, the aim is to forecast future energy demand using a number of different approaches

(termed 'Forecast Studies' below). Turkish energy demand studies are briefly reviewed below in a general context with a detailed summary presented in Table 4.2, followed by a more detailed discussion of the studies that focus explicitly on modelling Turkish electricity consumption.

- *Causality Studies:* The focus is whether statistical causality (usually defined as Granger Causality) between energy consumption and economic variables, such as GDP exists. These include, Erdal, et al. (2008), Karanfil (2008), Erbaykal (2008), Jobert and Karanfil (2007), Soytas and Sari (2007), Lise and Montfront (2007), Altinay and Karagol (2005) who applied different techniques including simple Granger Causality, Vector Auto Regression (VAR), Instantaneous Causality, Bonds Testing co-integration, Johansen co-integration, Pair-wise Granger Causality, Error Variance Decomposition, Impulse Response and Vector Error Correction Model (VECM). However, whatever techniques were applied, all studies in this group aimed to determine whether causality between energy consumption and certain economic variables exists plus the direction of the causality.
- *Relationship Studies:* The focus is generally on identifying the relationship between energy, activity, and price variables and the magnitude of the relationship. These include Bakirtas et al. (2000), Erdogdu (2007), and Halicioglu (2007) who employed different methods such as Engle-Granger two-step procedure, Auto Regressive Moving Average, Bonds Testing Co-integration and the Partial Adjustment Model, to estimate price and income elasticities for total Turkish electricity demand and residential electricity demand.

 Forecast Studies: Here the focus is on predicting future energy demand such as Kavakhoglu et al. (2009), Ediger and Akar (2007), Hamzacebi (2007), Erdogdu (2007), Akay and Atak (2006), Ceylan and Ozturk (2004), Ozturk et al. (2005) and Ediger and Tatlidil (2002). These studies used various methods including Univariate Cycle Analysis, Genetic Algorithm Approach, Grey Prediction with Rolling Mechanism, Auto Regressive Integrated Moving Average (ARIMA), and Artificial Neural Networks.

**Table 4.2: Summary of Previous Turkish Energy Demand Studies** 

Reference	Focus of Study	Method	Summary
Kavalioglu et al. (2009)	Total Electricity Demand	Artificial Neural Networks	Turkish total electricity consumption would reach 240 TWh by 2020.
Erdal, et al. (2008)	Energy Consumption and Growth	Johansen co- integration, Pair- wise Granger causality	Energy consumption and GNP are co- integrated and there is bidirectional causality running from energy consumption and GNP and vice versa.
Karanfil (2008)	Energy Consumption, Growth and Unrecorded Economy	VECM-VAR	There is a long term equilibrium relationship between the officially calculated GDP and energy consumption. However when unrecorded economy is taken into account there is no causality between energy consumption and GNP.
Erbaykal (2008)	Oil and Electricity Consumption and Economic Growth	Bounds testing co- integration approach	Both electricity and oil consumption have a short term effect on economic growth.
Soytas and Sari (2007)	Industrial Electricity Consumption	Error Variance Decomposition & Impulse Response	Industrial Value added, industrial electricity consumption, labour and fixed investment are co-integrated in long term, no significant impact on each other in short term
Hamzacebi (2007)	Total and Sectoral Electricity Consumption	Artificial Neural Networks	The total electricity consumption will reach to 500 TWh by 2020 where industrial, residential, agricultural and transport sector electricity consumption are forecasted 219TWh, 257 TWh, 20 TWh, and 4 TWh respectively.

Erdogdu (2007)	Electricity Consumption per capita	Partial Adjustment Model & ARIMA	Long term and short Term price elasticities are -0.04 and -0.030 respectively, income elasticity is 0.06 in short term and 0.41 in the long term. Electricity consumption is projected to reach to 160 TWh by 2014
Ediger and Akar (2007)	Primary Energy Consumption	ARIMA	In the low case scenario the total primary energy consumption is projected to be 135.896 mtoe and in the high case scenario it will reach to 152.285 mtoe by 2020
Halicioglu (2007)	Residential Electricity Consumption per capita	Bounds testing co- integration Approach	Long term and short term price elasticities are varying -0.52 to -0.63 and -0.33 to -0.46 respectively and where long term and short term income elasticities varying 0.49 to 0.70 and 0.37 to 0.44 correspondingly according to lag criteria. Urbanization rate is a significant factor and has a 0.04 and 0.90 effects in the long term and in the short term respectively.
Jobert and Karanfil (2007)	Sectoral Energy Consumption by Source and Growth	Granger Causality- Instantaneous Causality	There is no evidence of a long term relationship between energy and income. They appear to be neutral with respect to each other. Strong evidence is found for instantaneous causality between variables.
Lise and Montfront (2007)	Electricity Consumption and Economic Growth	Granger Causality	The causality is running from GDP to Energy consumption
Akay and Atak (2006)	Total and Industrial Electricity Consumption	Grey Prediction with Rolling Mechanism	It is projected that industrial and total consumption will be 140.37 and 265.7 TWh in 2015 respectively.
Altinay and Karagol (2005)	GDP and Energy Consumption	VAR and Granger Causality	Unidirectional causality running from electricity consumption to income
Ozturtk and Ceylan (2005)	Total Energy Consumption	Genetic Algorithm Approach	Genetic algorithm approach might be a better estimation method when it is compared with MAED projections of MENR.
<i>Ozturk et al.</i> (2003)	Total Electricity Consumption	Genetic Algorithm Approach	Genetic algorithm approach might be a better estimation method when it is compared with MAED projections of MENR.
Ediger and Tatlidil (2002)	Primary Energy Demand	Univariate cycle analysis	The primary energy demand will reach 130 mtoe by 2010
Bakirtas et al. (2000)	Total Electricity Consumption per capita	Engle-Granger two step procedure & ARMA	Insignificant price elasticity. Income elasticity, 0.7 short run and 3.1 long run.
Soytas and Sari (2007) focused on the relationship between economic activity and industrial electricity demand for Turkey. Using annual data for 1968 to 2002, employing co-integration Granger causality tests, Soytas and Sari (2007) explored the relationship between Turkish industrial value added and industrial electricity consumption, whilst accounting for labour and fixed investment. Whilst they found that all these variables are co-integrated, they found only uni-directional causality from electricity consumption to value added. However, arguably one criticism of this research is the failure of Soytas and Sari (2007) to include industrial electricity prices in the model, which might explain the results obtained, and hence the outcome arguably does not enlightening Turkish policy makers very much.

Halicioglu (2007) investigated Turkish residential electricity demand using the Bounds Testing approach and found a range of estimated elasticities depending upon the number of lags chosen, such as:

- Short and long run price elasticities of -0.33 and -0.52 respectively.
- Short and long run income elasticities of 0.44 and 0.70 respectively.

Halicioglu (2007) argues that the urbanization rate is also a significant variable in determining Turkish residential energy demand finding estimated urbanization short run and long run elasticities of 0.90 and 0.04 respectively. He also finds that the short run income and price elasticities are lower than the long run elasticities and argues that policy makers should consider this when implementing policy. He claims that in the short term the response to policy changes will be limited because of the fixed energy appliances.

Although Halicioglu (2007) contributes significantly to the exploration of the residential sector electricity demand modelling, it can arguably be improved in two main ways. Firstly, Halicioglu (2007) uses an energy price index rather than real electricity prices. Secondly,

Household Total Final Expenditure probably represents household consumption capability better than Gross National Product per capita, which Halicioglu uses.

Bakirtas et al. (2000) using price, income, population and energy consumption data over the period 1962 to 1996, investigated the long run economic relationship between total electricity demand per capita, income per capita and prices by using the Engle and Granger two-step procedure and the Johansen procedure. However, they failed to find a significant price effect and stated that this was to be expected given electricity prices were subsidised by various Turkish governments. Nonetheless, it would not appear that this is the reason given the degree of variability in Turkish real electricity prices, historically being somewhat more variable (and higher) than general European real electricity prices, as illustrated in Figure 4.17. On the other hand, Bakirtas et al. (2000) concluded that the short and long run income per capita elasticities were about 0.7 and 3.1 respectively. Furthermore, as a separate exercise, Bakirtas et al. (2000) undertook a univariate ARMA process in order to forecast future Turkish electricity consumption between 1997 and 2010 and concluded that aggregate electricity consumption per capita would reach about 2222 KWh in 2010 (Bakirtas et al., 2000).

Erdogdu (2007) also took a 'two part' approach to estimation and forecast. In the first part, the Partial Adjustment Model (PAM) was employed with quarterly data including real GDP per capita, price, and net total electricity consumption per capita between 1984 and 2004. Erdogdu (2007) found that the short and long run price elasticities were -0.04 and -0.30 correspondingly and that the short and long run income elasticities were 0.06 and 0.41 respectively. However, Erdogdu states "data on net electricity consumption, population and GDP is not available quarterly" hence the annual series on these data were "converted into

quarterly data by linear interpolation so as to make use of them together with quarterly data on electricity prices" (Erdogdu, 2007, p. 1134). This might have helped to overcome lack of data and observations problems, but arguably introduces an 'artificial data generating process' given three out of the four series used (including the dependent variable) had an artificial seasonal pattern imposed an might have led to biased estimated elasticities.<sup>31</sup>

Figure 4.17: Industrial and Residential Electricity Price Comparison of OECD-Europe and Turkey 1978-2008 (2005 constant US \$ PPP / Kwh)



Source: IEA, 2010

In the second part, Erdogdu (2007) estimated a simple ARIMA model with annual data from 1923 to 2004 in order to construct the forecast of future Turkish electricity consumption. He

<sup>&</sup>lt;sup>31</sup> For example, GDP fluctuates seasonally and electricity-using appliances are likely to differ seasonally; hence, the simple linear interpolation is likely to ignore these seasonal fluctuations and hence, is likely to have led to the misidentification of the electricity demand relationship.

concluded that electricity consumption would increase by 3.3% per year until 2014 reaching about 156 TWh in 2010 and about 160 TWh in 2014 (Erdogdu, 2007).

As discussed above, both Erdogdu (2007) and Bakirtas et al. (2000) attempt to explain past electricity demand by exploring the relationship and/or causality between income, total electricity consumption and electricity prices by using the PAM, the Johansen procedure and the Engle and Granger two step procedure. It is somewhat surprising, therefore, that to produce their forecasts these relationships are ignored, instead preferring to predict the future, they both used univariate models, as described above. This is arguably a weakness in their approach, which this research attempts to correct.

Hamzacebi (2007) used 1970-2004 sectoral electricity consumption data and Artificial Neural Networks method to forecast the total, residential, and industrial electricity consumption. Hamzacebi (2007) suggest that by 2020:

- i) Residential electricity consumption will reach about 257 TWh.
- ii) Total electricity consumption will reach about just below 500 TWh.
- iii) Industrial electricity demand will reach just less than 220 TWh.

Akay and Atak (2006) using the Grey Prediction with Rolling Mechanism, focused on forecasting Turkish industrial and total electricity demand. Akay and Atak (2006) argued that the industrial and total electricity consumption will be about 140 TWh and just below 266 TWh correspondingly by 2015.

However, both Akay and Atak (2006) and Hamzacebi (2007) could arguably be criticised for their failure to take account of the electricity price and economic activity in driving future electricity demand – which might result in forecasts being somewhat different from outturn.

Ozturk and Ceylan (2005) utilized the Genetic Algorithm approach with data over the period 1980 to 2003 for total electricity consumption, population, imports, exports and GDP data. Nevertheless, despite identifying a number of economic variables their interaction with electricity consumption is not clearly defined; moreover, the effect of electricity prices was neglected. Ozturk and Ceylan (2005) concluded that total electricity consumption would be between about 462 TWh and 500 TWh in 2020 (Ozturk and Ceylan, 2005).

Kavaklioglu et al. (2009) employed the variables population, GDP, imports and exports in an artificial neural network model and concluded that the Turkish total electricity consumption would reach 240 TWh by 2020. However, the interaction of the economic variables and the electricity consumption is not identified clearly by Kavaklioglu et al. (2009); moreover, once again the effect of electricity prices on electricity demand is ignored (Kavaklioglu et al., 2009).

By using only previous years' electricity consumption values in their forecasts without allowing for any economic demand relationship, Erdogdu (2007), Hamzacebi (2007), Akay and Atak (2006) and Bakirtas et al. (2000) ignore the important interaction between energy demand and economic variables in their forecasts and take into account only past electricity consumption. On the other hand, Ozturk and Ceylan (2005) and Kavaklioglu et al. (2009) include economic variables in their models as described above but as the relationships

between electricity consumption and economic variables are not identified, it is not clear how these economic variables are taken into account for future electricity demand projections.

Consequently, all the forecasts above are arguably not as reliable as they might be given the highlighted issues above; whereas, one based on the structural time series methodology will hopefully prove more fruitful.

## 4.7 Empirical Framework

As stated in the methodology chapter above, it is assumed that the general relationship for Turkey's electricity demand (be it for the industrial sector, the residential sector, or the economy as a whole) is given by:

$$E_t = f(Y_t, P_t, UEDT_t) \tag{4.1}$$

Where:  $E_t$  = electricity demand (industrial, residential or aggregate);

- $Y_t$  = activity variable [industrial value added (or 'output' for short), household total final consumption expenditure (or 'expenditure' for short), or 'GDP';
- $P_t$  = real electricity prices (industrial residential, or average); and
- $UEDT_t$  = Underlying Energy Demand Trend (industrial, residential, or aggregate electricity.

## **4.8 Data**

Annual time series data from 1960-2008 for E (industrial, residential and aggregate electricity consumption in KWh), Y (industrial value added, household total final expenditure and gross

domestic product in 2005 constant Yeni Turk Lirasi, YTL) and *P* (real industrial, residential and average electricity prices in 2005 constant YTL) are used for the analysis.

*E* is obtained from the International Energy Agency (IEA, 2010c), *Y* from the World Bank (World Bank, 2010), and nominal industrial and residential electricity prices are obtained from the archives of the SIS, the MENR, and IEA (2010c). The weighted averages of nominal industrial and residential prices are used in order to calculate an approximation for the nominal average aggregate electricity price. In order to obtain the real industrial, residential, and average electricity price, *P*, the nominal prices are deflated by Turkey's Consumer Price Index obtained from the World Bank (World Bank, 2010).

## 4.9 Estimation Results

## 4.9.1 Turkish Industrial Electricity Demand

After eliminating the insignificant variables and including interventions, (irregular for 1991, level for 1979 and slope for 1981), in order to maintain the normality of residuals and auxiliary residuals, the preferred estimated equation for Turkish industrial electricity demand is given by:

$$e_t = 0.14969y_t - 0.16086p_t + UEDT_t \tag{4.2}$$

Where the estimated *UEDT* for industrial electricity demand is 20.8124 at the end of the estimation period with a slope of 0.04793.<sup>32</sup> The detailed estimation results and the diagnostics tests are given in Table 4.3 and Figure 4.18.

 $<sup>^{32}</sup>$  The figure of 0.04793 (representing an annual increase of just under 5%) is the sum of the estimated slope at the end of the period of 0.086766 and the estimated coefficient for the slope intervention of -0.0338 (Figure 4.20).

The preferred model passes all the diagnostic tests including the additional normality tests for the auxiliary residuals generated by the STSM approach, with no need for any dynamic terms giving estimated short and long run industrial output and price elasticities of 0.15 and -0.16 respectively. Therefore, the estimated price elasticity is between previous Turkish estimates discussed above, being greater (in absolute terms) than that found by Bakirtas et al. (2000) but less than that found by Erdogdu (2007) and Halicioglu (2007). However, the estimated income elasticity is somewhat lower than that found by Bakirtas et al. (2000), Erdogdu (2007), and Halicioglu (2007). Nevertheless, these previous Turkish studies were not for the industrial sector and importantly, did not allow for a UEDT; hence, it is not surprising that they found a bigger income effect.



**Figure 4.18: STAMP Predictive Tests Graphics** 

Variables	Estimated Coefficients	Standard Errors	Probabili	ties				
р	-0.16086	0.04483	0.001					
у	0.14969	0.05142	0.007					
Lvl 1979	-0.16873	0.03436	0.000					
Slp 1981	-0.03883	0.01378	0.007					
Irr 1991	-0.08426	0.02793	0.006					
Level and Slope Components of UEDT <sub>2008</sub>								
Level	22.06831							
C1	0.08677							
Slope	0.00077							
Slope	Residuals			Auxiliary Re	siduals			
Slope	Residuals		Irregular	Auxiliary Re Level	siduals Slope			
Std. Error	Residuals	Std. Error	Irregular 1.011	Auxiliary Re Level 0.992	siduals <u>Slope</u> 0.911			
Std. Error Normality	0.08077 Residuals 0.923 0.466	Std. Error Normality	<i>Irregular</i> 1.011 0.689	Auxiliary Re Level 0.992 0.634	<i>siduals <u>Slope</u></i> 0.911 0.278			
Stope Std. Error Normality Skewness	0.923 0.466 0.382	Std. Error Normality Skewness	<i>Irregular</i> 1.011 0.689 0.617	<i>Auxiliary Re</i> <i>Level</i> 0.992 0.634 0.438	siduals <u>Slope</u> 0.911 0.278 0.112			
Std. Error Normality Skewness Kurtosis	0.923 0.466 0.382 0.382	Std. Error Normality Skewness Kurtosis	<i>Irregular</i> 1.011 0.689 0.617 0.482	<i>Auxiliary Re</i> <i>Level</i> 0.992 0.634 0.438 0.661	siduals <u>Slope</u> 0.911 0.278 0.112 0.872			
Std. Error Normality Skewness Kurtosis H(14)	0.923 0.466 0.382 0.382 0.594	Std. Error Normality Skewness Kurtosis	<i>Irregular</i> 1.011 0.689 0.617 0.482	Auxiliary Re Level 0.992 0.634 0.438 0.661	siduals <u>Slope</u> 0.911 0.278 0.112 0.872 -			
Stope Std. Error Normality Skewness Kurtosis H(14) R(1)	0.923 0.466 0.382 0.382 0.594 0.023	Std. Error Normality Skewness Kurtosis	<i>Irregular</i> 1.011 0.689 0.617 0.482 -	Auxiliary Re Level 0.992 0.634 0.438 0.661 -	siduals <u>Slope</u> 0.911 0.278 0.112 0.872 -			
Std. Error Normality Skewness Kurtosis H(14) R(1) R(7)	0.923 0.466 0.382 0.382 0.594 0.023 0.146	Std. Error Normality Skewness Kurtosis	<i>Irregular</i> 1.011 0.689 0.617 0.482 - -	Auxiliary Re <u>Level</u> 0.992 0.634 0.438 0.661 - -	siduals <u>Slope</u> 0.911 0.278 0.112 0.872 - - -			
Stope Std. Error Normality Skewness Kurtosis H(14) R(1) R(7) DW	0.03077         Residuals         0.923         0.466         0.382         0.382         0.594         0.023         0.146         1.945	Std. Error Normality Skewness Kurtosis	<i>Irregular</i> 1.011 0.689 0.617 0.482 - - -	Auxiliary Re <u>Level</u> 0.992 0.634 0.438 0.661 - - -	siduals <u>Slope</u> 0.911 0.278 0.112 0.872 - - - - - -			

 Table 4.3: Turkish Industrial Electricity Demand STSM Estimates and Diagnostics

 Sample 1960-2008

Predictive Test 2001-2008 LR Test Failure Test (a) 0.9048 96.31 (0.000)Cusum t(4) 0.7996 Test (b) 22.72 (0.000)Goodness of Fit *Hyperparameters* Level *p.e.v.* 0.001 0.0003149  $p.e.v./m.d.^{2}$ 1.137 Slope 0.0001536  $R^2$ 0.999 Irregular 0.0004675 $R_d^2$ 0.651 Nature Of Local Trend Trend : Model

Notes:

-Model estimation and all statistics are from STAMP 8.10;

-Model includes a level intervention for the year 1979, a slope intervention for the year 1981 and an irregular for the year 1991;

-Prediction Error Variance (p.e.v.), Prediction Error Mean Deviation (p.e.v./m.d.2), and the Coefficients of Determination ( $R^2$  and  $Rd^2$ ) are all measures of goodness-of-fit;

-Normality (corrected Bowman - Shenton), Kurtosis and Skewness are error normality statistics, all approximately distributed as  $\chi^2_{(2)}$ ; as  $\chi^2_{(1)}$ ; as  $\chi^2_{(1)}$ ; respectively;

-H(14) is a Heteroscedasticity statistic distributed as F(14,14);

*-r*(1) and *r*(7) are the serial correlation coefficients at the equivalent residual lags, approximately normally distributed;

-DW is the Durbin-Watson statistic;

-Q(7,5) is the Box – Ljung statistic distributed as  $\chi^2_{(5)}$ ;

-Failure is a predictive failure statistic distributed as  $\chi^2(8)$  and Cusum is a mean stability statistic distributed as the Student t distribution; both are STAMP prediction tests found by re-estimating the preferred model up to 2000 and predicting for 2001 thru 2008;

-LR Test(a) represent likelihood ratio tests on the same specification after imposing a fixed level and zero slope hyperparameter and Test(b) after imposing a fixed level and fixed slope; both are distributed as  $\chi^2_{(2)}$  and probabilities are given in parenthesis.

As discussed in the methodology chapter, the irregular, the slope and level residuals need to be normally distributed, and during the estimation process, it was found that some interventions were needed to ensure this condition is maintained. As also discussed in methodology section, from a statistical standpoint, the existence of such interventions in the STSM might be a sign of a structural break and instability over the estimation period; however, from an economics standpoint, the interventions provide valuable information about certain events and periods that affects electricity consumption behaviour and therefore warrants further investigation. In this case, the preferred estimated equation for Turkish industrial electricity demand required interventions in 1979, 1981 and 1991 (as level, slope, and irregular interventions correspondingly) all of which can be identified as important events:

 the level intervention for 1979 probably reflects the serious economic crises that Turkey experienced resulting from the oil price hike. This caused a large decrease in GDP and led to a military coup, and therefore the estimated output elasticity for industrial energy demand would be unlikely to adequately pick up this shift effect;

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- the slope intervention for 1981 probably reflects the important change in Turkish industrial electricity consumption, because of the first implementation of planned energy conservation activities for the industrial sector by the General Directorate of Electrical Power Resources Survey Administration-EIE (Hepbasli and Ozalp, 2003);
- the irregular intervention for 1991 probably reflects the economic crisis that year following from the Gulf war and sanctions against Iraq; the export oriented Turkish industrial sector was quite negatively affected bringing about a 4% reduction in industrial electricity consumption, which would not be captured adequately by the estimated output and price elasticities (being outside the usual 'norm').

It would appear that the 1991 and 1979 crises effected Turkish industry in a different manner. As discussed in the introduction, prior to the 1980s the Turkish economy was inward looking with an import-substituting industrialization strategy; whereas, after 1980 the strategy changed with an export oriented industrialization strategy adopted. Therefore, before 1980 the domestic market is more important whereas after 1980 exports became more important. Even though Turkey experienced a bigger domestic economic crisis in 2001 compared to 1991, the 1991 crises had a narrowing effect on export potential of Turkey because of the first gulf war.

The estimated UEDT from this procedure is non-linear given the estimated hyper-parameters (Table 4.3) and is illustrated in Figure 4.19. It can be seen that the estimated stochastic trend is generally increasing (but at a decreasing rate) over the estimation period, i.e. it is generally energy using. It also clear in Figure 4.20, given the interventions, that there is a level drop in 1979 and the slope changes at 1981; moreover Figure 4.20 illustrates that the slope and the

'adjusted slope' generally diminishes over the estimation period.<sup>33</sup> The preferred equation and the estimated non-linear UEDT are now used to construct future scenarios for Turkish energy demand, which are explained in the next section.

Figure 4.19: Underlying Electricity Demand Trend (UEDT) of Turkish Industrial Sector Electricity Consumption 1960-2008



Figure 4.20: Slope and Level of UEDT for Turkish Industrial Sector 1960-2008



<sup>&</sup>lt;sup>33</sup> The estimated 'adjusted slope' is equal to the estimated slope plus the slope intervention.

### 4.9.2 Turkish Residential Electricity Demand

After eliminating the insignificant variables and including interventions in order to maintain the normality of residuals and auxiliary residuals, a summary of the preferred estimated equation for Turkish residential demand is given by:

$$e_t = 0.75767e_{t-1} + 0.37978y_{t-1} - 0.09171p_t + UEDT_t$$
(4.3)

where  $UEDT_{2008} = -4.43093$  at the end of the period. The detailed estimation results and the diagnostics tests are given in Table 4.4. The model passes all the diagnostic tests including the additional normality tests for the auxiliary residuals generated by the STSM approach. This includes the STAMP prediction tests over 2001 – 2008, as illustrated in Figure 4.21.

The previous years' electricity consumption has a significant effect on residential sector electricity consumption the magnitude being just above 75%. In the short run, household appliances are fixed and given the derived demand nature of residential electricity, the short run impact of changes in prices and income is limited. However, in the long run households are able to change the appliances so that the household expenditure and price elasticities will be greater in the long run.

The estimated results suggest that expenditure does not have a significant impact in the current year; that is the 'impact elasticity' is estimated to be zero. However, the impact of expenditure is estimated to come through during the next year; hence, this is interpreted here as the 'short run' expenditure elasticity of 0.38. This compares to the estimated 'impact/short run' price elasticity of -0.09. Whereas the estimated long run residential expenditure and price elasticities are 1.57 and -0.38 respectively.

Variables	Estimated Coefficients	Standard Errors	Probabilit	ies	
$e_{t-1}$	0.75767	0.05054	0.000		
<i>Yt</i> -1	0.37978	0.08089	0.000		
$p_t$	-0.9171	0.04432	0.045		
Irr 1973	-0.1345	0.03008	0.000		
Level 1971	-0.1199	0.03688	0.002		
Level 1975	0.1013	0.03931	0.014		
Components	OFUEDT		Long R	un Elasticity	
<u>Components</u>	4 4124		<u>Estimates</u> Drico	0.29	
Level	-4.4124		Incomo	-0.38	
Stope	-		mcome	1.37	
				Auxiliary Residuals	
	Residuals		Irregular	Level	Slope
Std. Error	0.960	Std. Error	0.986	0.969	-
Normality	0.281	Normality	0.816	0.299	-
Skewness	0.111	Skewness	0.827	0.120	-
Kurtosis	0.967	Kurtosis	0.549	0.992	-
H(13)	1.201		-	-	-
<b>R</b> (1)	0.047		-	-	-
<b>R</b> (6)	0.099		-	-	-
DW	1.856		-	-	-
Q(6,5)	1.563		-	-	-
Predictive Test 2001-2008		<u>-</u>	LR Test		
Failure	0.30		Test (a)	30.507	(0.0000)
Cusum	0.07			10.054	
t(4)	0.97		Test (b)	19.954	(0.0000)
Goodness of Fit		_	Hyperparameters		_
<i>p.e.v.</i>	0.001		Level	0.00111	
$p.e.v./m.d.^2$	1.134		Slope	-	
$R^2$	0.999		Irregular	0.00044	
$R_d^2$	0.720		Nature of		1.1
			Irend:	Local Level Mod	aei

 Table 4.4: Turkish Domestic Electricity Demand STSM Estimates and Diagnostics

 Sample 1960-2008

Notes:

-See notes to Table 4.3<sup>34</sup>

-Model includes a level intervention for the year 1971, an irregular for the year 1973 and a level intervention for the year 1975;

-LR Test(a) represent likelihood ratio tests on the same specification after imposing a fixed level and zero slope hyperparameter and Test(b) after imposing a fixed level and fixed slope; both are distributed as  $\chi^2_{(2)}$  and probabilities are given in parenthesis.





The estimated UEDT is the local level model that consists of a stochastic level but no slope and is shown in Figure 4.22, which illustrates that the estimated UEDT decreases and increases over the estimation period. This UEDT would appear to reflect the compulsory electricity cuts introduced by the Turkish governments (primarily in the residential sector) aimed at conserving electricity consumption between 1971 and 1983. An irregular intervention in 1973 and level interventions in 1971 and 1975 were required in order to maintain the normality of residuals and auxiliary residuals. The level interventions appear to

<sup>&</sup>lt;sup>34</sup>For simplicity and to save space the notes given in the previous table are not repeated again.

reflect the impact of cuts on the behaviours of consumers in 1971<sup>35</sup> that were almost reversed in 1975 (probably reflecting the way consumers adjusted their behaviour accordingly).



Figure 4.22: Underlying Electricity Demand Trend of Turkish Residential Sector 1961-2008

The irregular intervention for the year 1973 probably reflects the impact of the electricity cuts that peaked in 1973 by a factor of 37 from 1972 to 1973 and kept increasing slightly after 1973 (Altas et al. 1994) as illustrated in Figure 4.23. Thus in 1973 it appears that desired residential demand was severely constrained by the cuts; hence the need for the irregular intervention. Moreover, given the intervention for 1973 represents a 'pulse effect' it does not affect the electricity consumption permanently, only in 1973 electricity consumption decrease 14% for the year.

<sup>&</sup>lt;sup>35</sup> The electricity cuts that were applied for couple of hours during the day decrease the level of total electricity consumption permanently by 12%.

Figure 4.23: The Compulsory Energy Conservation Measures between 1971 and 1983



Source: Altas et al. (1994)

## 4.9.3 Turkish Aggregate Electricity Demand

After sequentially eliminating variables not statistically significantly different from zero at the 5% level and including interventions in order to maintain the normality of residuals and auxiliary residuals, the preferred estimated equation is given by:

$$e_t = 0.16947y_t - 0.11101p_t + UEDT_t \tag{4.4}$$

where the estimated UEDT<sub>t</sub> is 20.95 at the end of the period, with a slope of 0.0608. The detailed estimation results and the diagnostics tests are given in Table 4.5 and Figure 4.24.

Variables	Estimated	Standard	Prob.					
	Coefficients	Errors						
y <sub>t</sub>	0.16947	0.06162	0.001					
p <sub>t</sub>	-0.11101	0.02384	0.001					
Level Break 1976	0.09233	0.03696	0.004					
Level Break 1979	-0.08495	0.06162	0.009					
Level And Slope Components' of UEDT2008								
Level :	20.9526							
Slope :	0.0608							
Diagnostics								
Residuals		Auxiliary Residuals						
			Irregular	Level	Slope			
Std.Error	0.918	Std.Error	0.999	0.974	0.883			
Normality	0.895	Normality	0.702	0.629	0.394			
Skewness	0.734	Skewness	0.456	0.602	0.694			
Kurtosis	0.744	Kurtosis	0.696	0.418	0.191			
H(14)	0.675							
r(1)	-0.002							
r(7)	0.006							
DW	1.908							
Q(7,5)	4.806							
Hyperparameters			Goodness o	f fit				
Level	0.00004		p.e.v.	0.001				
Slope	0.00003		p.e.v./md <sup>2</sup>	1.120				
			$\mathbf{R}^2$	0.999				
			$R_d^2$	0.655				
Predictive Tests 20		LR TEST	1					
Failure	0.92		Test(a)	72.992	0.000			
Cusum t(4)	0.99		Test(b)	17.336	0.000			
			Nature O	f Trend:	Local Level			

Table 4.5: Turkish Total Electricity Demand STSM Estimates and DiagnosticsSample 1960-2008

Notes:

-See notes to Table 4.3<sup>36</sup>

-Model includes level interventions for 1976 and 1979;

<sup>&</sup>lt;sup>36</sup>For simplicity and to save space the full notes already given in Table 4.3 are not repeated.

-LR Test(a) represent likelihood ratio tests on the same specification after imposing a zero level and slope hyperparameter and Test(b) after imposing a zero slope hyperparameter distributed as  $\chi^2_{(1)}$  and  $\chi^2_{(2)}$  probabilities are given in parenthesis.



Figure 4.24: STAMP Predictive Tests Graphics 2001-2008

The preferred model passes a series of diagnostic tests including the normality test for both the residuals and the auxiliary residuals, as illustrated in Table 4.5 and the prediction tests in for 2001 thru 2008 (illustrated in Figure 4.24) suggesting that the model is stable and predicts well. Furthermore, the preferred model does not include any dynamic terms suggesting the short run and long run income and price elasticities are 0.17 and -0.11 respectively. Furthermore, the preferred equation consists of two level interventions for 1976 and 1979 in order to maintain the normality of residuals and auxiliary residuals. However, from economic point of view, these can be explained as follows:

- the level intervention for 1976 probably reflects the unusual 9% increase in Turkish GDP and 12% decrease in real average Turkish electricity prices in 1976. The coincidence of both of these unusual circumstances brought about an increase of 20% in aggregate electricity consumption which would not be captured by the estimated income and price elasticities (being outside the usual 'norm');
- the level intervention for 1979 probably reflects the serious economic crisis that Turkey experienced resulting from the world oil price hike. This caused a large decrease in GDP and led to a military coup, and therefore the estimated elasticities for total electricity demand would be unlikely to adequately pick up this effect;

The estimated UEDT from this procedure is given by the estimated hyperparameters (Table 4.5) and is illustrated in Figure 4.25 and Figure 4.26. It can be seen that the estimated stochastic trend is increasing with a break in 1976 and 1979 over the estimation period.



Figure 4.25: Underlying Electricity Demand Trend of Turkey 1960-2006



Figure 4.26: Slope of UEDT for Turkish Total Electricity 1960-2008

Given the preferred equations for industrial, residential, and aggregate electricity demand with the estimated UEDTs has been uncovered; they are now used to construct future scenarios for Turkish electricity demand, which is explained in the next section.

## 4.10 Forecast Scenarios and Assumptions

As described in the methodology section three scenarios are implemented namely reference, high case, and low case. Although, where data (and 'intelligence') are available for 2009 (such as the nominal industrial electricity price)<sup>37</sup> these are used in all scenarios. This therefore produces the forecast scenarios up to 2020 for aggregate, residential and industrial electricity demand based upon the estimated equations discussed in the previous section as

<sup>&</sup>lt;sup>37</sup>In 2009, Turkish industrial electricity prices increased by 18% in nominal terms. At the time of writing, the required deflator (the Consumer Price Index from World Bank) is not available, although it is known that Turkish inflation was around 6.5% in 2009; hence based on this the real industrial electricity price is assumed to have increased by 11.5% in 2009 for all three scenarios. In 2009 the average price of electricity (weighted average of residential and industrial prices) prices increased by 18.5% in nominal terms. Hence, based on this, average electricity price is assumed to have increased by 12% in 2009 for all three scenarios. In 2009 for all three scenarios. In 2009 Turkish residential electricity prices increase d by 19.3% in nominal terms; hence, based on this, the real residential electricity price is assumed to have increased by 12.8% in 2009 for all three scenarios.

well as the 'residual' sector as described in the methodology chapter. The detailed information about the scenario assumptions follows.

• *In the 'reference' scenario*, it is assumed that real industrial, residential, and average electricity prices will increase 1% after 2009 annually (Figure 4.27). The Turkish Parliament ratified the Kyoto protocol and it is likely that the government will introduce measures such as carbon taxes and incentives to encourage renewables, which are likely to contribute to an increase in end use prices of electricity. However, the improving efficiency in electricity generation is likely to reduce the cost and hence, counteract the price increase to some extent. Consequently, it is assumed that real industrial, residential, and average electricity prices will increase 1% annually.

Figure 4.27: Reference Scenario for Residential, Industrial, and Aggregate Electricity Prices 2000-2020



The increase of industrial value added (output) is expected to be 1.5% in 2009, and 2% for 2010 and 2012 because of the global crises. It is further assumed that there would then follow a recovery period with annual increases of 2.5%, 3% and 3.5% for 2013 to 2015 and a 4% per annum thereafter (Figure 4.28). The increase of total household final consumption expenditure (expenditure) is assumed to be 1% in 2009 because of the global crises followed by a recovery period with an annual expenditure increasing by 2% per year in 2010 thru 2012, 3% per year in 2013 thru 2016 and 3.5% per year thereafter (Figure 4.28). The increase of GDP is assumed to be 1% in 2009 due to the global economic slowdown, followed by a recovery period with GDP increasing by 1.5% per annum in 2010 thru 2012, 2% per annum in 2013 thru 2016 and 2.5% per annum thereafter (Figure 4.28).



Figure 4.28: Reference Scenario for Expenditure, Output, and GDP 2000-2020

Given that the adjusted slope of the UEDT generally diminishes over the estimation period for industrial electricity demand, it is assumed that this will continue into the future, hence it is assumed that the adjusted slope decreases by 0.0011 each year from the estimated value of 0.04793 in the last period of the estimation (Figure 4.29).<sup>38</sup> It implicitly assumes that the annual change in exogenous 'energy using' behaviour for Turkish industrial electricity demand at the end of the estimation period will continue to increase but at a decreasing rate throughout the forecast period. The residential electricity demand is a local level model with no estimated slope, this suggests that the UEDT for residential electricity demand is fixed over the future at the estimated level in 2008. However, given that the estimated UEDT generally rises its average change over the estimation period is utilized for the slope of the UEDT after 2008; it is therefore assumed that the slope of the UEDT is 0.003 for the 'reference' scenario (Figure 4.29).<sup>39</sup> This assumption suggests that the general electricity using behaviour of the Turkish residential sector by the estimated UEDT will continue into the future. Additionally, for aggregate electricity demand it is assumed that the observed generally diminishing slope of the UEDT over the estimation period continues to decrease by 0.00140 each year (Figure 4.29).

• In the 'low' case scenario, it is assumed that the reduction in the costs of power production due to increased efficiency in electricity generation are relatively small; hence these savings are outweighed by the rise in prices brought about from the

<sup>&</sup>lt;sup>38</sup>The figure of -0.0011 being the average change in the estimated adjusted slope over the estimation period.

<sup>&</sup>lt;sup>39</sup>As opposed to the zero suggested by the estimation results.

<sup>&</sup>lt;sup>40</sup> The figure -0.001 is therefore the average change in the estimated slope over the estimation period.

measures introduced in order to comply with the Kyoto Protocol. The assumed rise in real electricity prices is therefore 2% per annum after 2009 (Figure 4.30).



Figure 4.29: Reference Scenario for Residential, Industrial, and Aggregate UEDTs 2000-2020

For industrial value added it is assumed that it will decrease 3% in 2009 and increase 0.5% in 2010 and 2011 because of the global economic crises and increase by 1% in 2012, 1.5% in 2013, 1.5% in 2014, 2% per year in 2015 and 2016 and 2.5% thereafter until 2020 (Figure 4.31). The annual increase of total household final expenditure is assumed to decrease 0.5% in 2009, increase 1.5% per year in 2010 thru 2012 because of the global economic crises, but then increase 2% per year in 2013 thru 2016, and 2.5% per year thereafter (Figure 4.31). GDP is assumed to increase by only 0.5% in 2009 due to the global economic crisis and by only 1% per annum in 2010 thru 2012

but then recover a little and increase 1.5% per annum in 2013 thru 2016 and 2% per annum thereafter (Figure 4.31).

0.375 0.300 0.225 0.150 0.005 2000 2005 200 0.205 1 Industrial Electricity Prices 1 Indus

Figure 4.30: Low Case Scenario for Residential, Industrial, and Aggregate Electricity Prices 2000-2020

Figure 4.31: Low Case Scenario for Expenditure, Output, and GDP 2000-2020



Because of improved efficiency and faster transformation of the Turkish industrial sector, it is assumed that the adjusted slope of the UEDT decreases by 0.0033 each year (Figure 4.32).<sup>41</sup> It is thus assumed that the exogenous underlying 'energy using' behaviour for Turkish industrial electricity demand will continue throughout the forecast period, but is offset by some improvement in efficiency. Furthermore, for the UEDT a shock effect is included for 2009 with the same magnitude as that estimated by the irregular intervention for 1991 in order to take into account a shock that might have occurred because of the global crisis. In the 'low' case scenario, an energy using UEDT for residential electricity demand with a decreasing slope of 0.001 is introduced from 2009 (Figure 4.32). This assumption express the view that energy using UEDT will continue but at a slower pace than the 'reference' scenario because of an increase in energy efficiency. Furthermore, for aggregate electricity demand, it is assumed that the slope of the UEDT decreases by 0.003 per annum, suggesting that the 'energy using' trend for electricity will continue, but at a slower pace (Figure 4.32).

<sup>&</sup>lt;sup>41</sup> The figure of -0.0033 is obtained by assuming that over the forecast period the adjusted slope declines by an additional factor of two of the average change over the estimation period.



Figure 4.32: Low Case Scenario for Residential, Industrial, and Aggregate UEDTs 2000-2020

• *In the 'high' case scenario*, the real electricity prices is assumed to increase 0.5% per year over the period 2010 to 2020 period (Figure 4.33). Even though the Kyoto protocol is ratified by the Turkish parliament, and is likely to result in new carbon taxes, in this scenario it is assumed that the increasing efficiency standards in electricity generation will decrease the cost of power production. Therefore, it is assumed that these two factors balance each other out and the electricity price will increase only 0.5% per year in real terms.



Figure 4.33: High Case Scenario for Residential, Industrial, and Aggregate Prices 2000-2020

Furthermore, it is assumed that industrial value added will increase by 3% each year in 2009 and 2010 and 2.5% in 2011, because of the global economic crisis. It is further assumed that this is followed by a recovery period with an increase of 3% in 2012, 3.5% per year in 2013 4.5% per year in 2014 and 2015, 5% per year in 2016 and 2017 and slightly higher at 6% per year thereafter (Figure 4.34). Moreover, it is assumed that total household total final consumption expenditure will increase by 1.5% in 2009 and 2.5% per year in 2010 thru 2012, followed by a 3.5% per year increase in 2013 thru 2016. It is further assumed that the annual increase of expenditure will be 4% per year thereafter (Figure 4.34). In addition, it is assumed that GDP will still see an increase of 1.5% in 2009 despite the global slowdown, followed by a good recovery increasing by 2% per annum in 2010 thru 2012, followed by 2.5% per annum in 2013 thru 2016, and 3% per annum thereafter to 2020 (Figure 4.34).



Figure 4.34: High Case Scenario for GDP, Output, and Expenditure 2000-2020

For the UEDT of industrial electricity demand, it is assumed that the slope will increase by 0.0011 each year (Figure 4.35);<sup>42</sup> implicitly assuming that the exogenous 'energy using' behaviour for industrial electricity demand increases at an even greater pace. Additionally, for residential sector contrary to the 'low' case scenario, an energy using UEDT is assumed with a slope of 0.007 from 2009 (Figure 4.35), assuming that the exogenous 'energy using' behaviour for the residential electricity demand increases at an even greater pace. Finally, for the aggregate electricity demand it is assumed that the slope of the UEDT will increase 0.001 per annum from 2009 to 2020

<sup>&</sup>lt;sup>42</sup>The figure of +0.0011 mirrors that assumed for the 'low' scenario.

(Figure 4.35), suggesting that the 'energy using' trend for electricity will continue, but at a faster pace.



Figure 4.35: High Case Scenario for Residential, Industrial, and Aggregate UEDTs 2000-2020

In order to summarise together the above assumptions for the 'reference', 'low', and 'high' case for each variables are given in Figure 4.36.







# C: Reference, Low, and High Case Scenarios for Residential, Industrial, and Aggregate

## **4.11 Forecast Results:**

# 4.11.1 Turkish Industrial Electricity Demand

Based on the estimated equation presented in the previous section and applying the scenario assumptions discussed above, Turkish industrial electricity demand is predicted to be 97, 121, and 148 TWh by 2020 according to the 'low', 'reference' and 'high' case scenarios respectively. The paths to 2020 for the three scenarios are illustrated in Figure 4.37.



**Figure 4.37: Turkey's Industrial Electricity Demand Forecast over the period 2009-2020** 

# 4.11.2 Turkish Residential Electricity Demand

Given the above assumptions, it is predicted that future residential electricity consumption in 2020 will be 48 TWh, 64 TWh and 80 TWh in the, 'low', 'reference' and 'high' case scenarios respectively. The annual residential electricity consumption forecast scenarios over the period 2009-2020 are given in Figure 4.38.



**Figure 4.38: Turkey's Residential Electricity Demand Forecast over the period 2009-2020** 

## 4.11.3 Turkish Aggregate Electricity Demand

Given the above assumptions, future Turkish aggregate electricity consumption is predicted to be 259, 310, and 368 TWh in the 'low', 'reference' and 'high' case scenarios respectively as illustrated in Figure 4.39.



**Figure 4.39: Aggregate Turkish Electricity Demand Forecast over the period 2009-2020** 

#### 4.11.4 Turkish 'Residual' Electricity Demand

Using the procedure outlined in Chapter 3 the projections for aggregate, residential, and industrial electricity demand are used to construct the forecast scenarios for Turkish 'residual' sectors. From this the 'residual' sector's electricity demand is predicted to be 115, 125 and 140 TWh in the 'low', 'reference' and 'high' case scenarios respectively.

### **4.12** Conclusions and Further Discussion

This chapter estimates and forecast Turkish residential, industrial, aggregate, and 'residual' electricity demand. Given its importance, the focus of this chapter is to identify and quantify the main drivers of Turkish electricity demand for different sectors. This is undertaken to assist Turkish policy makers and planners when deciding upon future investment decisions for the Turkish electricity sector. Hence, an understanding of the key drivers of Turkish
electricity demand and their impact are vital for policy implementation and evaluation. Therefore, given the results here not only should the estimated price and income elasticities be incorporated in any policy analysis but also the estimated UEDT to hopefully avoid some of the mistakes made in the past.

Ediger and Tatlidil (2002), Keleş (2005), Ediger and Akar (2007), Hamzacebi (2007), Akay and Atak (2006) argue that previous electricity demand forecasts for Turkey were mostly unsuccessful. A possible reason for this might be that the UEDT, structural changes and breaks in energy demand behaviour, and the impact of previous shocks were not adequately taken into account in the models underpinning the forecasts, and arguably, they should be in order to make useful and usable forecasts. Since the STSM enables the UEDT to be estimated it provides valuable information about the structural change and breaks in electricity consumption behaviour and adjustment process related to shocks to the system. It is therefore concluded that the STSM approach is the right solution for determining forecasts of future energy demand.

As stated above this chapter estimates the Turkish residential, industrial, aggregate and 'residual' electricity demand functions by using STSM approach which was not done before, as far as known. Therefore, the findings of this chapter can be summarized as follows:

*For residential electricity demand:* it is found that the estimated household total final expenditure elasticity is 0.38 in the short run and 1.57 in long run. Additionally the short run and long run price elasticity is -0.09 and -0.38 respectively. Furthermore, this chapter has uncovered the UEDT for the Turkish residential sector, which is highly stochastic with increasing and decreasing periods.

The trend in Turkish residential electricity consumption was generally diminishing between 1971 and 1983 (except for 1974, 1975, 1976, and 1981) and, as discussed above, probably reflects the compulsory conservation measurements (in addition to the impact in 1973 identified by the irregular intervention) that were adopted by the government between 1971 and 1983 and identified by the STSM. This arguably illustrates the power of this approach in distinguishing the structural changes of demand behaviour. In addition, after the end of these compulsory conservation measurements starting from 1982, the UEDT follows a generally increasing trend until 1996 and follows a stochastic movement afterwards until the end of estimation period.

The only previous study focusing on estimating Turkish residential electricity demand function Halicioglu (2007), found estimated short run and the long run price elasticities of -0.33 and -0.52 respectively. Although the estimated short run price elasticity is somewhat different to the -0.09 obtained here, the long run estimate is similar to the estimated -0.38 found here. This is probably due to firstly, the different real price variable used and secondly the inclusion of the UEDT in this study. Arguably, the more relevant price variable and the inclusion of the UEDT in this study render it more appropriate and therefore more reliable. Additionally, Halicioglu (2007) found the estimated short run and long run income elasticities to be 0.44 and 0.70 respectively. Although the estimated short run expenditure elasticity of 0.38 found here is similar to that of the income elasticity in Halicioglu (2007), the estimated long run expenditure elasticity of 1.57 differs considerably. These differences are probably due to first, the different activity variables used and second, as with price, the inclusion of the UEDT in this study. It is believed that the expenditure variable used for economic activity here is more appropriate for residential electricity demand.

Given the analysis undertaken, it is expected under the different forecast assumptions (Figure 4.41) that Turkish residential electricity consumption will be between 48 and 80 TWh by the year 2020. There is only one previous forecast study Hamzacebi (2007) which predicted that the residential electricity consumption would be 257 TWh in 2020, which is noticeably greater than even the high case scenario of this study. This forecast is arguably highly unlikely and unreasonable. Hamzacebi (2007) does not investigate the relation between economic activity and residential electricity consumption but as was explained earlier, the electricity demand highly affected by economic activity. Thus, any forecast that ignores this effect will arguably lead to a misleading outcome.

*For industrial electricity demand:* it is found that industrial value added (output) elasticity is 0.15 and the estimated price elasticity is -0.16. Furthermore, the UEDT for the Turkish industrial sector is uncovered, showing that, *ceteris paribus*, although electricity demand has been increasing, the underlying rate of increase appears to be diminishing with a significant structural change in 1981. This might well reflect the implementation of the first planned energy conservation activities by the General Directorate of Electrical Power Resources Survey Administration-EIE (Hepbasli and Ozalp, 2003) and illustrates once again the power of STSM in identifying structural changes.

Because of the recent global economic crisis and the export-oriented nature of the Turkish industrial sector a similar impact to that observed in 1991 might be observed again. Although the Turkish economy has experienced several economic crises, it is expected that the effect of the current global economic crisis might have an important impact on future industrial electricity demand at least in the short to medium term; hence, it is incorporated in the 'low' (Figure 4.40) industrial electricity demand forecast but not the 'reference' and 'high'

scenarios. Overall, therefore, based upon the different forecast assumptions, Turkish industrial electricity demand is predicted to be between 90 and 106 TWh in 2015 and between 97 and 148 TWh in 2020 (Figure 4.40). This is somewhat less than the previous forecasts for Turkish industrial electricity demand; Akay and Atak (2006) suggested that demand would be 140.4 TWh in 2015 and Hamzacebi (2007) suggested demand would be 219.2 TWh in 2020 – both of which are somewhat higher than the high case scenario of this study. The difference in forecasts, it is argued, being primarily due to these other studies neglecting the relationship between economic variables, underlying trend, and electricity consumption.<sup>43</sup>

As far as known, there are no other previous studies that investigate the output elasticity and industrial electricity price elasticity. Therefore, this chapter fills a gap in the literature in terms of identifying the relationship between the economic activity, industrial electricity prices, and industrial electricity consumption for Turkey.

*For aggregate electricity demand:* it is found that the estimated income and price elasticities are 0.17 and -0.11 respectively. Furthermore, the UEDT for the aggregate electricity consumption is estimated and is found to be generally upward sloping (energy using) but at a generally decreasing rate. The estimated income elasticity being somewhat smaller than those obtained by Bakırtas et al. (2000) and Erdogdu (2007) which are 3.13 and 0.41 respectively. One of the reasons for this might be that previous studies do not take into account UEDT. As the UEDT for Turkish aggregate electricity demand is upward sloping and the GDP generally has been increasing over the forecast period. Therefore not taking into account UEDT might lead over estimated income elasticity. On the other hand the estimated price elasticity is being

<sup>&</sup>lt;sup>43</sup> Although also probably reflects the impact of the recession in the late 2000s.

smaller than (in absolute terms) than that obtained by Erdoğdu (2007). This might be again because of ignoring the UEDT coupled with the prices that have generally been declining (although there were some price hikes in mid 1980s and 2008) over the estimation period.

These estimates are used to project future Turkish aggregate electricity. From this, it is expected that Turkish aggregate electricity consumption will be between 259 and 368 TWh in 2020 (Figure 4.40). These forecast figures being noticeably smaller than the previous forecasts (except by Kavaklioglu et al., 2009).

*For 'residual' electricity demand:* the results suggest that the 'residual' sector electricity demand will increase faster than the industrial and residential electricity demand. One explanation being the future Turkish economy becomes more service and commercial sector oriented. As a result, Turkish 'residual' sector's electricity demand is predicted to be between 125 and 140 TWh in 2020.

The forecast results that are generated for aggregate, residential, industrial, and 'residual' sectors by utilizing 'reference', 'low' case, and 'high' case scenarios are summarised in Figures 4.40). As stated above the forecast outcome of this chapter will hopefully assist Turkish policy maker and planners to avoid some of the mistakes of the past, and help them to implement sustainable and economic policy options for Turkey.

As stated above, the previous Turkish electricity demand forecasts were mostly unsuccessful and predicted the future electricity demand more than the actual consumption. It is argued that these 'over forecasts' are due mainly to the lack of investigation into the relation between electricity consumption, economic activity, real electricity prices and a UEDT – since, as

explained earlier, electricity demand is a derived demand and highly affected by these important drivers. Thus, any forecast that ignores these effects will arguably lead to a misleading outcome that is compounded by the inability of the Turkish authorities in establishing credible and transparent assumptions to drive the forecast. This study therefore addresses some of the shortcomings by introducing consistent assumptions as illustrated above.

On the other hand, the Kyoto protocol was ratified by the Turkish Parliament in February 2009, which is leading to the introduction of legally compulsory commitments for the reduction of greenhouse gases. Although the Copenhagen Summit in 2009 and the Cancun Summit in 2010 did not result in any legal obligations it is reasonable to assume that eventually there will be a legally binding agreement between nations in order to reduce GHG emissions and that this will lead to a change in Turkish energy policy; which might well include  $CO_2$  taxes and energy efficiency regulations. If this is the case then the new environment will require a thorough evaluation of electricity demand relationships like those estimated here and will be an important part of the evaluation of possible new policy measures.

To this end, sensible and reliable energy demand forecasts assist in financing and developing the necessary measures for the sustainable economic growth of Turkey. Furthermore, one of the most important issues of 21<sup>st</sup> century is energy security. Arguably, the policies and strategies cannot be neither assessed nor constructed without sound demand forecasts. Therefore, it is suggested, that the methodology and estimated equation from this research should be taken into account when implementing future Turkish energy policies for energy security, climate change etc.



## Figure 4.40: Summary of Forecast Results

# **CHAPTER 5: OECD-Europe Natural Gas Demand**\*

### **5.1 Introduction**

This chapter investigates the relationship between OECD-Europe natural gas demand and its main determinants by applying the STSM to annual data over the period 1978 to 2009. This is, as far as known, the first study that allows for a stochastic UEDT when estimating an OECD-Europe natural gas demand function. After estimating the OECD-Europe natural gas demand function by the STSM it is used to highlight the relative importance of the different drivers and to produce future scenarios. Given the importance of reliable natural gas forecasts for assessing European energy security, forecasts are produced that should be useful for European policy makers, natural gas producing companies and financial institutions.

Energy security has become one of the primary economic and political objectives of both developed and developing countries over the last few decades (Yergin, 2006; IEA, 2010b). From a theoretical viewpoint, liberalisation of fuel markets is seen by some as an adequate way to deliver both energy security and an efficient allocation of scarce resources. Nonetheless, as identified by Bilgin (2009) and Helen (2010), structural and institutional conditions often impede efficiency of fuel markets. Market agents (including states, other political units, and energy supplier companies), act strategically by evaluating both demand and supply side competition in the short and the long run. In this context, being able to

The results from this chapter have been published in:

• 'What Drives Natural Gas Consumption in Europe? Analysis and Projections', *Surrey Energy Economics Discussion papers (SEEDS)*, *forthcoming* (with O. Dilaver-Kalkan and L. C. Hunt).

<sup>\*</sup>Earlier preliminary work for this chapter was presented at the following:

<sup>• 11&</sup>lt;sup>th</sup>International Association for Energy Economics (IAEE) European Conference 'Energy Economy, Policies and Supply Security: Surviving the Global Economic Crises.', Vilnius, Lithuania, 25-28 August 2010; and

<sup>• 8&</sup>lt;sup>th</sup> British Institute of Energy Economics (BIEE) Academic Conference 'Energy in a Low Carbon Economy: New Roles for Governments and Markets', Oxford, UK, 22-23 September 2010.

understand the determinants of natural gas demand and be able to make reliable projections have become ever more important.

Given this, an understanding of the key drivers of natural gas demand and the production of reliable scenarios of future demand are an essential element when considering European gas security. This chapter therefore addresses this need by analysing OECD-Europe<sup>44</sup> natural gas consumption, which in 2009 accounted for about 17% of total world natural gas consumption (IEA, 2010c).

## 5.2 Analysis of the Energy Situation in OECD Europe

OECD-Europe is a net energy importer and it is expected in the future that these imports will increase due to the expected decline in the indigenous production (Honore, 2006; Remme et al., 2008). In 2009 OECD-Europe's primary energy demand reached 1740549 ktoe where only 1033439 (59%) ktoe was met by domestic production and the rest met by imports including coal, natural gas, and petroleum (Table 5.1) (IEA, 2011). Moreover, OECD-Europe imported 43% of its coal, 67% of its petroleum and 48% of its natural gas demand (Figure 5.1) (IEA, 2011). This import dependency, especially on natural gas and petroleum, arouses fears about future energy security (Honore, 2006; Remme et al., 2008).

<sup>&</sup>lt;sup>44</sup> OECD-Europe consists of the EU member and candidate countries, hence the study covers the natural gas consumption of Austria, Belgium, the Czech Republic, Denmark, Finland, France, Germany, Greece, Hungary, Iceland, Ireland, Italy, Luxembourg, the Netherlands, Norway, Poland, Portugal, the Slovak Republic, Spain, Sweden, Switzerland, Turkey and the United Kingdom.



Figure 5.1: OECD-Europe Production, Net Imports, and Primary Demand of Imported Energy Sources 2009 (ktoe)

Source: IEA, 2011

OECD-Europe's total primary energy demand was 1740549 ktoe in 2009. 452867 ktoe (26%) of this demand was used for transfers and transformation, 84888 (5%) ktoe part was used by energy industries, 22576 (1%) ktoe lost during the distribution process and 1180220 (68%) ktoe was used by end users (Figure 5.2) (IEA, 2011).

OECD-Europe's total final energy consumption was 1180220 ktoe in 2009; of which 258802 ktoe (22%) was consumed by the industrial sector, 336929 ktoe (29%) by the transport sector, 295341 ktoe (25%) by the residential sector, and 181839 (15%) ktoe by the other sector (Figure 5.3) (IAE, 2011).

Source	Coal and Coal Products	Peat	Crude, NGL, Feed Stocks	Petroleum Products	Natural Gas	Nuclear	Hydro	Geothermal	Solar Wind Other	Bio fuels and Waste	Electricity	Total
Indigenous Production	171375	3060	211680	0	235288	230449	44274	10950	14512	111851	0	1033439
Imports	142998	163	600419	323058	365875	0	0	0	0	6858	26733	1466103
Exports	-23635	-15	- 155633	- 283584	- 159208	0	0	0	0	-1983	-25709	-649766
Int. Marine Bunkers	0	0	0	-46999	0	0	0	0	0	0	0	-46999
Int. Aviation Bunkers	0	0	0	-44797	0	0	0	0	0	0	0	-44797
Stock Changes	-10736	-190	3314	47	-4707	0	0	0	0	-45	0	-12316
Total Primary Energy Supply	280002	3018	659781	-52276	437248	230449	44274	10950	14512	116681	1024	1745663
Statistical Difference	391	-45	3505	-6479	-2410	0	0	-9	0	-71	4	-5113
Primary Demand	280393	2973	663285	-58755	434839	230449	44274	10942	14512	116610	1028	1740549
Transfers	0	0	7439	-5138	0	0	0	0	0	0	0	2301
Transformation	-225941	-2582	-666380	634531	-151377	-230449	-44274	-8045	-12859	-45178	297388	-455168
Energy Industry Use	-5434	-35	0	-37424	-17207	0	0	0	-129	-194	-24465	-84888
Losses	-735	0	0	-6	-2927	0	0	-142	0	-33	-18734	-22576
Total Final Consumption	48283	355	4345	533207	263328	0	0	2755	1524	71205	255218	1180220
Non Energy Use	1113	0	2387	92779	11030	0	0	0	0	0	0	107307
Energy Consumption by Sector	47171	355	1959	440428	252298	0	0	2755	1524	71205	255218	1072912
Industry	28233	209	1959	36113	76057	0	0	29	3	22178	94021	258802
Transport	6	0	0	316542	2174	0	0	0	0	11876	6332	336929
Residential	15100	129	0	46940	118484	0	0	2192	1317	33470	77710	295341
Other Final Consumers	3832	17	0	40833	55584	0	0	534	204	3681	77155	181839

Source: IEA, 2011



Figure 5.2: Allocation of Primary Demand in OECD-Europe 2009

Source: IEA, 2011



Figure 5.3: OECD-Europe Energy Consumption by Sector 2009

Source: IEA, 2011

OECD-Europe's total final energy consumption of 1180220 in 2009 consisted of 48283 ktoe (4%) coal and coal products, 355 ktoe (0.03%) peat, 4345 ktoe (0.4%) petroleum, 533207 ktoe (45%) petroleum products, 263328 ktoe (22%) natural gas, 2755 ktoe (0.02%) geothermal, 1524 ktoe (0.01%) solar & wind and other renewable, 71205 ktoe (6%) combustible renewables and waste and 255218 ktoe (22%) electricity (Figure 5.4) (IAE, 2011).



Figure 5.4: OECD-Europe Energy Consumption by Fuel 2009

The fuel mix of the sectoral energy consumptions OECD-Europe varies somewhat. The industrial sector consumed 258802 ktoe energy of which, 8233 ktoe (11%) was coal and coal products, 209 ktoe (0,08%) was peat, 1959 ktoe (8%) was petroleum, 36113 ktoe (14%) was petroleum products, 76057 ktoe (29%) was natural gas, 29 ktoe (0.01%) was geothermal, 3 ktoe (0.001%) was solar & wind and other renewable sources, 22178 ktoe (9%) was

Source: IEA, 2011

combustible renewables and waste, and 94021 ktoe (36%) was electricity (Figure 5.5) (IEA, 2011).



Figure 5.5: OECD-Europe Industrial Energy Consumption 2009

The OECD-Europe transport sector consumed 336929 ktoe of energy in 2009. This was made up of 6 ktoe (0.002%) of coal and coal products, 316542 ktoe (94%) of petroleum products 2174 ktoe (1%) of natural gas, 11876 ktoe (3%) of combustible renewable and waste, and 6332 ktoe (2%) of electricity (Figure 5.6) (IEA, 2011).

OECD-Europe's residential energy consumption consumed 295341 ktoe in 2009. This consisted of 115100 ktoe (5%) of coal and coal products, 129 ktoe (0.04%) of peat, 46940 ktoe (16%) of petroleum products, 118484 ktoe (40%) of natural gas, 2192 ktoe (1%) of geothermal, 1317 ktoe (1%) of solar & wind and other renewable sources, 33470 ktoe (11%)

Source: IEA, 2011

of combustible renewables and waste, and 77710 ktoe (26%) of electricity (Figure 5.7) (IEA, 2011).



Figure 5.6: OECD-Europe Transport Sector Energy Consumption 2009

Source: IEA, 2011



Figure 5.7: OECD-Europe Residential Energy Consumption 2009

Source: IEA, 2011

OECD-Europe's other final consumer's energy consumption was 181839 ktoe in 2009, made up of 3832 ktoe (2%) of coal and coal products, 17 ktoe (0.009%) of peat, 40833 ktoe (23%) of petroleum products, 55584 ktoe (31%) of natural gas, 534 ktoe (0.3%) of geothermal, 204 ktoe (0.1%) of solar & wind and other renewable sources, 3681 ktoe (2%) of combustible renewables and waste, and 77155 ktoe (42%) of electricity (Figure 5.8) (IEA, 2011).



Figure 5.8: OECD-Europe Other Sector Energy Consumption 2009

In 1971 OECD-Europe total indigenous primary energy production was 608655 ktoe of which, 423263 ktoe (70%) was coal and coal products, 1527 ktoe (0.3%) was peat, 22616 ktoe (4%) was crude oil, 88160 ktoe (15%) was natural gas, 13258 ktoe (2%) was nuclear power, 27825 ktoe (5%) was hydro power, 2618 ktoe (0.4%) was geothermal, 43 ktoe (0.007%) was solar & wind and other renewable, and 29344 ktoe (5%) was combustible renewable and waste. In general, OECD-Europe's economy was highly dependent on coal and coal products by having a share of 70% of total primary energy production (Figure 5.9) (IAE, 2010).

Source: IEA, 2011



Figure 5.9: OECD-Europe Indigenous Energy Production 1971 – 2009

Source: IEA, 2011

However the coal and coal product production peaked in 1982 with 430244 ktoe and began to decline thereafter, replaced mainly with nuclear, natural gas and petroleum. In 2009; OECD-Europe indigenous production reached 1,033,439 ktoe; which consisted of 171375 ktoe (17%) of coal and coal products, 3060 ktoe (0.3%) of peat, 211680 ktoe of crude oil, 235288 ktoe (21%) of natural gas, 230449 ktoe (22%) of nuclear power, 44274 ktoe (4%) of hydro power, 10950 ktoe (1%) of geothermal, 14512 ktoe (1%) of solar & wind and other renewable, and 111,851 ktoe (11%) of combustible renewable and waste (Figure 5.9) (IAE, 2011). The primary energy resources imported into OECD-Europe are petroleum, natural gas, and coal. In 1971, the share of coal was 3%, natural gas 0.1% and petroleum 96% of all net imports of primary energy resources. However, in 2009, the share of coal had increased to 15%, natural gas to 27% and the share of petroleum had decreased to 58% (Figure 5.10) (IAE, 2011).



Figure 5.10: OECD-Europe Net Energy Imports 1971 – 2009

Source: IEA, 2011

In 1971, OECD Europe total final energy consumption was 919,171 ktoe. This consisted of 203618 ktoe (23%) of coal and coal products, 727 ktoe (under 1%) of peat 507959 ktoe (56%) of oil products, 61980 ktoe (9%) natural gas, 306 ktoe (under 1%) of geothermal, 26820 ktoe (3%) combustible renewable, and 99819 ktoe (11%) electricity (IAE, 2011). However during the period 1971 to 2008 the structure of final consumption has changed somewhat so that in 2009, total final energy consumption was 1,226,984 ktoe; consisting of 48,283 ktoe (4%) of coal and coal products, 355 ktoe (under 1%) of peat, 4345 ktoe (under 1%) of petroleum, 533,207 ktoe (44%) of oil products, 263,328 ktoe (21%) natural gas, 2755 ktoe (under 1%) of geothermal, 1524 ktoe (under 1%) of solar & wind and other renewables, 71205 ktoe (6%) of combustible renewable and waste, and 255219 ktoe (21%) of electricity (Figure 5.11) (IAE, 2011).



Figure 5.11: OECD-Europe Final Consumption by Fuel 1971 – 2009

Source: IEA, 2011

OECD-Europe energy intensity decreased over the period 1971 to 2009. In 1971; in order to create 1000\$ (2000 constant PPP) of GDP, 0.23 toe was required. In 2009, this requirement has declined to 0.14 toe in order to create same amount of income (Figure 5.12) (IAE, 2011).



Figure 5.12: OECD-Europe Energy Intensity 1971 – 2009

Source: IEA, 2011

On the other hand, OECD-Europe household energy consumption increased over the period 1971 to 2009, reflecting the more energy dependent life styles. In 1971, a household consumed an average of 2.77 toe where in 2008 this figure had increase to 3.18 toe (Figure 5.13) (IAE, 2011).



Figure 5.13: OECD-Europe Energy Consumption per Person 1971 – 2009

Source: IEA, 2011

### 5.3 Overview of OECD-Europe Natural Gas Market

Natural gas is an important resource fuel for Europe and it is expected to remain important in the next few decades (Holz et al., 2006; EIA, 2009 and IEA, 2010b) due to increasing environmental concerns and related policies. In particular, the increasing use of natural gas in electricity generation is expected to continue given the lower carbon intensity of natural gas relative to other fossil fuels and its relative fuel efficiency (EIA, 2009 and IEA, 2010d). At the same time, indigenous natural gas production in Europe is declining; hence, Europe's natural gas import dependence is expected to increase (Honore, 2006 and Remme et al., 2008) and accurate forecasts of future natural gas demand are necessary to assess the scale of this dependency.

It is important to put the expected growth in OECD-Europe's natural gas demand and import dependency in a global perspective for appreciating their impact on OECD-Europe's energy security. Due to the abovementioned advantages, EIA (2009) expects that the power sector will consume 35% of the world's total natural gas consumption by 2030 compared to 32% in 2006. Although Europe's neighbouring regions have substantial reserves and resources (Hafner et al. 2009), there is also increasing demand for natural gas in developing countries, in particular China. Increasing demand for natural gas puts pressure on Chinese officials to actively penetrate the Caspian Region, develop infrastructure and contractual solutions and import natural gas (Hall and Grant, 2009; Remme et al., 2008). In recent years, China has developed effective policy tools for both oil and natural gas and provided package solutions covering finance, field development, and pipeline construction. As a result, China has gained direct access to Caspian energy sources and secured long-term production sharing agreements. There is, therefore, also global competition for accessing energy resources and this competition puts pressure on OECD-Europe to develop necessary measures to secure natural gas for its future needs. In this respect, identification of future natural gas needs is a vital and urgent issue for policy makers in OECD-Europe (Christoffersen, 1998 and Bilgin 2009).

While the demand for natural gas is expected to rise globally, the resources are not geographically distributed equally. The largest natural gas reserves are located in the Russian Federation (48,000 billion cubic metres, bcm), Iran (28,000 bcm) and Qatar (26,000 bcm). In 2004, these three countries account for 58% of proven global natural gas reserves (BP, 2005). Furthermore, the Gas Exporting Countries Forum (GECF), which was created in 2001, has become another concern for net importers of natural gas, since in future the GECF might act as a cartel to gain control over the gas supplies and prices (Stern, 2002).

Hence, on the demand side, the global competition for natural gas is getting increasingly fierce and on the supply side, the natural gas resources are concentrated in a limited number of countries that may establish a powerful cartel. Not surprisingly, these developments create anxiety across an import dependent Europe (see, for example, EC, 2009). Volatility in the natural gas prices or supply can have devastating effects on European economies.

According to Bilgin (2009), Europe could possibly diversify its natural gas suppliers by including Middle Eastern and Caspian sources (such as Iran, Iraq, Azerbaijan, Algeria, Egypt, and Turkmenistan). Despite their relative market power over their clients, the suppliers of natural gas also compete for accessing a diverse mix of markets in order to minimize the uncertainty over their export revenues (Shaffer, 2010, Nichol, 2009 and Denison, 2009). For instance, Caspian Region countries such as Turkmenistan, Kazakhstan, and Azerbaijan share the same interests with Europe for exporting their gas through non-Russian transport routes (Shaffer, 2010, Nichol, 2009 and Denison, 2009). Hence, both OECD-Europe and the Caspian suppliers might benefit from diversification of Europe's natural gas procurement.

On the other hand, there are also some difficulties related to diversification of OECD-Europe's natural gas procurement. Firstly, it is important to highlight that natural gas is transported either via pipelines or in the LNG form. When operating costs are taken into account, pipelines often provide a more efficient alternative (Hanfer et al., 2008). According to Pirani et al. (2009), in 2008, 90% of European natural gas imports were delivered via pipelines. For this reason, energy security issues cover investments on necessary infrastructure and the energy security of transit countries as well. The importance of transit countries has become evident during the Russia-Ukraine gas conflict in 2006 and in 2009. Even though it is frequently argued that there were hidden political motives, the main reason for this conflict appears to be related to price. Accordingly, Russia was unwilling to continue subsidising the natural gas prices for Ukraine and the Ukrainian economy struggled to pay the full price charged to Europe. As a result, Russia cut natural gas supplies to Ukraine in January 2006 for three days and in January 2009 for nearly three weeks.

Europe has experienced supply disruptions because of the abovementioned conflicts between Russia and Ukraine. In particular, during the January 2009 conflict, exports to 16 EU member states and Moldova decreased significantly on 6 January 2009 and cut totally from 7 January 2009. The countries hit by this supply disruption seriously in the Balkans, faced a humanitarian emergency; a considerable share of the households in the Balkan region could not be heated during coldest time of the year. Countries including Hungary and Slovakia also experienced economic loss and problems because of this supply disruption (Pirani et al., 2009). A staff working document published by the European Commission summarises Europe's vulnerability with respect to this matter, stating: "One quarter of all energy consumed in the EU is gas. 58% of this gas is imported. Of this, 42% comes from Russia, and around 80% of EU imports of gas from Russia pass via Ukraine." (EC, 2009; p. 2).

It can be argued, therefore, that not only diversification of sources but also diversification of transit routes has become imperative for OECD-Europe. The Nabucco project, <sup>45</sup> which enables Europe to import gas from both the Middle East and Caspian resources, can help

<sup>&</sup>lt;sup>45</sup> Nabucco is 3,300 km pipeline project that will run from Turkey's borders with Georgia and Iran to Baumgarten in Austria, along a route passing through Bulgaria, Romania and Hungary.

Europe to achieve both of these objectives; diversifying import source and transit routes of natural gas (Holz et al. 2006). Feeling the need to respond, China's long-term and comprehensive institutional solutions for accessing to Caspian gas, EU and its financial institutions have become actively involved in the Nabucco project. The Nabucco Summit was held in Budapest on 27th of January 2009. The European Union's political and financial institutions including the European Bank of Reconstruction and Development (EBRD) and European Investment Bank declared their support and, as a part of its economic recovery plan, the European Commission proposed 250 million Euros to be contributed for funding the project via the European Investment Bank (Nabucco Declaration, 2009 and Deutche Welle, 2009).

The second barrier related to diversification of OECD-Europe's natural gas procurement is the political power of Russia who, not surprisingly does not want to lose its share and market power in the European natural gas market (Socor, 2008; Smith, 2010). Russian authorities are strongly against the Nabucco project and similar formations. Russia advocates that Gazprom is a reliable supplier and therefore diversification of transport routes will be sufficient for Europe's energy security (Socor, 2008). In this respect, Russian policy is to encourage Caspian countries to divert their export routes to the east rather than west. Russia also uses its political power to obstruct new European Union projects aiming to diversify import sources including the Nabucco pipeline and instead, push forward a more expensive South Stream project. The idea behind the South Stream project is to diversify the transport routes of Russian gas to Europe so that reoccurrence of supply disruptions during the Russia-Ukraine conflict can be avoided. From the perspective of Europe, however, South Stream does not diversify the risks related to the import source (Pirani et al., 2010). Further complications in the natural gas market involve the European Commission's objective to liberalize the natural gas sector. In the natural gas and other fuel markets, a major consideration for liberalisation efforts is the use of long-term contracts. These generally involve take-or-pay obligations between 80-90% of the annual contract quantity, often for a period between 15 to 20 years. When most transactions occur in long-term basis the market is expected to lose from its competitiveness (Newbery, 1984). As a part of the undergoing efforts for liberalization of the downstream wholesale market and of gas distribution, long-term natural gas supply contracts in Europe (which are generally issued for 20-25 years) are expected to be issued for shorter periods such as 8-15 years (Kavalov et al, 2009).

That said, it has also been argued that long-term contracts will still dominate over the next two decades but with more flexible price options (Stern, 2002; see also Neuhoff and von Hirschhausen, 2005). Neuhoff and von Hirschhausen (2005) argue that suppliers' preference for long-term contracts depend on the difference between short run and long run price elasticities of demand. If the long-run elasticity is significantly higher than the short run elasticity, the suppliers prefer long-term contracts. It has also been argued that longer-term contracts may be socially beneficial if they facilitate infrastructure investments that appear to be much riskier with spot transactions and price volatility (Oren, 2003).

Overall, from the perspective of energy security of OECD-Europe several issues appear to be important. Natural gas will remain an important fuel over the coming decades, largely due to its central role in power generation. Both global and European demand for natural gas will be increasing. On the supply side, OECD-Europe's indigenous production will be declining while the global suppliers that are already low in number may initiate cartel-like organisations. Although OECD-Europe can diversify its suppliers by accessing Middle Eastern and Caspian gas, this would require investments in pipeline projects, which would lead to diplomatic struggles against the political power of Russia and would probably involve binding long-term purchase agreements. Arguably, reliable energy forecasts are essential for analysing all these aspects. They are necessary for policy makers, energy planning and regulative bodies for adopting the policies and measures that are necessary for delivering energy security of OECD-Europe.

Future natural gas demand is also very important for energy providing firms and financial institutions in order to assess multibillion-dollar investment projects. Uncertainty about the future could make such investment decisions risky, delaying investment decisions. The natural gas producing countries and their national energy companies such as Russia and Gazprom are often criticized for being late in their investments, and these criticisms arouse the concerns about the supply security. If Gazprom fails to meet future natural gas demand, it might lose its position as a reliable supplier. Thus, reliable demand projections are also vital to natural gas producers for protecting their position as reliable suppliers.

As discussed above identifying the main drivers of natural gas and forecast future natural gas demand can provide number of benefits to policy makers of both natural gas importing and exporting countries and energy companies by minimizing the uncertainty about the future, identifying the price-income elasticities and UEDTs. In the next section, previous natural gas demand studies are discussed.

### 5.4 Review of Studies Focussing on OECD Europe Natural Gas Demand

In this section, the key literature is discussed in two main parts. Firstly, previous studies that have estimated natural gas demand elasticities are reviewed. Secondly, previous projections for future natural gas consumption are summarised.

#### 5.4.1 Previous Studies on Price and Income Elasticities of Natural Gas Demand

Pindyck (1979) analysed the structure of world energy demand for different fuels and sectors for nine OECD countries including Belgium, Canada, France, Italy, Netherlands, Norway, Sweden, Switzerland, UK, West Germany, and US over the period 1955-1972. He found estimated natural gas price elasticities for residential and industrial sectors ranging from -0.9 to -1.8 and -0.41 to -2.34 respectively. Griffin (1979) investigated natural gas demand functions for different sectors of 18 OECD countries including Austria, Belgium, Canada, Denmark, France, West Germany, Greece, Ireland, Italy, Japan, Netherlands, Norway, Spain, Sweden, Switzerland, Turkey, United Kingdom and US over the period 1955 to 1974. He concluded that the price elasticity of natural gas varied between -0.83 to -1.60.

Estrada and Fugleberg (1989) investigated the price responsiveness of natural gas demand for West Germany and France and found estimated price elasticities varying between -0.75 and - 0.82 for West Germany and from -0.61 to -0.76 for France. Nilsen et al. (2005) examined natural gas demand per capita in 12 European countries including Austria, Belgium, Denmark, Finland, France, Germany, Ireland, Italy, Netherlands, Spain, Switzerland, and UK over the period 1978-2002. Their results suggest that the short run and long run price elasticities vary between 0 to -0.3 and 0 to -0.6 respectively, whereas the short and long run income elasticities range from 0.3 to 0.7 and 1.9 to 2.2 correspondingly.

There are also some survey studies, which investigate the price and income elasticities of natural gas demand. The summary of these surveys are given in Table 5.2.

Tuble 5.2. Summary of Estimated Futural Gus Demand Surveys							
Survey	Short Run	Short Run	Long Run	Long Run			
	Price	Income	Price	Income			
	Elasticity	Elasticity	Elasticity	Elasticity			
Taylor (1977)	0 to -0.38	0.01 to 1	0 to -3.85	-0.29 to 3.11			
Bohi (1981)	0.09 to -0.50	-0.03 to 0.05	0.33 to -2.42	0.02 to 2.18			
Kirby (1983)	-	-	-0.3	0.4			
Bohi and Zimmerman (1984)	0.16 to -0.63	0.02 to 0.78	0.99 to -3.44	0.09 to 3.08			
Dahl (1993)	0.02 to -1.63	-0.33 to 1.74	1.56 to -10	-2.19 to 4.46			

**Table 5.2: Summary of Estimated Natural Gas Demand Surveys** 

Overall, these previous studies and surveys suggest a wide range of price and income natural gas elasticities. One reason for this might be previously applied models are insufficient in terms of identifying the structural changes in natural gas demand. Hence, as stated before, one of the aims in this work is to attempt to overcome some of the shortcomings of previous studies by attempting to identify key structural changes in OECD-Europe natural gas demand behaviour by using the UEDT/STSM approach. However, before this, studies focusing on European natural gas demand projections are reviewed in the next section.

### 5.4.2 Previous Projections of European Gas Demand

There appear to have been few academic authors and institutions working on natural gas demand projections. Mackay and Probert (1995), one of the early studies, predicted that French natural gas demand will be somewhere between 46 - 58 bcm (38-43 million tonnes of oil equivalent, mtoe)<sup>46</sup> by 2010.<sup>47</sup> According to Eurogas (2010), natural gas demand of EU-

<sup>&</sup>lt;sup>46</sup> Mackay and Probert (1995) present their natural gas projections in mtoe; the bcm figures are based upon the IEA conversion factor of 1 mtoe = 1.2125 bcm (IEA, 2010b).

27 would be between 535-562 bcm (482-507 mtoe) in 2020. However, this is somewhat lower than Eurogas's previous (Eurogas, 2007) where they projected EU natural gas demand to be 641 bcm (578 mtoe) in 2020.<sup>48</sup>

Honore (2006) focuses on EU-25 natural gas demand by the power sector and concludes that in 2015 natural gas demand by the power sector and the non-power sector would be 195 bcm and 406 bcm (161 mtoe and 335 mtoe) respectively; a total of 601 bcm (496 mtoe).<sup>49</sup>There are two institutions, the US Energy Information Administration (EIA) and the International Energy Agency (IEA) that produced annual forecasts for OECD-Europe. EIA (2010b) projected that OECD-Europe natural gas demand would be between 575 and 609 bcm (474 and 502 mtoe)<sup>50</sup> by 2020, whereas IEA (2010b) predicted that OECD-Europe natural gas demand would be somewhere between 534 and 589 bcm (440 and 486 mtoe)<sup>51</sup> by 2020. However, both of these institutions reduced their reference case projections considerably from previous forecasts in 2008; the EIA's natural gas demand reference scenario projection for 2020 was 644 bcm (531 mtoe) and for the IEA was 699 bcm (576 mtoe) (EIA, 2008 and IEA, 2008). The differences are illustrated in Figure 5.14.

<sup>&</sup>lt;sup>47</sup> Which looks to be a little high given that French natural gas consumption was 40 bcm (33 mtoe) in 2008 (IEA, 2011).

<sup>&</sup>lt;sup>48</sup> Eurogas (2010) and Eurogas (2007) present their natural gas projections in mtoe; the bcm figures are based upon the conversion factor of 1 mtoe = 1.11 bcm (as it is used in Eurogas publications).

<sup>&</sup>lt;sup>49</sup> Honore (2006) present their natural gas projections in bcm; the mtoe figures are based upon the IEA conversion factor of 1 mtoe = 1.2125 bcm (IEA, 2010d).

 $<sup>^{50}</sup>$  EIA (2010) present their natural gas projections in tcf, these figures have first been converted to bcm and then to mtoe based upon the IEA conversion factor of 1 mtoe = 1.2125 bcm (IEA, 2010d).

<sup>&</sup>lt;sup>51</sup> IEA (2010a) present their natural gas projections in both bcm and mtoe.

Although it is not possible to compare the above studies directly,<sup>52</sup> it is clear that there is a wide range of projections related to European natural gas demand. One reason might be the dynamic structure of European natural gas demand that makes it difficult to minimize the uncertainty about the future. This study therefore attempts to help uncover the structural changes in the European natural gas market and help to reduce the uncertainty by utilizing the STSM with the UEDT explained in previous chapters.



Figure 5.14: IEA and EIA OECD-Europe Natural Gas Demand Projections for 2020

### **5.5 Empirical Framework**

As discussed in Chapter 3, it is assumed that OECD-Europe natural gas demand is identified

by:

$$G_t = f(Y_t, P_t, UEDT_t) \tag{5.1}$$

<sup>&</sup>lt;sup>52</sup> This is primarily due to the differences in country groups, but also the different definitions and conversion factors used.

Where:  $G_t = OECD$ -Europe total natural gas demand;

 $Y_t = \text{GDP}$  (US Dollar 2000=100 PPP)

 $P_t$  = OECD Europe natural gas price index (2005=100); and

 $UEDT_t$  = Underlying Energy Demand Trend for OECD-Europe Natural Gas.

# 5.6 Data

Annual time series data from 1978-2009 for E (natural gas consumption ktoe), Y (GDP 2000 constant US dollar-PPP) and P (OECD-Europe Real natural gas price index 2000 =100) are used for the analysis (Figure 5.15). All variables are obtained from the International Energy Agency (IEA, 2011).





### **5.7 Estimation Results**

The final preferred equation resulting from the estimation procedures outlined above is given in Table 5.3 and Figure 5.16 along with the diagnostics. It can be seen that the preferred model passes all the diagnostic tests including the additional normality tests for the auxiliary residuals generated by the STSM approach, with limited estimated dynamic terms. The estimated impact elasticities for both income and price are zero, whereas the estimated long run income elasticity of 1.16 and the estimated long run and price elasticity of -0.17 come through after a lag of one year.

The estimated UEDT from this procedure is a local level model without a slope, but despite this the estimated UEDT illustrated in Figure 5.17 and summarised in Table 5.4 is clearly non-linear given the estimated level hyper-parameter; with periods when it increased and periods when it is decreased, with a sharp decrease after 2004.

As explained in the methodology section, in order to illustrate the UEDT's importance relative to income and price, their estimated contributions to the change in OECD-Europe natural gas demand are estimated using the method proposed by Broadstock and Hunt (2010) by decomposing the change in natural gas demand as follows:

$$\Delta \widehat{g}_t = 1.164 \Delta y_{t-1} - 0.171 \Delta p_{t-1} + \Delta \widehat{UEDT}_t \tag{5.2}$$

The decomposition is shown in Figure 5.18 and summarised in Table 5.5. This shows that since 1979 income was the main driver of OECD-Europe natural gas demand closely followed by the UEDT. In contrast, the estimated contribution from price is relatively small.

<u>Variables</u>		<u>Coefficients</u>	<u>Std.Error</u>		<u>Probabilities</u>
Yt-1		1.1642	0.21532		0.000
p <sub>t-1</sub>		-0.1709	0.07480		0.030
Lvl1988		-0.0881	0.03276		0.012
<b>Hyperparameters</b>	<u>;;</u>		Goodness of	<u>f fit:</u>	
Level:		0.00079	p.e.v		0.0007
Irregular:		0.00000	p.e.v/m.d.²		1.2799
			R <sup>2</sup>		0.9918
UEDT <sub>2009</sub> : 2.9453			$R_d^2$		0.4066
<b>Diagnostics</b>					
Residuals:		Auxiliary Resic	luals:		
			Irregular	Level	
Std. Error	0.90	Std. Error	0.90	0.98	
Normality	0.66	Normality	0.89	0.86	
Skewness	0.42	Skewness	0.64	0.60	
Kurtosis	0.67	Kurtosis	0.93	0.91	
H <sub>(9)</sub>	0.76				
r <sub>(1)</sub>	0.17		Nature of Tr	end: Loca	al Level
r <sub>(5)</sub>	0.05				
	-0.05				
Q <sub>(5,4)</sub>	1.41				
Predictive Tests(2	2002-200	9) <u>LR TEST</u>	24.	5186	(0.000)
Failure	0.47	,			
Cusum t <sub>(8)</sub>	1.64				

Table 5.3: OECD-Europe Total Natural Gas Demand STSM Estimates and DiagnosticsSample 1978-2009

Notes:

-See notes to Table 4.3<sup>53</sup>

-Model includes a level intervention for the year 1988;

- LR Test represents a likelihood ratio tests on the same specification after imposing a fixed level and no slope hyperparameter and distributed as  $\chi^2_{(1)}$  and probabilities are given in parenthesis.

-Failure is a predictive failure statistic distributed as  $\chi^2_{(8)}$  and Cusum is a mean stability statistic distributed as the Student t distribution; both are STAMP prediction tests found by re-estimating the preferred model up to 2000 and predicting for 2001 thru 2009;

<sup>&</sup>lt;sup>53</sup>For simplicity and to save space the notes given in the previous table are not repeated again.



Figure 5.16: Prediction Graphics of European Natural Gas Demand 2001-2009





	8 8				
Period	Average Annual Change of UEDT				
1979-1989	- 0.0096				
1989-1999	0.0134				
1999-2009	- 0.0059				
1979-2009	- 0.0007				

Table 5.4: The Average Annual Change of the UEDT

Figure 5.18: Estimated Contributions to the Annual Percentage Change in OECD-Europe Natural Gas Demand



 Table 5.5: Summary of the Estimated Contributions to the Average Percentage per

 Annum Change in OECD-Europe Natural Gas Demand

	Contribution f	Total change		
Period	Income	Price	UEDT	in Gas Demand
1979-1989	2.62	-0.17	-0.96	1.50
1989-1999	2.57	-0.01	1.34	3.90
1999-2009	2.76	-0.86	-0.59	1.31
1979-2009	2.65	-0.34	-0.07	2.24

Note: Following from Equation (5.2) the estimated annual changes per annum contributions are approximated as follows:  $((1.164\Sigma\Delta y_{t-1})/n)\%$ ,  $((-0.171\Sigma\Delta p_{t-1})/n)\%$  and  $((\Sigma UEDT_t/n)\%$ -for the contributions of income, price, and the UEDT respectively. (The total change being approximated by  $(\Sigma \Delta g_t/n)\%$ .) Where n is the span of years that the change is calculated.

To show this more clearly, the contributions are re-calculated in absolute terms, presented as shares in Figure 5.19<sup>54</sup> and summarised in Table 5.6. This shows that the share of the contribution of income is the largest and generally, increases over the estimation period. The second largest share is clearly the UEDT, which was at its highest in the 1990s when it was making a positive contribution (see Table 5.5) compared to the 1980s and the 2000s when it was making a negative contribution. Price clearly makes the smallest contribution. Given the relative importance of the UEDT, it should arguably be taken into account when modelling and forecasting OECD-Europe natural gas demand. The preferred estimated equation will therefore now be used to construct future scenarios for OECD-European natural gas demand, as explained in the next section.



Figure 5.19: Estimated Shares of the Contributions to the Change in OECD-Europe Natural Gas Demand

Contribution share of  $y_t = \frac{|Est. cont. of y_t|}{|Est. cont. of y_t| + |Est. cont. of p_t| + |Est. cont. of UEDT_t|}$ .

<sup>&</sup>lt;sup>54</sup>The absolute value of the estimated contribution of each factor is divided by the sum of the absolute values of all estimated contributions of the factors; e.g.
D · 1	Average shares of contribution from:				
Period	Income	Price	UEDT		
1979-1989	41.2%	24.3%	34.6%		
1989-1999	47.0%	13.8%	39.2%		
1999-2009	52.8%	18.6%	28.6%		
1979-2009	47.0%	18.9%	34.1%		

## Table 5.6: Summary of the Estimated Shares of the Contributions to the Change in OECD-Europe Natural Gas Demand

*Note: The shares of the contributions to the change in OECD-Europe Natural Gas Demand per annum are approximated as follows:* 

 $((\frac{|1.164\Sigma\Delta y_{t-1}|}{|1.164\Sigma\Delta y_{t-1}|+|-0.171\Sigma\Delta p_{t-1}|+|\Sigma\Delta U \widehat{EDT}_t|})/n) \times 100,$  $((\frac{|-0.171\Sigma\Delta p_{t-1}|}{|1.164\Sigma\Delta y_{t-1}|+|-0.171\Sigma\Delta p_{t-1}|+|\Sigma\Delta U \widehat{EDT}_t|})/n)) \times 100, \text{ and}$ 

 $\left(\frac{|\Sigma\Delta U E D T_t|}{|1.164\Sigma\Delta y_{t-1}|+|-0.171\Sigma\Delta p_{t-1}|+|\Sigma\Delta U E D T_t|}\right)/n\right) \times 100 \text{ for the shares of the contributions of income,}$ price, and the UEDT respectively. Where *n* is the span of years that the change is calculated.

#### **5.8 Forecast Assumptions**

This section outlines the assumptions about the future UEDT and other variables that are used to construct the scenarios and presents the forecast results based on these assumptions. Three scenarios are implemented in this chapter, namely 'high' case, 'reference' and 'low 'case as discussed in methodology section.

*In the 'reference' scenario*, it is assumed that real natural gas OECD Europe prices will increase 1.5% annually over period 2010-2020. The average annual prices increase is around 2% over the estimation period, however, for the future, the price increase is assumed slightly less than before. The increase of GDP is expected to be 1% for 2010 and 2011 and a 2% per annum thereafter. The average annual increase of GDP is around 2% over the estimation period. Hence, it is assumed that after the global crises, GDP will increase 2% annum. For the UEDT<sup>55</sup>, a slope of -0.004 is projected for the period 2009-2020. Although the average

<sup>&</sup>lt;sup>55</sup> Although the estimated slope of UEDT is zero over the estimation period, in order to create future values of UEDT, a series of slope values for UEDT is assumed based on the estimated past values of the UEDT and future expectations.

decrease of UEDT is -0.006 for the last decade (Table 5.5), it is expected that because of environmental concerns, there might be some new regulations that encourages the consumption of natural gas especially in the power sector.

*In the 'high' case scenario,* the natural gas price is assumed to increase 0.5% annually for the period 2010 and 2020 (less than the increase observed over the estimation period). Furthermore, it is assumed that GDP will increase 1.5% increase for both 2010 and 2011 and will increase 2.5% per year thereafter to 2020. In the high case scenario, it is assumed that the transformation of power sector to natural gas will be much higher than the reference case hence it is assumed that the UEDT has a slope of -0.002 over the forecast period.

*In the 'low' case scenario*, it is assumed that the rise in natural gas prices will be 2% per annum (similar with the estimation period). For GDP it is assumed to increase 0.5% for both 2010 and 2011 because of the global economic crises and then increase annually 1% per year (lower than the estimation period average) until 2020. For the UEDT, it is assumed that it will have a slope of -0.006 per annum (same as it was observed for 2000 and 2009) between 2010 and 2020. A graphical presentation of the scenario assumptions for GDP, real natural gas price index, and the UEDT are illustrated in Figure 5.20.



Figure 5.20: Forecast Scenarios for Price, GDP, and UEDT

#### **5.9 Forecast Results**

The three scenarios up to 2020 are illustrated in Figure 5.21. These show that OECD Europe natural gas demand is predicted to grow to 536, 585 and 644 bcm (442, 482 and 531 mtoe) by 2020 according to the low reference and high case scenarios respectively.



Figure 5.21: OECD Europe Natural Gas Demand Forecast Scenarios

#### **5.10** Conclusion and Further Discussion

This chapter estimates an OECD-Europe Natural gas demand function by using the STSM over the period 1978-2009. As far, as is known this is the first attempt to estimate a non-linear UEDT for OECD-Europe natural gas demand. The results suggest the following:

- i) In order of importance, Income, the UEDT, and real natural gas prices are all factors that shape European natural gas demand.
- ii) The income and the price elasticities are 1.16 and -0.17 respectively.
- iii) Income has a greater impact on OECD-Europe natural gas demand than price and this finding is consistent with previous studies.
- iv) The UEDT has a stochastic process that increases and decreases over the estimation period; however starting from 2004, it follows a decreasing path,

perhaps due to improved energy efficiency standards. However the environmental concerns make natural gas a popular choice rather than other fossil fuels for power generation, therefore it is expected that the power sector will widely use natural gas as a fuel in the future, which might change the direction of UEDT to upward.

v) OECD-Europe natural gas demand is expected to be 536, 585 and 644 bcm (442, 482 and 531 mtoe) by 2020, according to the generated low, reference and high case scenarios.

In summary, given its relative importance, the UEDT should be taken into account when modelling OECD-Europe natural gas demand in addition to the main driver, income, and price. Arguably, the UEDT has important information that is of value to European decision makers when developing gas security policies.

As discussed in previous sections, some of the main challenges of OECD-Europe in terms of natural gas are import dependency and increasing global demand for natural gas, security and diversity of gas supply, liberalization of natural gas markets and investment requirements of the gas sector. For policy makers, energy companies and financial institutions alike, it is important to minimize the uncertainty around future natural gas demand in order to establish appropriate energy security measures. This research contributes in this area by identifying the structure and composition of OECD-Europe natural gas demand and its responsiveness to its main determinants and provides invaluable information for the stakeholders.

#### **CHAPTER 6: US Gasoline Demand\***

#### **6.1 Introduction**

As outlined in the methodology above, in this chapter a US per capita gasoline demand function is estimated with annual data over the period 1949-2008 using an extended version of the STSM/UEDT approach that includes asymmetric price responses and time varying parameters (TVP). As far as is known, this is the first attempt to estimate an energy demand relationship that incorporates a stochastic UEDT and asymmetric price responses within a TVP framework.

World demand for oil increased rapidly until 2008. As a result of this increase, the market produced crude oil prices that went beyond their highest peak of the early 1980s (Huntington, 2010). One reason being the growth in oil demand was not met by production increases with OPEC spare capacity decreasing to historically low levels; thus leaving the world market in a weak position against supply shocks (IMF, 2005, and Huntington, 2010). Coupled with the fast oil demand growth was the resultant increase in GHG emissions – that contribute towards global climate change.

The security of oil supply and the related economic vulnerability along with the environmental concerns put pressure on policy makers to deal with these problems. Before assessing any policy implications such as carbon taxes, vehicle efficiency standards, cap and trade schemes, and reducing oil vulnerability, it is vital that the factors affecting oil demand

<sup>\*</sup>Earlier preliminary work for this chapter was presented at the following:

<sup>• 33</sup>rd IAEE international Conference: The Future of Energy Global Challenges, Diverse Solutions. Rio De Janeiro, Brazil 6-9 June 2010; and

<sup>• 3</sup>rd International Workshop on Empirical Methods in Energy Economics, University of Surrey, Guildford, UK 24-25 June 2010.

are investigated (Huntington, 2010) and a key part of this investigation is to obtain information on the key price and income elasticities of oil demand. Consequently, there have been many previous studies of US Gasoline demand in order to estimate price elasticities. However, no previous study, as far as is known, has attempted to capture the impact of unobserved factors (via a UEDT) and asymmetric price responses, while also experimenting to see whether or not the price and income elasticities change over time. The research for this chapter therefore attempts to rectify this omission.

In summary, the key motivations for this chapter are as follows:

- i) to estimate time varying income and asymmetric price elasticities for US per-capita gasoline demand;
- ii) to uncover the UEDT for US per-capita gasoline demand;
- iii) to investigate if/how the parameters of the model change over time;
- iv) produce forecast scenarios for US per-capita gasoline demand to 2020; and
- v) to evaluate the findings in terms of policy application and assessment.

However, before these issues are addressed the next section sets the scene in terms of US gasoline consumption and associated  $CO_2$  emissions before summarising the associated literature.

#### 6.2 An Overview of US Gasoline Consumption and CO<sub>2</sub> Emissions

In 1971, the US economy generated 4291 Mt of  $CO_2$  while the world economies in total generated 14096 Mt of  $CO_2$ ; therefore, in 1971 the US was individually responsible for 30% of global  $CO_2$  emissions. Within this, the US transport sector produced 1081 Mt of  $CO_2$ , accounting for 25% of the total US  $CO_2$  emissions. In 2008,  $CO_2$  emissions created by the US

economy had increased to 5587 Mt, which accounted for 19% of global  $CO_2$  emissions of 29454 Mt (Figure 6.1) with the share of the US transport sector being 30%, producing1691 Mt of  $CO_2$  (Figure 6.2)(IEA, 2010c).

The US transport sector has historically had a big share of  $CO_2$  emissions (Figure 6.2); moreover, in 2008 combusted oil products accounted for 1655 (98%) Mt of total 1691 Mt  $CO_2$  emissions generated by the transport sector (IEA, 2010c).Given this large share of  $CO_2$ any US policies developed to attempt to curb  $CO_2$  and other GHG emissions and contribute towards the halting of climate change should therefore address the consumption of oil products in transport sector where the emissions emanate from.



Figure 6.1: US CO<sub>2</sub> Emissions 1971-2008 (Mt.)

Source: IEA, 2010

The demand for US oil products increased from 431,423 ktoe to 781,703 ktoe from 1960 to 2008 with most of the demand generated by the transport sector. Furthermore, the demand for oil products by the US transport sector increased from 225,242 ktoe (52%) to 565,116 ktoe

(72%) for the same period (Figure6.3) (IEA, 2010c). This increase transformed the US economy making it even more dependent on oil and oil products and consequently more vulnerable to supply disruptions, thus raising serious concerns about US oil and energy security.



Figure 6.2: Sectoral CO<sub>2</sub> Emissions 1971- 2008 (Mt.)

US CO<sub>2</sub> emissions from the transport sector was also the fastest increasing source of GHG's, a net 47% increase between 1990 to 2006 (US EPA, 2010). US EPA (2006) illustrates that in 2003, light–duty vehicles (passenger cars, SUVs, Minivans, Pickup Trucks and Motorcycles) fuelled by gasoline had a 62% share in transport sector GHG emissions and, moreover, it was the fastest growing with a net increase of 20% between 1990 and 2003. This illustrates that gasoline demand plays a significant role in terms of US GHG emissions.

Source: IEA, 2010



Figure 6.3: US Oil Products Consumption by Sectors 1960-2008 (ktoe)

In order to try to solve this problem, in 2002, the US Congressional Budget Office investigated three policy tools aimed at reducing US gasoline demand, namely gasoline taxes, increasing fuel economy standards for vehicles and cap and trade. Following a cost and benefit analysis, the report suggested that introducing gasoline taxes might be the most effective tool out of the three investigated. Nevertheless, in order for a gasoline tax to be effective the US consumers' response to price movements, or in other words the gasoline price elasticity, needs to be relatively 'high' (i.e. not too inelastic). In their study, US Congressional Budget Office used the outcome of the Dahl and Sterner (1991) survey and assumed that the short run and long run price elasticity of US gasoline demand was -0.26 and -0.86 respectively. Therefore, the US Congressional Budget Office envisaged that an increase tax of 15 cents (or equivalently a 10% increase in price) would cause a decrease in gasoline demand of 2.6% in the short run and 8.6% in the long run. However, the report stressed that the long run responsiveness to the price change could differ for various reasons such as changes in average income, options for public transit, the availability of technologies for

Source: IEA, 2010

improving fuel economy. Therefore, for the long run the assumption by the US Congressional Budget Office was that suggested by the US Department of Energy of a long run price elasticity of –0.38. However, this is smaller (in absolute terms) than the -0.86 from the Dahl and Sterner (1991) survey. It is important therefore that well estimated robust estimates of the price responsiveness (price elasticity) underpin this type of analysis. Consequently, one of the main aims of this chapter is to re-estimate the US Gasoline price responsiveness (price elasticity) and income responsiveness (income elasticity) using the structural time series approach, and importantly assessing whether or not they are changing over time.

Before this, the next section reviews the literature specific to this chapter, namely time varying parameters, asymmetric price responses and US gasoline demand studies.

#### **6.3 Literature Review**

#### 6.3.1 Previously Estimated (Symmetric) Gasoline Demand Elasticities

A considerable amount of research has focussed on gasoline demand with a noteworthy number of surveys summarizing the results; such as Taylor (1977) Bohi (1981), Kouris (1983a), Bohi and Zimmerman (1984), Dahl (1986), Dahl and Sterner (1991), Goodwin (1992), Dahl (1993), Espey (1998). The results and the main findings of these surveys are summarized below (Table 6.1).

Overall, these surveys suggest a wide range of price and income elasticity estimates. Most of the surveys, such as Bohi and Zimmerman (1984), Dahl (1986), Dahl and Sterner (1991), suggest that the previously estimated models might be insufficient in terms of identifying important structural changes. Hence, one of the aims of the research for this chapter is to attempt to identify key structural changes in US gasoline demand behaviour by using the UEDT and TVP approach. Before that, however, the literature on imperfect price reversibility

as applied to energy and oil demand is reviewed in the next section.

Survey	Price Elasticity		Income Elasticity		Main Findings	
	Short Run	Long Run	Short Run	Long Run		
Kouris (1983c)	-0.2 to -0.4	-0.7	0.20 to 0.90	-	The price elasticities of the static models are greater than the elasticities of the dynamic model, particularly those that utilize lagged endogenous formulation. Furthermore, the variety of estimated elasticities of dynamic models is wider.	
Bohi & Zimmerman (1984)	0 to -0.77	0 to -1.59	-0.18 to 1.20	-0.34 to 1.35	There is a great variation between the estimated elasticities. Dynamic models based on monthly or quarterly data present most unstable results.	
Dahl (1986)	-0.29	-1.02	0.47	1.38	The market able to cope with short term disruptions. Single equation techniques estimates smaller price elasticity. Strict cross section models provide most elastic price response.	
Dahl & Sterner (1991)	-0.26	-0.86	0.48	1.21	There is a little variation between short run price elasticities, however long run price response vary more widely. The results suggest that the price and income responses might be getting larger.	
Goodwin (1992)	-0.27	-0.73	-	-	The long run cross section models estimates more responsive price elasticity than the time series models.	
Dahl (1993)	-0.2	-0.6	0.5	0.8	The income and price elasticities of new studies are lower. The low income elasticities might reflect effect of CAFE standards.	
Espey (1998)	-0.26	-0.58	0.47	0.88	The results suggest that gasoline demand seems to be getting more price-elastic and less income elastic over time.	

 Table 6.1: Energy Demand Surveys that Investigate US Gasoline Demand

### 6.3.2 Imperfect Price Reversibility in Energy and Oil Demand Studies: Discussion of Key Previous Papers

As discussed briefly and stated in Chapter 2, the imperfect price reversibility for gasoline demand is reviewed in this section. The imperfect price reversibility concept for gasoline demand has been investigated in a number of previous papers, such as Dargay (1992), Gately (1992), Dargay and Gately (1995 and 1997), Gately and Streifel (1997), Gately and Huntington (2002), Huntington (2006), and Huntington (2010). All of these studies decomposed the price term (in logarithms) into three components, price maximum, price recovery, and price cuts in order to estimate the differential asymmetric effects.<sup>56</sup>

Dargay (1992) investigated the asymmetric price responses by examining the demand for motor fuels for road transport in France, Germany, and UK by using the annual data over the period 1960 and 1988. She concluded that price shocks had a permanent effect that were not reversible. According to Dargay (1992), in Germany the long run price elasticity is -0.44 and demand does not respond to price falls; in France the long term price elasticity is -0.8 and demand also reacts to price falls with an elasticity of -0.45; and in the UK the permanent decline in demand is a result of a structural break caused by the price shocks in 1970s and all other price rises and falls had negligible effects.

Gately (1992) investigated the imperfect price reversibility on US vehicle miles per driver, miles per gallon and gasoline demand per driver by using the annual data over period 1966-1989, 1966-1989 and 1960-1990 respectively. In all the cases, he rejects the perfect price reversibility assumption; furthermore, the study illustrates that the gasoline demand response

<sup>&</sup>lt;sup>56</sup> The actual definition and calculation of price maximum, price recovery, and price cuts are explained later in the chapter.

to a new price maximum is approximately twice that of response to price cuts, whereas the response to a price recovery is uncertain.

Dargay and Gately (1994) examined oil and energy demand for the OECD as a whole and the regions within the OECD by utilizing the annual data over period 1970-1990. They concluded that price reversibility is imperfect, with the impact of price increases larger than the price decreases and the demand response for future income growth would not be significantly smaller than in the past.

Dargay and Gately (1995) investigated the asymmetric price responses and income effect for world energy and oil demand by using annual data over the period 1970-1991. They concluded that demand in less developed countries is much more sensitive to income than the demand in the industrialized countries. In industrialized countries, the price responses are asymmetric, whereas in less developed countries there is less evidence for imperfect price reversibility.

Dargay and Gately (1997) investigated the asymmetric price responses and income effect of fuel demand for transport by using the pooled time series/cross section data over the period 1961-1990 for eleven OECD countries. They concluded that demand is not reversible to price changes; response to price rises is greater than falling prices and price recoveries.

Gately and Streifel (1997) investigated the demand for oil products in 37 developing countries with annual time series data over the period 1971-1993. Their results suggest that income is the most significant driver of oil demand, and that oil exporting countries show asymmetric responses to income increases and decreases. In only one third of the countries

that are investigated, the price of oil is found to be a significant factor and the estimated price elasticities are smaller than the estimated income elasticities. Furthermore, the estimated price responses of the countries differ; some petroleum products in some countries are found to be symmetric and others asymmetric.

Gately and Huntington (2002) investigated the response of energy and oil demand to income and price change for 96 of the world's largest countries with annual time series data over the period 1971 and 1997. They examined asymmetric price and income effects and the different speed of adjustments to income and price variation. They concluded that the OECD demand is more sensitive to price increases than to price decreases and not taking into account this asymmetric effect can cause underestimated income elasticities. They also argue that the demand response to income decline is not symmetric to its response to income increase for most of the non-OECD countries and ignoring this asymmetric response can lead to biased estimated income elasticities.

Griffin and Schulman (2005) criticizes Gately and Huntington (2002), arguing that the price decomposition approach is really capturing exogenous energy saving technological progress, which could be better characterized by a series of dummy variables for each year (given a panel data approach is used). Their results for a panel of sixteen OECD countries over the periods 1971 to 1996 and 1961 and 1999 suggest that asymmetric price terms are significant is some cases for both energy and oil demand. However, the also find that the inclusion of asymmetric price terms dramatically affects the income elasticity and conclude that symmetric responses should be used for forecasting.

In his reply to Griffin and Schulman (2005), Huntington (2006) employs an F-Test in order to evaluate the symmetric specification versus asymmetric specification and the inclusion or exclusion of the time dummies. He found that for almost all the specifications for energy and oil demand, symmetry was rejected at the 1% significance level and for the other specification, symmetry was rejected at the 10% level of significance. He also found that that the removal of the time dummies was rejected for all specifications at the 1% level of significance. Hence, Huntington's (2006) results suggest there might be a role for asymmetric prices *and* a UEDT – an approach followed in the general model underpinning the research for this chapter.<sup>57</sup>

Huntington (2010) investigated total oil, other petroleum products, gasoline, and residual fuel oil demand for US over the period 1950 and 2005. He imposed both asymmetric price responses and a deterministic trend and concluded that long term adjustments are greater than short term adjustments and price increases higher than previous price hikes have a significantly greater impact on long term energy demand.

In summary, these key studies suggest that oil and energy demand responds differently to price increases above the previous maximum, price recoveries (below the previous maximum) and price decreases and that this should be taken into account for policy evaluation. The research for this chapter therefore incorporates asymmetric prices in the general model to attempt to capture these effects within the STSM/UEDT framework as well as allowing for TVPs. The next section therefore outlines the empirical framework used.

<sup>&</sup>lt;sup>57</sup> Although the UEDT in this chapter is in terms of a stochastic trend using time series data rather than times dummies used by Griffin and Schulman (2005) and Huntington (2006). Further support to incorporating both asymmetry and a UEDT for both time series and panel data is given in Adeyemi et al. (2010).

#### 6.3.3 Time Varying Parameters in US Gasoline Demand

As discussed in Chapter 2, as far as known the only US gasoline demand study that utilized TVP is Park and Zhao (2010). This study estimated a US gasoline demand function using monthly aggregate data over the period 1976 to 2008. Their findings suggest that the price and income elasticities increased from 1976 to 1980, decreased from 1980 to 1986, increased from 1986 to 1994, decreased from 1995 to 2005, and decreased from 2005 to 2008. The estimated income elasticity is smaller size with less variation than the price elasticity. Park and Zhao (2010) suggest that the price elasticity varies between -0.35 to -0.10 and the income elasticity varies between 0.02 and 0.10. Although the estimated price elasticity is consistent with current literature, the income elasticity is not.

#### **6.4 Empirical Framework**

As explained in the methodology chapter it is assumed that US per-capita gasoline demand is characterized by:

$$E_t = f(Y_t, p_t^{max}, p_t^{rec}, p_t^{cut}, UEDT_t)$$
(6.1)

For the econometric estimation of Equation (6.1), the log linear specification with time varying parameters is utilised (similar to Equations (3.16) and (3.17) in chapter 3) as follows:

$$e_t = \lambda_{1,t} y_t + \lambda_{2,t} p_t^{max} + \lambda_{3,t} p_t^{rec} + \lambda_{4,t} p_t^{cut} + UEDT_t + \epsilon_t$$
(6.2)

$$\lambda_{i,t} = \lambda_{i,t-1} + v_{i,t}$$
 where  $i = 1, 2, 3, 4$  (6.3)

 $e_t = Ln$  (gasoline demand per capita);  $y_t = Ln$  (GDP per capita);  $p_t^{max}$  = cum. increase in the nat. log. of maximum historical real gasoline prices;  $p_t^{rec}$  = cum. sub-maximum increase in the nat. log. of historical real gasoline prices;  $p_t^{cut}$  = cum. decrease in the nat. log. of historical real gasoline prices in year t;

 $\lambda_{1,t}$  = the income elasticity at time t;

 $\lambda_{2,t}$  = price max elasticity at time t;

 $\lambda_{3,t}$  = price recovery elasticity at time t;

 $\lambda_{4,t}$  = price cut elasticity at time t;

 $UEDT_t$  = underlying energy demand trend for gasoline;

#### 6.5 Data

US gasoline consumption and price data are obtained from the Energy Information Agency (EIA, 2010c) Gross Domestic Product, the Consumer Price Index, and Population are obtained from the US Department of Commerce Bureau of Economic Analysis (US BEA, 2010) for the period 1950 and 2008. In order to obtain the real gasoline price (*P*) and real GDP (Y) the nominal prices and nominal GDP are deflated by the US Consumer Price Index obtained from the US Department of Commerce Bureau of Economic Analysis (US BEA, 2010).

#### **6.6 Estimation Results**

In the first stage, the general specification with fixed coefficients as described in Equation (3.17) in Chapter 3 is estimated and the following results are obtained for  $\hat{e}_t$  and illustrated in Table 6.2.

Parameter	Coefficient		Std. Error		Probability	
Level Break 1979		-0.02909	0.00947		0.003	
Level Break 1955		0.02788	0.00923		0.004	
Outlier 1951		0.06022	0.00574		0.000	
$y_t$		0.40338	0.05911		0.000	
$p_t^{max}$		-0.27534	0.03659		0.000	
$p_t^{rec}$		-0.12787	0.02550		0.000	
$p_t^{cut}$		-0.05224	0.02892		0.077	
			Auxiliary		Residuals	
	Residua	ls	Irregular	Level	Slope	
Std. Error	0.981	Std. Error	0.965	0.982	0.980	
Normality	0.328	Normality	0.346	0.667	0.133	
Skewness	0.778	Skewness	0.912	0.452	0.164	
Kurtosis	0.143	Kurtosis	0.146	0.622	0.147	
H(17)	0.623		-	-	-	
<b>R</b> (1)	-0.025		-	-	-	
<b>R</b> (8)	0.032		-	-	-	
DW	1.997		-	-	-	
Q(8,6)	4.615		-	-	-	
Goodness of Fit		Hyperparameters				
<i>p.e.v.</i>	0.00009		Level	-0.0370		
$p.e.v./m.d.^2$	0.883		Slope	-0.00223		
$R^2$	0.997					
$R_d^2$	0.900		Nature Of Trend :	f Local Tren	d Model	

 Table 6.2: Estimation Results and Diagnostics Test for Fixed Coefficients (Stage 1)

Notes:

-See notes to Table 4.3<sup>58</sup>

-Model includes level interventions for the years 1955 and 1979;

-Model includes an outlier for the year 1951.

The above model passes all diagnostics tests that are summarized in Table 6.2 and furthermore illustrates some interesting results: firstly, the signs of all parameters accord with *a-priori* expectations; secondly, the estimated price elasticities conform to the *a-priori* expected relationship  $|\widehat{\lambda_p^{max}}| \ge |\widehat{\lambda_p^{rec}}| \ge |\widehat{\lambda_p^{cut}}|$ ; and thirdly, the estimated income elasticity is somewhat larger than the estimated price-max elasticity, which is consistent with previous

<sup>&</sup>lt;sup>58</sup>For simplicity and to save space the notes given in the previous table are not repeated again.

studies. In obtaining the estimated equation in Table 6.2, it was necessary to include an irregular intervention for 1951 and level interventions for 1955 and 1979 respectively in order to maintain the normality of the residuals and auxiliary residuals.

This first stage provides valuable information in order to set up the estimated specification for the second stage. It shows that, except for  $p_t^{cut}$ , all variables appear to have a significant role in US per-capita gasoline demand; therefore, in the second stage the restriction that the pricecut elasticity is equal to zero is imposed, by eliminating  $p_t^{cut}$  from the estimated equation.

*In the second stage* therefore, the coefficients are allowed to vary over time as given in Equation (3.16) in Chapter 3. The regression output is shown in Table 6.3 and the resultant equation at the end of the time period, for 2008 is given by:

 $e_t = 0.424255y_t - 0.30578p_t^{max} - 0.166972p_t^{rec} + 0.06170 Outlier 1951 + UEDT_t$ where;  $UEDT_t$  is 0.33775 in 2008.

The preferred model passes all the diagnostic tests including the additional normality tests for the auxiliary residuals generated by the STSM approach and has the lowest AIC value. The diagnostics tests are summarized in Table 6.3 and Figure 6.4.

Parameter		Coefficient	Std.Error	Probability		
Outlier 1951		0.06170	0.00706	0.000		
				Auxiliary Residuals		
	Residuals		Irregular	Level	Slope	
Std. Error	0.998	Std. Error	1.007	1.007	0.985	
Normality	0.893	Normality	0.893	0.884	0.673	
Skewness	0.803	Skewness	0.790	0.803	0.511	
Kurtosis	0.667	Kurtosis	0.693	0.667	0.549	
H(18)	0.692		-	-	-	
<b>R</b> (1)	-0.061		-	-	-	
<b>R</b> (8)	-0.084		-	-	-	
DW	2.103		-	-	-	
Q(8,6)	2.547		-	-	-	
Predictive Test 2001-2008			Information	ion Criterion Akaike (AIC)		
Failure	0.8728	-	AIC(a)		-8.9818	
Cusum t(4)	1.5625		AIC(b)		-8.9351	
			AIC(c)		-5.4334	
			AIC(d)		NA	
Goodness of Fit			Hyperparameters			
<i>p.e.v.</i>	0.0001	-	Level	0.3378	-	
$p.e.v./m.d.^{2}$	0.911		Slope	0.00218		
$R^2$	0.997					
$R_d^2$	0.888		Nature Of Trend :	Local Trend	Model	

 Table 6.3: Estimation Results and Diagnostics Test for TVP (Stage 2)

Notes:

-See notes to Table 4.3 and Table 6.2.

-Model includes an irregular for the year 1951;

-Information Criterion Akaike compensates for the number of estimated parameters in the model so that comparing models, which has a different number of parameters become possible. Small AIC values indicate better fitting models. Normally, the model with the lowest AIC is the 'statistically' preferred model

-AIC(a) represents model with time varying parameter and stochastic trend, AIC(b) represents model with fixed parameters and stochastic trend, AIC(c) represents model with fixed parameters and linear trend, and AIC(d) represents model with time varying parameters and linear trend (however, this model would not fully converge).

For the second stage, the resultant model has one irregular intervention for the year 1951. The

other interventions that were defined in the first stage (level interventions for 1955 and 1979)

were no longer needed to maintain the normality of the residuals and auxiliary residuals. As discussed in the methodology chapter, the irregular intervention might provide valuable information about certain events and periods that affects energy demand behaviour:

• the irregular intervention for 1951 probably reflects the record 8% increase in economic output that year (most of which came from the production for military purposes because of the Korean War) (US BEA; 1952). Also in this year, the trends for the passenger car index slightly decreased in the second half of the year, but despite this the transport equipment (excluding passenger cars) index increased more than a factor of two (US BEA; 1952). The irregular pulse effect found here affecting US per-capita gasoline demand is around 6%, which might be explained by this sudden increase in production and transport equipment.



**Figure 6.4: Prediction Graphics** 

The historical movements of coefficients and the stochastic trend with its components (slope and level) are presented in Figures 6.5 and 6.6 respectively. Although the elasticities vary over time, these fluctuations are relatively very small (when reduced to two decimal places they become identical). The estimated UEDT follows a stochastic process, which is successfully captured by the STSM approach. The signs of all parameters accord with *apriori* expectations. Moreover; the estimated price elasticities have the following relationship  $|\widehat{\lambda_p^{max}}| > \widehat{\lambda_p^{pec}}| > |\widehat{\lambda_p^{out}}|^{-59}$  which also accords with *a*-*priori* expectations, i.e. the estimated pricemax, price-recovery and price-cut elasticities are -0.31, -0.17 and 0 respectively. The estimated income elasticity is 0.42, which is somewhat larger than the estimated price-max elasticity and consistent with previous studies. These results are discussed in more detail in the conclusion section below.





 $<sup>{}^{59}\</sup>lambda_p^{\widehat{cut}}$  being zero given it is insignificant and hence excluded from the preferred equation.



Figure 6.6: UEDT of US Gasoline Demand and Slope-Level of UEDT

Given the preferred equation with the estimated non-linear UEDT has been obtained it is used to construct future scenarios for US gasoline demand per capita. The next section therefore outlines the assumptions about the future UEDT and other variables (price and income) that are used to construct the scenarios and presents the forecast scenarios.

#### **6.7 Forecast Assumptions**

As in previous chapters, the three forecast scenarios are implemented, a 'high' case, a 'reference' case and a 'low' case. However, where data are available for 2009 and 2010 (including GDP per capita and gasoline prices)<sup>60</sup> these are used in all scenarios. The detailed information about these scenarios follows.

<sup>&</sup>lt;sup>60</sup> US GDP per capita decreased 4% in 2009 and increased 2% in 2010, whereas gasoline prices decreased 28% in 2009 and increased 17% in 2010 in real terms. Hence, the data for 2009 and 2010 are utilized for all scenarios.

In the 'reference' scenario, it is assumed that real US gasoline price will increase by 1.5% annually after 2010. The average annual prices increase is around 1% over the estimation period however, the global oil demand is expected to increase at a faster pace in the future because of increasing oil demand from emerging economies, therefore the price increase is assumed slightly more than before. The increase in GDP per capita is expected to be 1% in 2011 and a 2% per annum thereafter. The average annual increase of GDP per capita is around 2% over the estimation period; hence, it is assumed that after the recovery period from the global economic crises GDP per capita will increase again by 2% annum. For the UEDT, a slope of  $0.002^{61}$  is projected for the period 2009-2020.

*In the 'low' case scenario*, it is assumed that the rise in the real US gasoline price will be 2.5% per annum after 2010, based on the assumption that the growing global demand for gasoline will increase the gasoline prices faster than it has been observed before. For GDP it is assumed that it will increase 0.5% in 2011 because of the economic recession and then increase annually 1.5% per year (lower than the estimation period average) until 2020. For the UEDT, a slope of -0.002 per annum between 2008 and 2020 is assumed suggesting that US authorities will introduce policies aiming improvement in efficiency standards. A graphical presentation of the scenario assumptions for GDP, real natural gas price index, and the UEDT are illustrated in Figure 6.7.

*In the 'high' case scenario*, the real US gasoline price is assumed to increase 1% annually for the period 2011-2020 (similar with the estimation period). Although it is expected that the demand for oil from emerging economies will push the petroleum products price up, it is assumed that although emerging technologies in the downstream will increase oil production,

<sup>&</sup>lt;sup>61</sup> Note that 0.002 is the same value of slope of UEDT at the end of estimation period.

this will balance the increase in demand. Furthermore, it is assumed that GDP will increase 2% in 2011 suggesting that US economy starts recovering from the global economic crisis, followed by a slightly faster recovery period with an annual 2.5% increase for 2012, and will increase by 3% per year thereafter to 2020. It is further assumed that energy using behaviour will continue for US per-capita gasoline demand at an even greater pace, suggesting that US citizens preference for the gasoline-fuelled appliances will increase faster than before. It is therefore assumed that the UEDT has a slope of 0.004 over the forecast period.



Figure 6.7: Forecast Scenarios for Price, GDP per capita and UEDT

#### **6.8 Forecast Results**

The three scenarios up to 2020 are illustrated in Figure 6.8. This shows that US per-capita gasoline demand is projected to be 10, 11, and 12 barrels (1590, 1740, and 1908 litres) in 2020 according to the 'low', 'reference' and 'high' case scenarios respectively.



Figure 6.8: US Gasoline Demand per capita Forecast Scenarios

#### **6.9 Summary and Conclusion**

Environmental and energy security concerns have led policy makers to attempt to implement measures in order to decrease US gasoline consumption. Carbon taxation is one of their favoured measures given it is easy to implement relatively to alternatives. However, its efficacy crucially depends on the price elasticity of gasoline demand, hence the importance of acquiring sound and robust estimates of this vital parameter. Furthermore, it is important to know how stable the estimate is; to have confidence that it is not going to change adversely over time. Hence, it is vital that the most appropriate model is used to estimate these vital parameters. It is argued here that the best way to achieve this is to estimate a US per capita gasoline demand relationship using the STSM/UEDT approach with asymmetric price responses in order to estimate the price and income elasticities as adopted in the research for this chapter. Using annual data for the period 1949 and 2008, the results suggest the following:

- i) The fluctuations in the estimated income and price elasticities over the estimation period are relatively small; in fact, when reduced to two decimal places they become identical. Hence, these results suggest that they are stable over time.
- ii) Price movements do not have a symmetric effect on US per-capita gasoline demand.
   Changes in the maximum historical real gasoline prices have a greater impact on the US gasoline demand than price recoveries that in turn has a greater impact than price cuts, with the estimated elasticities of -0.31, -0.17, and zero respectively over the estimation period.
- iii) The estimated income elasticity is around 0.42 over the estimation period.
- iv) The UEDT for US per-capita gasoline demand increases over the period 1949 to 1976 (except for 1952) and then starting from 1977 it declines until 1996 (except for 1994) and starting from 1997 the direction of UEDT switches to being upward until 2008. Between 1949 and 1976, the continuous increase in the underlying US per-capita gasoline demand might be because of several factors such as, change in lifestyles and widespread private car usage, and the rebound effect. After the first oil shock in 1973, the Energy Policy and Conservation Act of 1975 established corporate average fuel economy (CAFE) standards for new passenger cars. This act initiated the manufacturing of more efficient cars and might well be a reason for the decline of the UEDT between 1977 and 1996.

v) US per-capita gasoline demand is expected to be 10, 11, and 12 barrels by 2020, according to the generated 'low', 'reference' and 'high' case scenarios.

The results of this chapter suggest that the asymmetric price responses should be taken into account for sensible policy implications. US Congressional Budget Office (2008) used symmetric price elasticity of -0.26 for their assessment of different policy options for reduction of gasoline consumption and GHG emissions. However, the asymmetric price responses might affect the policy makers decisions as the price elasticity of -0.26 and -0.17 might lead to different outcomes. The results of this chapter advocate that prices need to increase above any previous maximum, otherwise the required demand reductions and GHG savings will only be 1.7% instead of the 2.6% required.

Another important outcome of this research is that polices to try and drive down US gasoline demand, other than raising prices through taxes, may have more of an impact given the impact of the exogenous estimated UEDT. The estimated reductions that look to come through exogenously via the UEDT appear (at times) to be driven by the CAFE standards, suggesting that these have a noteworthy impact on reducing gasoline demand. Thus, the imposition of even tighter CAFE standards should arguably be re-evaluated in the light of the results found here.

#### **CHAPTER 7: Summary and Conclusions**

#### 7.1 Introduction

The research for this thesis utilized the Structural Time Series Model (STSM) approach of Harvey (1989) coupled with the Underlying Energy Demand Trend (UEDT) concept of Hunt et al. (2003a and 2003b) to model and forecast:

- i) Turkish Electricity demand (in Chapter 4);
- ii) OECD-Europe natural gas demand (in Chapter 5); and
- iii) US per-capita gasoline demand (in Chapter 6).

Chapter 1 discusses the importance of energy in our daily life and the factors that affect energy demand as well as the importance of energy demand modelling. Chapter 1 also sets out the objectives of the research and details the research questions that are attempted to be answered. Chapter 2 presents the literature review, discussing the different energy demand modelling approaches including arguing that in order to answer the research questions, an econometric approach is chosen, in particular the STSM/UEDT approach which is adopted throughout the research. Given this choice, Chapter 3 reviews previous energy demand studies that have adopted a similar approach as well as explaining the STSM and the UEDT concept in detail as well as the empirical framework, estimation strategy, and the way the results are interpreted in Chapters 4-6. Chapter 3 also details how the future scenarios are constructed in Chapters 4-6 as well explaining the extensions to the basic STSM/UEDT approach introduced in Chapters 5 and 6.

The STSM/UEDT approach therefore underpins the research throughout the thesis since, as argued in the earlier chapters, it is seen as the most appropriate econometric technique for estimating energy demand relationships. Nonetheless, the core methodology was enhanced in

the latter chapters by attempting to analysis the relative importance of the economic and noneconomic drivers of OECD-Europe natural gas demand (Chapter 5) and including time varying parameters and asymmetric price responses for US per-capita gasoline demand (Chapter 6).

As explained in the introductory chapter, one of the main reasons for favouring the STSM/UEDT approach is that, in addition, to estimating the impact of key economic drivers of energy demand, income and price, it also attempts to capture the impact important, but unobservable, components in a non-deterministic way. This thus allows for the identification of important structural changes in energy demand behaviour, thus attempting to uncover robust income and price elasticities. Information about points of structural change and robust estimates of price and income elasticities of energy demand are vital for a number of energy market participants (such as governments, regulative bodies, energy companies and financial institutions) in order to assess the implications of past policy, to help reduce future uncertainty, and to assist in developing future policy and its implications. Consequently, in addition to the modelling and forecasting, the history of the energy situation and policies are considered and evaluated, as well as offering some recommendations for where future energy policy might develop for Turkish electricity (Chapter 4), OECD-Europe natural gas (Chapter 5), and US gasoline (Chapter 6). The next section therefore revisits and answers the Research Questions outlined in Chapter 1 followed by the final section that summarizes the key policy implications of the results and discuss the areas of possible future research.

#### 7.2 Research Questions Re-visited

#### 7.2.1 Main research questions

#### Q1: What are the advantages of STSM approach when estimating energy demand functions?

As discussed in detail, energy is a derived demand rather than being a demand for its own sake and there are number of exogenous factors that affect the resultant energy demand. Therefore, it is argued that it is important that these effects are not ignored when modelling energy demand and attempting to estimate robust energy demand relationships. The uneven structure of the exogenous factors makes it almost impossible to model them separately and/or within a linear framework; hence, the need for the flexibility of the STSM/UEDT approach to capture the effects adequately. The estimated UEDTs are important components of energy demand reflecting how (holding price and income constant) energy demand behaviour develops over time and it is argued that they should therefore be treated in an appropriate way in order to obtain unbiased and robust elasticities and the STSM approach provides a flexible framework to deal with the lumpiness characteristics of exogenous factors that affect energy demand behaviour.

# *Q2:* What are the implications of the estimated UEDTs, and the price and income elasticities for future energy demand and policy analysis?

With the UEDTs estimated, the energy demand responses to income and price movements are also estimated and it is argued that these estimates are more robust than alternative estimates. Moreover, future projections are not just dependent upon income and price effects but require thought and assumptions about future behaviour based upon the estimated UEDTs over the past. Thus, future projections should also prove more robust as applied to Turkish electricity, OECD-Europe natural gas and US per-capita gasoline (discussed further below).

#### 7.2.2 Sub Research Questions

In addition to the primary research questions, Chapter 1 introduced a number of sub-research questions for the various sectors and fuels for Turkey, OECD-Europe, and the US:

-What are the shape and directions of UEDTs? Do they indicate any structural changes in demand behaviour of the investigated countries?

-What is the best estimate of short-long run price and income elasticities?

-What will be the future energy demand?

In addition, the following sub research question was introduced for OECD-Europe natural gas demand:

-What are the relative contributions of income, price, and the UEDT in driving OECD-Europe natural gas demand?

Finally, the following two additional sub research questions were in included for US per capita gasoline demand:

-Are Asymmetric Price Responses important in driving US gasoline demand per capita?

-Is there evidence of time varying elasticities for US gasoline demand per capita?

The answers for these sub questions are as follows:

*i)* For the Turkish Industrial Sector

- The estimated UEDT is generally increasing (but at a decreasing rate) over the estimation period, i.e. it is generally energy using; as shown in Figure 7.1. The estimated UEDT for the Turkish industrial sector is generally increasing, but the underlying rate of increase diminishes with a significant structural change in 1981 (reflecting the implementation of the first planned energy conservation activities by the General Directorate of Electrical Power Resources Survey Administration-EIE).

Figure 7.1: Underlying Electricity Demand Trend (UEDT) of Turkish Industrial Sector Electricity Consumption 1960-2008



-The estimated industrial value added (output) elasticity is 0.15 and the estimated industrial energy price elasticity is -0.16.

- Turkish industrial is projected to be 97, 121, and 148 TWh by 2020 according to the 'low', 'reference' and 'high' case scenarios respectively.

*ii)* For the Turkish Residential Sector

- The estimated UEDT for the Turkish residential sector is highly stochastic with periods when it is increasing and periods when it is decreasing. This is displayed in Figure 7.2, showing that it reflects the compulsory electricity cuts introduced by the Turkish governments (primarily in the residential sector) aimed at conserving electricity consumption between 1971 and 1983.

Figure 7.2: Underlying Electricity Demand Trend of Turkish Residential Sector 1961-2008



- The estimated household total final expenditure elasticity is 0.38 in the short run and 1.57 in long run. Additionally the short run and long run price elasticity is -0.09 and -0.38 respectively.

- It is projected that future residential electricity consumption will be 48 TWh, 64 TWh and 80 TWh in the, 'low', 'reference' and 'high' case scenarios respectively in 2020.

#### *iii)* For Turkish Aggregate Electricity Demand:

- The estimated UEDT for the Turkish aggregate electricity is generally upward sloping (energy using) but at a generally decreasing rate as shown in Figure 7.3.

- The estimated income and price elasticities for Turkish aggregate electricity are 0.17 and -0.11 respectively.



Figure 7.3: Underlying Aggregate Electricity Demand Trend of Turkey 1960-2006

-Turkish aggregate electricity consumption is predicted to be 259, 310, and 368 TWh in the 'low', 'reference' and 'high' case scenarios respectively by 2020.

#### iv) For OECD-Europe Natural Gas Demand:

-The estimated UEDT for OECD-Europe natural gas demand is increasing and decreasing over the estimation period but generally decreasing after 1996 as displayed in Figure 7.4.


Figure 7.4: The estimated UEDT of Natural Gas Demand of OECD Europe 1972-2008

- The estimated short and long run GDP and price elasticities for OECD-Europe natural gas demand are 0.95 and -0.18 respectively

-The OECD-Europe natural gas demand is expected to be 295, 357 and 468 mtoe by 2020, according to the generated low, reference and high case scenarios.

-The relative contributions of income, price and the UEDT in driving OECD-Europe natural gas demand is shown in Figure 7.5. This shows that the estimated contribution from income is consistently high, suggesting it was and remains the main driver of OECD-Europe natural gas demand. Whereas the estimated contribution from the UEDT has periods when it was relative important and periods when it was not but, in contrast, the estimated contribution from price is relatively small.





## *v)* For US Per Capita Gasoline Demand:

- The estimated UEDT for US per capita gasoline demand increases over the period 1949 to 1976 (except for 1952) and then starting from 1977 it declines until 1996 (except for 1994) and starting from 1997 the direction of UEDT switches to being upward until 2008, as shown in Figure 7.5. Between 1949 and 1976 the continuous increase of in underlying US per-capita gasoline demand (holding income and price constant) reflects several factors such as, change in life styles and widespread of private car usage, and the rebound effect. Furthermore, it reflects that after the first oil shock in 1973, the Energy Policy and Conservation Act of 1975 established corporate average fuel economy (CAFE) standards for new passenger cars. This act, which initiated the manufacturing of more efficient cars (Greene, 1990), is reflected in the decline of the estimated UEDT between 1977 and 1996.



Figure 7.6: UEDT of US Gasoline Demand and Slope-Level of UEDT

- Price movements do not affect US gasoline demand symmetrically. Changes in the maximum historical real gasoline prices have a greater impact on the US gasoline demand than price recoveries that in turn has a greater impact than price cuts, with the estimated elasticities of -0.31, -0.17, and zero respectively over the estimation period. The estimated income elasticity is around 0.42 over the estimation period 1949 to 2008. Furthermore, there is no evidence that income and price elasticities vary over time.

-It is projected that US per capita gasoline demand will be 10, 11, and 12 barrels (1590, 1740, and 1908 litres) by 2020, according to the generated low, reference and high case scenarios.

## 7.3 Conclusion and Future Research Areas

The energy needs of modern societies are currently mostly met by exhaustible fossil fuels. Energy scarcity is one of the important obstacles for sustainable economic growth. During the 1980s and 1990s, because of the relatively low and stable energy prices, the interest for energy demand studies diminished. However, in today's world the rapid increase in energy demand mostly coming from emerging economies has triggered concerns about energy scarcity and security. Different to the past, energy prices have (and are likely to continue to) go beyond their historical peaks and the need for rational planning might well become a priority for nations whose economic growth is highly dependent on energy. The understanding of energy consuming behaviour and robust reliable future projections of energy demand has therefore arguably never been so vital for welfare of humankind (Slade et al. 1993).

Therefore, this thesis, and the research that underpins it, demonstrates the advantages of the STSM coupled with the UEDT concept when estimating energy demand models, in addition to showing how it can be augmented with asymmetric price responses and time varying parameters. It is argued that the STSM approach has significant advantages in terms of:

- modelling stochastic UEDTs with its flexible empirical framework;
- identifying unbiased and robust price and income elasticities by taking into account the UEDT; and
- identifying structural breaks and changes in energy demand behaviour.

Therefore, the STSM approach enables the estimation of robust energy demand models that are vital for policy makers and other market participants. Firstly, they arguably enable the generation of better projections thus allowing the development of better policy tools and measures for future energy demand policy. Secondly, by detecting the structural changes in the UEDTs, the STSM allows an assessment of the impacts of past policy decisions on energy demand behaviour; hence, using this approach arguably facilitates the choice of the more effective policies. Finally, by providing information about the components of the UEDT (such as the level and the slope), the STSM provides information about the unobserved components that affect energy demand behaviour; thus making it possible to develop assumptions about our future expectations of these unobserved components.

That said, there is still scope to improve the research. Further research could disaggregate the Turkish sectors further to analyse sub industries in order to better understand their energy consuming behaviour and provide a more disaggregated forecast. Similarly, OECD-Europe gas demand could be disaggregated into to smaller regions and/or countries to test the robustness of the results and projections found here. Moreover, although the time varying parameters approach applied in Chapter 6 did not provide any evidence that income and price elasticities change over time, this might not always be the case. Hence, future energy demand models might explore this approach with general models assuming that the parameters do vary over time and only accepting that the elasticities are constant over time if that is accepted by the data – and the STSM approach has power to estimate such models. And one final point, although it has been argued that the STSM has a important advantage in terms of estimating a stochastic trend, an interesting extension to this research would be to compare the outcome here with more conventional econometric approaches, such as VECM type models of energy demand in order to evaluate the performance of different empirical frameworks.

Despite these possible extensions and improvements, this thesis has addressed a number of major issues in the energy demand modelling literature, combining and exploring several of them to examine different types of energy demands for different countries or group of countries. The insights, results and projections provided by this research should be of particular value to policy makers helping to reduce the risks related with the uncertainty of future energy demand and aid long term energy planning activities.

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