The Energy-Economic Growth Nexus: Empirical Evidence for New Zealand

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ABSTRACT

This study addresses the energy consumption and energy price-economic growth nexus for the case of New Zealand. Several hypotheses concerning the impacts of energy consumption and oil price shocks on economic growth are empirically examined, as these issues have important policy implications that have received little attention in New Zealand.

Utilising the Autoregressive Distributed Lag approach to cointegration, the energy consumption-economic growth relationship is analysed over the period 1960-2004. Two key approaches are followed in terms of a cointegration and causality framework to answer whether energy consumption is a stimulus for economic growth or if economic growth leads to energy consumption. The energy consumption-growth nexus are examined based on the theoretical arguments of the trivariate demand model, trivariate supply model and multivariate supply model. The results indicate that long run relationships exist between various sets of variables, i.e. energy consumption, energy prices, labour and capital. Given the central role of energy to New Zealand's domestic growth agenda as well as international climate change commitments, the estimated results provide a basis for policy prescriptions to deal with these issues for the short run and long run.

The related issue of oil price shock impacts on economic growth is considered for the period 1989-2006 using the Vector Autoregressive methodology based on quarterly data. Three oil price measures are considered, given the various theoretical implications that oil price shocks have on economic growth. The estimated results are based on the concept of 'net oil price shocks', and indicate that such shocks impact significantly on several key macroeconomic variables in a manner that is consistent with the economic theory. The findings of this study provide policy implications based on the key elements of New Zealand's energy-growth relationships and energy policies, in light of energy scarcity, climate change issues, and the related policy responses.

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LIST OF ABBREVIATIONS

ADF	Augmented Dickey-Fuller
AIC	Akaike Information Criterion
ARDL	Autoregressive Distributed Lag
BP	Beyond Petroleum
CPI	Consumer Price Index
ECNZ	Electricity Corporation of New Zealand
ECT	Error Correction Term
EEC	European Economic Community
EU	European Union
GDP	Gross Domestic Product
GFK	Gross Fixed Capital Formation
GHG	Greenhouse Gas
GIC	Gas Industry Company
GNP	Gross National Product
IEA	International Energy Agency
IFS	International Financial Statistics
IPCC	Intergovernmental Panel on Climate Change
KP	Kyoto Protocol
KPSS	Kwiatkowski-Phillips-Schmidt-Shin
LM	Lagrange Multiplier
LOP	Linear Oil Price
LR	Likelihood Ratio
MP	Monetary Policy
MTA	Motor Trade Association
MTOE	Million Tonnes of Oil Equivalent
MW	Megawatt
NOPI	Net Oil Price Increase
NZ	New Zealand
NZIER	Mew Zealand Institute of Economic Research
NZRC	New Zealand Refining Company
OECD	Organisation for Economic Cooperation and Development

OPEC	Organization of the Petroleum Exporting Countries
PPI	Producer Price Index
RBC	Real Business Cycle
RMA	Resource Management Act 1991
SBC	Schwarz Bayesian information Criterion
SOE	State Owned Enterprise
SOPD	Scaled Oil Price Decrease
SOPI	Scaled Oil Price Increase
TCE	Total Consumer Energy
TLF	Total Labour Force
UN	United Nations
UNFCCC	United Nations Framework Convention on Climate Change
US	United States
UK	United Kingdom
VAR	Vector Autoregression
VECM	Vector Error Correction Model

Chapter One

INTRODUCTION

Energy is the precursor of economies.

(Shelley, 2005, p. 1)

1.1 Aims and Objectives

The purpose of this study is to examine the issues of energy consumption and energy price shocks to New Zealand's growth. These are important issues in the current policy environment that have received little formal attention in New Zealand. Analysing the role of energy consumption and price signals to the process of economic growth, the study evaluates which energy resources interact with macroeconomic variables through the distinct channels of consumption and price effects to enhance growth.

The existing literature on energy consumption-growth relationships is based on the neoclassical and ecological economic theories of economic growth, which imply several relationships between energy and growth. Empirical time-series studies have considered the causal relationship between these variables for a range of country case-studies utilising several approaches to the issues of cointegration and causality. These studies provide mixed results that support both the neoclassical and the ecological economic hypotheses in different country contexts. Given the New Zealand Government's emphasis on achieving economic growth while simultaneously moving to a more sustainable energy system in the period of Kyoto Protocol commitments (New Zealand Government, 2002; Ministry of Economic Development, 2004), this study attempts to analyse the role of energy consumption and energy price shocks to economic growth, based on growth theories and their implications for economic and energy policies. To this end, several reduced-form models are utilised that are free of structural linkages. To examine the hypotheses of energy-growth in New Zealand, the models are estimated on time series annual data for the period 1960-2004 and quarterly data for the period 1989 Q1 to 2006 Q1. In light of the existing literature this study develops several models of energy-economic growth nexus for New Zealand. Based on the theoretical aspects, the models are empirically examined using the Autoregressive Distributed Lag (ARDL) approach to cointegration so that the long run and short run Granger causality can be investigated, as well as utilising the additional information for energy price, capital and labour variables. The results of these models provide policy implications on macroeconomic, energy and environmental policies that relate to New Zealand's economic growth.

A second crucial issue concerns energy price shocks, which have also been argued to have macroeconomic consequences. These concern oil prices in particular following the well-known oil 'price shocks' that occurred in the 1970s. Hamilton (1983) has demonstrated that all but one of the recessions in the United States (US) that occurred between 1948 and 1972 were Granger caused by exogenous increases in the price of oil, which is at odds with the prediction of the neoclassical theory. The basic neoclassical theory posits that given the small cost share of energy in Gross Domestic Product (GDP), energy price effects should not be important for economic growth. However, numerous empirical analyses conducted since Hamilton's (1983) study have found a vital impact for oil prices on the economic growth of the US economy and elsewhere. These studies utilise several oil price transformations, the origins of which are embedded in various theories of factor mobility, investment uncertainty and asymmetric prices, to evaluate the macroeconomic impacts.

Given the 'price taker' status of New Zealand as a small open economy, this study addresses the impact of oil price shocks from the economic growth perspective utilising several of the leading oil price measures. In particular, the study examines the issue of oil price shocks during the period of oil market deregulation of 1989-2006. Given the volatility of oil prices, both historically and in the recent period, thus quarterly observations are taken into consideration using the Vector Autoregressive (VAR) modelling framework. The variables employed include oil prices, economic growth, effective exchange rates, wage rates and inflation. This system of macroeconomic variables are analysed to address the direct effects of oil price shocks, as well as the indirect effects that are hypothesised to operate through labour market, exchange rate and inflation channels, on New Zealand's economic growth performance.

In order to empirically estimate the energy consumption and price effects on economic growth, reliable indicators are needed. The single best measure of economic performance at the national level for any country is GDP, which for New Zealand has fluctuated between 10 percent and -3 percent over the period 1960-2004. The GDP growth has consistently been positive in the period since 1989 (International Monetary Fund, 2006b). At the same time, the total consumption of oil, gas, electricity, coal, geothermal and renewable energy resources has increased from less than four Million Tonnes of Oil Equivalent (MTOE) to more than 14 MTOE (International Energy Agency, various). Furthermore, the majority of the energy resources (i.e around 50 percent) currently consumed are oil resources. Thus, several questions arise as to the role of energy consumption in economic activities and the possible impact of oil price shocks on growth.

An analysis of the energy-growth nexus for New Zealand is valuable for a number of reasons. First, it is important to understand the relationship between energy resources and economic growth such that policies can be formulated which allow for the joint achievement of energy sector and macroeconomic objectives. These include, for example, developing the sustainable energy system and delivering the higher rates of economic growth that are sought in various policy documents (Cf. Ministry of Economic Development, 2004; New Zealand Government, 2002). Second, the initial commitment round of the Kyoto Protocol during the period 2008-2012 requires a reduction in New Zealand's greenhouse gas (GHG) emissions burden that can be achieved by either reducing the level of emissions (through energy conservation measures) or through purchasing emissions credits from countries which have surplus emissions allocations. Identifying the prospects for undertaking energy conservation policies from the economic growth perspective can assist policy-makers in deciding which of the available options may be the more efficient measure in the long run. Finally, the dearth of empirical analyses addressing energy and growth issues for the case of New Zealand suggest an assessment of this topic is warranted, such that findings may result into important policy decisions in addition to highlighting the specific areas of inquiry requiring further analysis and research.

This study has several key objectives. The first objective is to provide an overview of the theoretical and empirical literature concerning the issues of energy consumption and energy price shocks and their relationship with economic growth in the developed and developing countries. The second objective is to synthesise the important elements of New Zealand's recent economic history, the key developments in the energy sector and the central elements of energy policy, focussing on the period since 1960. The third objective is to evaluate the energy consumption-economic growth relationship that could highlight the future direction of the energy sector in New Zealand. The final objective is to empirically address the issue of oil price shocks from the perspective of economic growth impacts over the short run, using several alternative definitions of oil price shock. Utilising vital variables of the labour market, foreign exchange market and inflation variables provide policy-makers the direction New Zealand needs to take. These areas of inquiry have been the subject of much theoretical and empirical research over the last 30 years, however little empirical work for New Zealand has been undertaken. It is anticipated that the findings from this study will inform policy-makers with simultaneously achieving energy policy objectives and a higher rate of economic growth, as well as providing useful information of this complex and little-known areas of energy resource-economic growth nexus in New Zealand.

1.2 Energy Resources and Economic Growth: An Overview

The supply and provision of numerous energy resources underscore various modes of economic production in both the developed and developing countries. Vast networks of trade in energy resources provide substantial wealth to the supplier countries and allow other nations to benefit from modern means of transport, production and social organisation. Undoubtedly, the harnessing of energy resources such as coal, oil and gas have been fundamental to the process of global industrialisation during the nineteenth and twentieth centuries (Goldstein *et al.*, 1997).

Various economic theories have been developed to explain the relationship between energy resources and economic growth, with two competing schools of thought placing vastly different emphases on the importance of energy resources to production in the industrialised economies. The mainstream neoclassical theory of economic growth highlights investment in capital, population growth and technological progress as the crucial drivers of growth in the historic processes of development. The role of energy as a factor of production is downplayed in the neoclassical theory, given that factor substitution and technical progress are assumed to be able to ameliorate energy resource shortages and hence to enable prolonged economic growth (Stiglitz, 1997). Therefore, it is the rate of economic growth that determines the rate of energy consumption, and not vice versa.

In addition, the neoclassical theory posits that the small cost share of energy resources in GDP (generally around 3-5 percent for the developed economies) disqualifies the potential impact that a rapid increase in the price of energy inputs – i.e. an energy 'price shock' - could have on economic growth. Given these observations, in the neoclassical model energy should not be an important economic growth determinant. Contrastingly, the ecological economics school of thought argue that energy is the sole primary factor of production, with the development and utilisation of physical and human capital dependent on the availability of energy in various forms (Stern and Cleveland, 2004). From this perspective, economic growth is not feasible without energy resources. The implications of the competing theories for policy-makers differ greatly, and furthermore the empirical evidence supporting the neoclassical and ecological economics theories is mixed.

On the one hand, the observed one-third reduction in energy per unit GDP of the Organisation for Economic Cooperation and Development (OECD) countries over the period 1971-2000 suggests that energy resources may not be vital to production, in light of the substitution and technological progress opportunities (International Energy Agency, 2004). On the other hand, this may be explained - as ecological economists claim - by the substitution of low quality resources, such as coal for high quality fuels, such as electricity (Cleveland *et al.*, 2000). Similarly, the statistical causality from oil price shocks to economic recession that Hamilton (1983) reports, for all bar one of the United States (US) recessions between 1948 and 1972, suggests that energy prices are indeed significant macroeconomic variables that may impact on the macroeconomy multifariously, through indirect channels.

A growing consensus among researchers is that energy resource-economic growth relationships are dependent on country-specific factors (Altinay and Karagol, 2004). Accordingly, the use of cointegration and causality analysis for the case of a single country study is prevalent in the recent empirical literature (for example, see Guttormsen, 2004). Furthermore, the use of appropriate models and methodologies is crucial in identifying the underlying relationship. Developments in the oil price-economic growth literature concern nonlinear transformations of the underlying price measures that are based on an array of theoretical extensions, and the potential importance of indirect transmission channels. These issues are all incorporated in the empirical analysis that follows in chapters 4 and 5 of this study. In the next section, the data and methodology issues used for evaluating the models are discussed.

1.3 Data and Methodology

The study utilises several models to analyse the energy-growth sector in New Zealand, evaluating various hypotheses relating to the energy-consumption growth relationships and energy prices-growth nexus. In order to develop each model datasets were constructed to capture the long run information and the behaviour of the variables. These data were collated from various sources. The primary data used in chapter 4 for GDP and capital variables were taken from the International Monetary Fund's *International Financial Statistics* (IFS) database, while the energy consumption data used in the models for chapter 4 are taken from the International Energy Agency's *Energy Balances of OECD Countries* (various). Labour force data are from the Groningen Growth and Development Centre's *Total Economy Database*. For the price-growth models in chapter 5, Statistics New Zealand's *Information Network for Official Statistics* (PC INFOS) database has been utilised to collate the primary data for the GDP, wage, inflation and exchange rate data. These have been supplemented by the IFS database for oil price data.

The primary data were supplemented by secondary energy-use data disaggregated by sector, and energy quality data disaggregated by resource type, that were provided by the Ministry of Economic Development and the New Zealand Centre for Ecological Economics, respectively. Nominal values have been transformed into real values (constant 2000 prices) using the relevant deflators as outlined in the text. All of the data are from reputable and generally-used sources of the studies, where these organisations have reliable data.

The methodologies employed to evaluate the various models include the most-current econometric procedures of the time series literature. In the case of the consumption models (chapter 4) based on 45 annual observations for the period 1960-2004, the Autoregressive Distributed Lag (ARDL) approach to cointegration is utilised given its advantageous small sample properties noted by Pesaran and Shin (1998b) and Pesaran *et al.*, (2001). Several different models are constructed based on demand-side and supply-side considerations of the energy-growth relationships, and Granger causality between the various variables is then explored by means of the Wald F-test. On the other hand, the oil price models (chapter 5) are based on 70 quarterly observations ranging over the period 1989 Q1 to 2006 Q1. Therefore the VAR modelling approach has been adopted to consider the short run causality between oil prices and real GDP growth, and the macroeconomic impacts of oil price shocks. Given the degrees of freedom available, parsimonious models with different specifications of the variables are constructed that incorporate the foreign exchange sector, macroeconomic and labour market impacts as well as the direct effect of oil prices on growth. These methodologies are appropriate given the modelling context of this study, as they allow for the formulation of policy-based discussion deriving from robust results that accurately reflect the underlying relationships between the variables. Detailed methodology for each modelling framework is discussed in the relevant chapters.

1.4 Chapter Outline

In examining the energy-growth nexus for New Zealand, the study is structured as follows. Chapter 2 provides a thorough review of the academic literature, discussing the range of relevant theoretical perspectives and presenting the existing evidence from empirical studies. Chapter 3 provides a background to the New Zealand macroeconomy over the twentieth century, tracing the important elements in the economic development of the nation. This is complemented by a detailed discussion of the energy sector and the critical aspects of energy and environmental policies as they relate to the economic growth performance. Chapter 4 presents an empirical evaluation of cointegration and causality between energy consumption and real GDP using a number of multivariate approaches that are based on economic theory of energy-growth nexus. Chapter 5 has a similar empirical focus; however the relationship of interest concerns oil price shocks and their impact on economic growth. Three oil price shock formulations are considered here based on the recent theoretical literature, with potential labour market, inflation and exchange rate effects evaluated as well as the direct effects on economic growth. Finally, chapter 6 concludes the study by considering the implications of the various empirical findings for economic and energy policies. It also highlights the further research questions from the broad energy-growth nexus that remain open to further scholarship.

Chapter Two

LITERATURE REVIEW

First of all, economists have been interested in the relative availability of economically recoverable natural resources and how the stock of these resources has been changing over time. Second, economists have been concerned with how the price, discovery, and depletion of natural resources have affected economic growth.

(Boyd and Caporale, 1995, p. 181)

2.1 Introduction

This chapter reviews the important theoretical and empirical literature examining the energy-economic growth nexus, focusing on the role and importance of energy consumption and price signals to the process of economic growth. The effect of these factors on economic variables relate to energy's role as both a key input to production and an important source of pollution. These issues have received important consideration for their presumed impact on macroeconomic activity (Cuñado and Pérez de Gracia, 2003).

An extensive literature considers the relationship between energy consumption and economic growth. An understanding of this relationship is vital for designing and implementing energy conservation policies with minimum economic disruption. Important considerations include the long-term prospects for energy availability and the environmental consequences of energy production and combustion. Given the extensive use of energy in historic processes of growth and development and the rapid modernisation of many developing countries, these are crucial issues to be addressed in the climate of scarcity and change.

The economic performance of many countries during the post-oil shock period of the 1970s has also given rise to an extensive body of research that addresses the direct impact of energy price shocks on macroeconomic performance, and the relationship between energy inputs and various other determinants of economic growth. Economic theory suggests a number of channels through which energy price shocks may impact on economic growth aside from energy's role as a factor of production. Relevant theoretical considerations include the labour market dispersion effects (for example, see Loungani, 1986; Finn, 2000; Davis and Haltiwanger, 2001), investment uncertainty (see Bernanke, 1983; Dixit and Pindyck, 1994; International Monetary Fund, 2005), consumption smoothing in durable goods (see Hamilton, 1988a, 2003; Lee and Ni, 2002) and the consequences for inflation (Pierce and Enzler, 1974; Gordon, 1975; Mork, 1981b; Bruno and Sachs, 1982).

The rest of the chapter is structured as follows: Section 2.2 presents the important theoretical elements which frame the debate on energy's role in the process of economic growth. Section 2.3 considers the relationship between energy consumption and economic growth that is implied by the economic theory in greater detail, drawing on the existing body of empirical literature. Section 2.4 addresses the impact of energy price shocks on the process of economic growth, with consideration given to a range of theoretical transmission mechanisms and the estimated magnitude from previous empirical studies. Finally, section 2.5 summarises and notes the relevance of this study for New Zealand.

2.2 Energy-Economic Growth Nexus: Theoretical Aspects

A central issue within macroeconomics is the process of long run economic growth. This is an important area for research, because understanding the process of economic growth creates the opportunity to make substantial improvements to human welfare. A range of different models have been utilised to explain the growth process dating back at least to Ramsey's (1928) study of inter-temporal household optimisation (Barro and Sala-i-Martin, 2004), while a role for energy signals dates back to Hicks's (1932) study that relates energy to economic growth by allowing for changing input prices to impact on the process of innovation. The dominant framework for undertaking theoretical and empirical evaluations of the economic growth process in the post-war period, however, has been the neoclassical structure presented by Solow (1956) and Swan (1956). The basic neoclassical theory has been expanded by several studies to take into account the fixed quantity of resource inputs, and applied to energy issues for the short run and the long run. The section below discusses the changing structures of various growth theories by incorporating the use of energy as a vital factor for growth.

2.2.1 The Neoclassical Model of Economic Growth

The seminal work of Solow (1956) and Swan (1956) is based on an aggregate production function with constant returns to scale, diminishing returns to inputs, and positive elasticities of substitution between inputs. Output (Y) is modelled principally as a function of capital (K), labour (L), and 'technological progress' (A), which is generally taken to represent the skills and knowledge used to turn labour and capital inputs into useful outputs (Romer, 2001). In its simple form, where the term 'AL' indicates 'effective labour' or labour-augmenting technological progress, the neoclassical production function is given as follows:

$$Y = F(K, AL) \tag{2.1}$$

When the assumption of constant returns to scale is invoked, so that $y = \frac{Y}{AL}$, $k = \frac{K}{AL}$ and $f(k) = F(k,1)$, the production function can be rewritten as:

$$y = f(k) \tag{2.2}$$

As it is the level of income per person that correlates to a country's standard of living, this form of the production function is often preferred to the aggregate measure. The implication is that output per unit of effective labour depends on the level of capital per unit of effective labour. The basic model assumes technological progress and population growth to be determined outside the model, hence the process of growth is driven by capital accumulation and so the dynamic behaviour of capital per unit effective labour, *k*, is central to the model (Aghion and Howitt, 1998).

Two simplifying assumptions of the Solow-Swan model are that the rate of savings is constant and equal to fraction s of income Y, and that fraction δ of the capital stock depreciates each year. Therefore, the rate of change of the capital stock can be given by the time-derivative $\dot{K}$ as: [1]

$$\dot{K} = sF(K) - \delta K \tag{2.3}$$

[1] Notational convention is for a dot over a variable to indicate the derivative of the growth rate of that variable with respect to time.

The implications of these assumptions for capital per unit of effective labour can be evaluated by considering the dynamics of population growth ($\dot{L} = n$) and productivity growth ($\dot{A} = g$). Both of these variables impact positively on the growth of the effective labour supply, so the time path of capital per unit of effective labour can be expressed with the following equation:

$$\dot{k} = sf(k) - (n + g + \delta)k \tag{2.4}$$

Additionally, the assumption of diminishing returns to capital implies that consecutive additions to the capital stock will contribute less at the margin. Formally this is given for all levels of K as:

$$\frac{\partial Y}{\partial K} > 0 \text{ and } \frac{\partial^2 Y}{\partial K^2} < 0$$

In the absence of some offsetting factor, diminishing returns to capital implies that growth will eventually cease in the neoclassical model. In the context of equation (2.4), diminishing returns to capital implies that eventually, total savings will be exhausted just offsetting the effective depreciation. This is implicit in the 'fundamental equation' of the Solow-Swan model, which takes the following form:

$$sf(k) = (n + g + \delta)k \tag{2.5}$$

At the point in time identified in equation (2.5), $\dot{k} = 0$ i.e. the capital stock grows at the same rate as the effective workforce (i.e. at rate $n + g$). The capital stock per effective worker is equal to k^*, and the economy is said to have reached the steady state where all variables grow at constant rates (Barro and Sala-i-Martin, 2004).

In the steady state (where $y^* = f(k^*)$), output per effective worker is constant, total output increases at the rate ($n + g$), and output per capita grows at the rate of technological progress, g. That is, long run growth is determined solely by the (exogenous) rate of technological progress. The neoclassical model has provided a pragmatic framework for empirical research and has been used extensively in the field of energy economics. A number of studies have expanded the simple neoclassical model presented above to consider important growth issues surrounding energy resources in the production process. These issues are noted in the next section.

2.2.2 The Neoclassical Model with Non-Renewable Energy Resources

The neoclassical theory of economic growth focuses largely on the role of capital and labour inputs. However, energy resources also constitute an important factor of production with distinct physical and economic properties. This suggests that energy inputs may be important for explaining economic growth. The neoclassical production function given by equation (2.1) can be expanded to incorporate energy resources explicitly. With 'E' representing energy resources, the other variables representing output, capital and labour as defined above, and assuming a given level of technology A, the expanded production function is given as follows:

$$Y = F(K, L, E) \tag{2.6}$$

The neoclassical model's key assumptions of constant returns to scale, diminishing marginal returns to inputs and positive elasticities of substitution imply a positive, though diminishing, marginal product of energy given such that output increases, though at a declining rate, with additional energy inputs. This is given as follows:

$$\frac{\partial Y}{\partial E} > 0 \text{ and } \frac{\partial^2 Y}{\partial E^2} < 0$$

The neoclassical theory also suggests how the utilisation of energy inputs affects the productivity of capital and labour. This is relevant to economic growth prospects if the total supply of energy resources is fixed, in which case the relationship with capital and labour inputs will govern the long run growth prospects (Brown and Wolk, 2000).

The neoclassical theory implies that capital and labour productivity increases with increasing energy inputs, for capital and labour, respectively. This is given as:

$$\frac{\partial^2 Y}{\partial K \partial E} < 0, \frac{\partial^2 Y}{\partial L \partial E} < 0$$

In addition, the productivity of energy inputs increases when the quantity of capital or labour increases. This is represented algebraically as:

$$\frac{\partial^2 Y}{\partial E \partial K} < 0, \frac{\partial^2 Y}{\partial E \partial L} < 0$$

These derivations are a direct result of the model's assumed elasticities-of-substitution between factor inputs, which have a fundamental bearing on the outlook for long run growth and are discussed further below. The crucial implication is that if energy use declines while capital and labour use increases, the marginal productivity of energy will increase and the marginal productivity of capital and labour will decrease. If energy use grows more slowly than labour and capital use, then sustained output growth requires substantial technological progress and particular elasticities of substitution between energy and the capital and/or labour inputs (Brown and Wolk, 2000). These issues are addressed in greater detail in the section below.

2.3 Energy Consumption and Economic Growth

From an economic perspective, the most important energy inputs are non-renewable. To the extent that energy is an important factor of production, the immediate implications of a finite energy resource base challenge the idea of unbounded economic growth. Furthermore, potential limits to the quantity of energy resources available as factor inputs need not be limited to supply-side concerns for resource availability; relevant concerns include demand management imperatives that *require* a reduction in energy resource inputs. This is particularly pertinent in the context of climate change, where the negative externalities associated with many of the vital energy resources (namely the greenhouse gases released during the combustion of oil and coal resources) are a crucial component of the global anthropogenic carbon emissions (Ministry for the Environment, 2005). The issue of resource supply constraints has been a feature of the economic literature on growth and energy consumption, with the question of whether or not energy resources are vital for economic growth a focal point. This debate has been shaped by the opposing views that stem from the mainstream neoclassical theory and the ecological economics school of thought, respectively. These theories of energy and economic growth present wildly-differing views of economic growth with limited energy resources. In particular, the theoretical debate centres on the potential for factor substitution (of capital and/or labour for energy) and technological progress to offset energy resource constraints (Stern and Cleveland, 2004).

Numerous proponents of the neoclassical theory have addressed the issue of resource-constrained growth, in the post-oil shock (i.e. post-1970s) period in particular. With an eye to the dismal predictions of Thomas Malthus (1798) two centuries previously,[2] the central neoclassical arguments in favour of sustained growth emphasise the role for substitution possibilities and technological progress to ameliorate resource scarcity. In turn, these are governed by what Stern and Cleveland (2004) refer to as the 'technical and institutional setting'. The technical setting refers to the mix of renewable and non-renewable resources in the energy supply, the initial levels of capital and resource inputs, and the elasticity of substitution between input factors. On the other hand, institutional conditions include the structure of markets and property rights, and the form of the social welfare function. Important contributions to this literature include Stiglitz (1974a; 1974b), Solow (1974a) and Dasgupta and Heal (1974; 1979).

The studies by Stiglitz, Solow and Dasgupta and Heal, noted above, raise some interesting questions surrounding the theoretical feasibility of economic growth under energy resource constraints, concerning the efficiency and equity of such growth. Stiglitz (1974a) presents a mathematical model of economic growth with finite resources and derives an optimal rate of resource utilisation that can sustain per-capita consumption growth indefinitely. The possibility of indefinite growth given a finite quantity of inputs is permitted by a key assumption of the neoclassical theory of growth with energy resources, namely that man-made capital can substitute for energy resources in production. Similarly, Solow (1974b) develops an ethical justification for 'running down' the stock of exhaustible resources provided sufficient investment is made in substitute reproducible capital. In the neoclassical model the finiteness of energy resources *per se* need not undermine long run growth; rather, the crucial requirement is for the product of energy resources *and* renewable capital not to decrease over time. As long as future markets and asset price signals are efficient, when resources become scarce rational investors will bid up the current price which should

[2] Ignoring the full potential for technological advancements to relieve resource scarcity, Malthus famously foresaw that an arithmetically-increasing food production system would be unable to sustain a geometrically-increasing population base, leading to wide-scale famine (Simpson *et al.*, 2005).

serve to dampen demand, spur innovation, and improve the prospects for substitution (Dasgupta and Heal, 1979; Simpson *et al.*, 2005). Therefore, as energy resources become scarce the market forces will automatically encourage the required substitution and technological change so as to offset the resource scarcity. Though intuitively appealing, this simple neoclassical theory suffers from a number of drawbacks. Several of these are detailed below.

One of the immediate issues identified by critics of the neoclassical model is its applicability to real world economic conditions. In a study on growth with finite resources under competitive market conditions, Stiglitz (1974b) identifies that an economic system with imperfect future and risk markets (arguably, most open, market economies) lacks the self-correcting mechanisms to ensure the precise rate of resource consumption required to ensure convergence to the optimal steady state.[3] Thus, while the neoclassical theory implies that under optimal conditions economic growth may be feasible without vital resource inputs, such as the key energy resources (i.e. oil, gas, coal and electricity), that result is not necessarily a given outcome under market conditions. Additionally, the neoclassical conclusion that energy resources are non-essential for growth hinges on the assumption that the elasticity of substitution between the energy resource inputs and the capital inputs is equal to unity, as well as assuming that technological progress is an exogenous, smooth and continuous process. These assumptions have been questioned by a number of studies. The ecological economics school of thought in particular has addressed these points to argue that the optimistic growth outlook of the neoclassical theory in the context of bounded energy resources is misplaced (Stern and Cleveland, 2004).

Biophysical models of the ecological economics school of thought present an alternative theoretical framework for analysing the energy consumption-economic growth relationship. While the neoclassical growth theory gives primacy to capital and labour inputs, various studies model energy as the sole primary factor of production. Primary energy inputs then facilitate the development of secondary capital factors, however the

[3] Future markets allow buyers and sellers to arrange transactions at a specified point in the future. This creates a 'future price' for a commodity at that forward point in time, distinct from its current market price. Relative price signals can then govern inter-temporal allocation of that resource efficiently. However, as futures markets are (necessarily) finite in their scope, the potential for sub-optimal resource allocation still exists. See also Shell and Stiglitz (1967).

nature of the specific capital is governed by the characteristics of the energy resources available (for example, see Georgescu-Roegen, 1975; Stern, 1993; Stern and Cleveland, 2004, and references cited therein). These studies are critical of the neoclassical propositions that substitution and technological change can mitigate long-term resource constraints. A number of arguments suggest that opportunities for substituting man-made capital for non-renewable resources are limited and that assuming a unit elasticity of substitution between energy and capital is inappropriate. Critics also question whether unbounded technological progress is a realistic assumption for modelling economic growth in the long run (Georgescu-Roegen, 1975, 1979; Stern, 1993; Daly, 1997).

Arguably, the key assumption of the neoclassical model that allows for the possibility of indefinite growth despite crucial energy resource constraints is the unit elasticity of substitution between energy and capital inputs. This assumption has been questioned by various critics, for example, Stern and Cleveland (2004), who refer to the 'essentiality condition' that governs the growth prospects and energy-capital substitutability. The key points noted by Stern and Cleveland therein are that energy is necessarily non-essential to production if the elasticity of substitution is more than one; that energy is essential when the elasticity of substitution is less than one; and crucially that "when the elasticity of substitution is unity, this "essential" amount can be infinitesimal if sufficient manufactured capital is applied" (Stern and Cleveland, 2004, p. 15).

The essentiality condition implies that the elasticity of substitution plays a very central role in the neoclassical model; therefore, the assumed elasticity of substitution must be justifiable in terms of the economic theory and also the observed factor relationships between energy and capital. It also suggests that the implications of the neoclassical model for growth with finite resources might differ from that presented above where an elasticity of substation is assumed to be not equal to one. Alternatively, studies have argued that smooth and continuous technological progress is not an appropriate assumption for the economic growth models. Dasgupta and Heal (1974) consider the issue of technological progress by evaluating the implications for growth and equity of discrete technological advancement, occurring at an unknown point in the future. Whereas the neoclassical theory emphasises that 'essential' finite resources such as specific types of energy (e.g. oil) need not remain essential to production for all time, because technological progress can (in theory) alter the nature of production away from a dependence on a particular 'essential' resource (i.e. the development of hydrogen fuel cells might ameliorate the dependence on fossil fuels for transport), crucially, the point in time at which the transition from one technology to another may occur cannot be known with certainty *ex ante*.

This observation may in fact be critical of the efficiency of the implied neoclassical growth path with finite resources rather than the technical feasibility of it, given the neoclassical theory's important role for price signals to smooth the resource consumption patterns during the period of transition to a new technology. A more compelling argument against the role of technological progress argues from the perspective that such progress is in fact a process of substitution from less efficient production processes to more efficient processes that is facilitated by new knowledge acquisition, in the form of better physical and human capital (Stern and Cleveland, 2004). This relates directly to a central issue within ecological economics concerning entropic limits to growth.

The ecological economics school of thought draw on the laws of thermodynamics governing the quantity and usefulness of energy available in a closed system to argue against the possibility of widespread factor substitution over the long run. Ruth (1993, p. 3) frames this argument succinctly, noting that "as modern economic systems are built to a large extent on the use of nonrenewable resources, the irreversible dissipation of energy, governed by the entropy law, affects present and future abilities to transform materials, and thus, limits the levels of production both in the economic system and the environment." The argument suggests that over time, increasing entropy must constrain the process of economic growth. Given that capital and labour inputs require energy (broadly defined) to function, the entropy law also governs the substitution between knowledge and capital, and knowledge and labour. Therefore, the marginal productivity of knowledge - or the rate of technological progress - is constrained by capital and labour inputs and, ultimately, entropy.

On the other hand, the ecological economics school of thought's 'entropy argument' implicitly pertains to the very long run. This perspective is at odds with the timeframe considered in the neoclassical theories. Solow (1997, p. 268) for example, argues that the entropy law is "of no immediate practical importance for modeling what is, after all, a brief instant of time in a small corner of the universe" (see also Stiglitz, 1997).

Though the debate between the neoclassical and ecological economics theories centres largely on the issues of technological progress and substitution, it is clearly also a debate over relevant time horizons and the availability of particular energy resources. Whereas the neoclassical model suggests that energy use is a function of economic growth rather than energy use driving economic growth, on the other hand the ecological economics theory implies that energy use leads economic growth. In the next section, the neoclassical and ecological economics arguments are considered in light of the empirical evidence. Some 'broad' evidence is discussed initially that touches on the theory of resource pricing, before considering the evidence from cointegration and causality studies that directly test the competing theories of energy consumption and growth.

2.3.1 Energy Consumption-Growth Effects: Macro-Level Evidence

There are a large number of studies that have reported evidence on the energy-economic growth relationship in various contexts. Numerous studies have empirically evaluated the technology and substitution issues at the broad level and with reference to energy-relevant activities. Furthermore, the success of technological progress in resolving energy resource scarcity should be reflected in energy price trends. The results of several studies that have empirically considered these lines of inquiry are presented below. Although the question of whether innovation and substitution can entirely offset diminishing energy resources is unclear, the available evidence seems encouraging.

In a broad sense, the market price of a particular commodity should be a prime indicator of the relative scarcity of that resource. The conventional argument underpinning this statement suggests that impending scarcity of a particular resource should cause agents to bid up its price. The origins of this thesis go back to Hotelling (1931) and the 'Hotelling rule' that establishes the price of a natural resource at any given time as being the product of its marginal production cost at that time *plus* its 'user cost', where user cost measures the value of holding an addition unit of the resource off the market until a future period. Defining $P_{NR,t}$ as the resource price at time *t*, $C_{NR,t}$ as the marginal production cost at time t, r as the market rate of interest and λe^{rt} as the user cost at time t (Brown and Wolk, 2000) this relationship can be given algebraically as follows:

$$P_{NR,t} = C_{NR,t} + \lambda e^{rt} \quad (2.7)$$

If a non-renewable resource is expected to become increasingly scarce, equation (2.7) implies that its price should rise. The neoclassical theory predicts that this in turn will encourage technology and substitution measures, which could be reflected in a subsequent reduction in the real unit price. The key issue is to what extent these measures can offset the increase in scarcity.

Brown and Wolk (2000) and Krautkraemer (2005) present evidence of substantial reductions in the real price of a number of non-renewable natural resources, suggesting massive technological advancement in the resource sector over the 20th century.[4] Of particular note, Brown and Wolk (2000) report that the real price of oil decreased almost 80 percent between 1870 and 1998, while many other resources are also cheaper (i.e. less scarce) in 2000 than in 1870. Exceptions are anthracite (coal), with real price 22 percent higher; tin, with real price 10 percent higher; and natural gas, with a real price 160 percent higher in 2000 than in 1920. This approach provides empirical support for the neoclassical theory's technological change arguments at a very broad level. Several studies that have taken more direct approaches to gauge the effect of technology in mitigating (energy) resource scarcity are discussed below.

In considering the role of technological progress in mitigating resource scarcity within the context of US oil and natural gas industries, Cuddington and Moss (2001) examine the effect of technological progress on average discovery costs for new oil and gas reserves. Technological progress is constructed as an aggregate index of annual technology diffusion that their study finds has significantly lowered the discovery cost of natural gas. In the empirical model, estimated finding costs increase at a reported rate of 2.7 percent per year, against a simulated 22 percent annual increase without technological progress (that is, the actual price change attributed to technological progress is considered *vis-à-vis* a counterfactual path with constant technology).

[4] These include: Aluminium, Coal, Copper, Iron, Lead, Natural Gas, Nickel, Oil, Silver, Steel, Tin, and Zinc.

Similarly, Forbes and Zampelli (2000; 2002) estimate regression models (for the offshore and onshore industries, respectively) for the US crude oil and natural gas production industries that consider the role of technology alongside price, tax, and geological variables in driving the rate of exploratory success over the period 1978-1998. The reported coefficients for the annual dummy variables that proxy technological change imply a positive and significant role for technological progress in driving exploratory success of the onshore industry in every year during the period 1986-1998, measured relative to a base period (i.e. 1978-1981) technology. These results suggest that the measured increase in successful exploration activity is the result of "a robust rate of technological advancement" (2002, p. 331).[5]

The above-noted studies provide a degree of empirical support for the neoclassical emphasis on substitution and technical progress energy scarcity effects. Further evidence can be gleaned from an examination of the crude oil reserves statistics; arguably, the historical changes within the global oil industry have played a leading role in shaping the common perceptions of relative resource abundance (Goldstein *et al.*, 1997). For example, following the energy price hikes of the 1970s where oil prices increased four-fold, consumption of oil and other resources declined substantially in the US and Europe. Total consumption in the US has only exceeded its previous peak of 1978 since 1999; while in 2005 Europe consumed 22 percent less oil overall than it did in 1979. At the same time, world proved reserves have increased from 660 billion barrels in 1980 to more than 1200 billion barrels in 2005 (British Petroleum, various).[6] In light of these results, researchers such as van den Bergh (1999, p. 555) argue that "it is difficult to provide unambiguous support for [the idea that] there is a limit to the amount of value that can be derived from a finite amount of physical resources" while Azar (2005, p. 98) is more blatant in pointing out that "energy is *not* scarce." These sentiments corroborate the declining energy intensity of industrial economies, well noted for the period since World War Two, that has coincided with substantial growth in the living standards in those regions (Cleveland *et al.*, 2000). They also reinforce the idea that 'scarcity' is an economic concept, rather a physical one.

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[5] A qualitatively similar result is also obtained for the US offshore industry (see Forbes and Zampelli, 2000).

[6] The concept of proved reserves is essentially an economic one, linked to price and technology developments. Positive movements of both allow the extraction of new sources of petroleum and increase the extractable share of oil within a given deposit (Organisation for Economic Cooperation and Development, 2004)

On the other hand, there are studies which present results contradicting the neoclassical intuition. Jorgenson (1984), for example, shows that in most industrial sectors of the US economy, technological change is biased toward *increased* use of electricity or non-electric energy. This is related to the productivity slowdown that followed the oil price shocks, and suggests that oil price and energy consumption effects may be important for economic growth. Similarly, Stern (1993) and Cleveland *et al.,* (2000) demonstrate that substitution towards higher quality forms of energy (e.g. substitution from coal to gas, and gas to electricity) has been prevalent in the post-war period for the US. In fact, these details are shown to explain much of the reported trend towards less energy-intensive production noted for the developed countries in particular (Stern, 1993).[7] This pattern of substitution has important economic and environmental implications because some higher quality energy resources are less abundant that the vital low quality resources in most regions of the world.[8] Moreover, they have important pollution, and to a lesser extent geopolitical, dimensions that may require demand management and energy conservation policies in the future.

Fauchex and Levarlet (1999) argue that the threat of climate change is taking on an increasingly important role in the design of economic development strategies and energy policies. It is certainly relevant to fossil fuel combustion, with important implications for energy use in both developing and developed countries. The Kyoto Protocol to the United Nations Framework Convention on Climate Change (UNFCCC) stipulates a cumulative reduction in industrialised countries' greenhouse gas emissions of 5.2 percent below 1990 levels by 2010.[9] For some countries, this implies a reduction of 25 percent in projected emissions (Schelling, 2002). Consequently, a focus of energy policy in recent years has been on reducing the energy intensity of output in the US and elsewhere.

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[7] Stern (1993, 2000) shows that when energy is weighted for its relative quality, rather than aggregated on thermal equivalence, the downward trending 'energy intensity of output' disappears from the US data. Oh and Lee (2004a, 2004b) present similar evidence for South Korea.

[8] New Zealand, as a good example, has enormous reserves of low quality lignite and sub-bituminous coal but relatively small deposits of discovered petroleum and gas, which together comprise more than 60 percent of total consumer energy on a quantity-equivalent basis. Around 70 percent of consumer petroleum is imported (Statistics New Zealand, 2004).

[9] The Protocol covers six main greenhouse gases. These are: Carbon Dioxide (CO_2), Methane (CH_4), Nitrous Oxide (N_2O), Hydrofluorocarbons (HFCs), Perfluorocarbons (PFCs), and Sulphur hexafluoride (SF_6). For most industrial countries, CO_2 is the main contributor to total greenhouse emissions. On the other hand, CH_4 is the most damaging in the case of New Zealand (Gillespie, 1997).

A substantial proportion of global greenhouse gas emissions result from the use of fossil fuels in industrial, agriculture and transport sectors of the developed economies, and to achieve the required reductions it is probable that complex initiatives beyond simple energy efficiency measures will be required. Such instruments will likely have economic consequences. Geo-political concerns also motivate an improved understanding of the role of energy resources in economic systems, especially for industrialised countries reliant on imported sources of energy (Shelley, 2005). Ross (2002) notes that improved energy security is a prominent concern of energy policy in the US, where the current Bush Administration's Advanced Energy Initiative seeks cuts of 75 percent to US imports of foreign oil supplies by 2025 (National Economic Council, 2006).

At the centre of all of these issues lies the question 'to what extent can energy consumption be reduced, while minimising the impact on economic development?' The neoclassical and ecological economics theories of growth imply diametrically-opposing responses to that vital question; moreover, some of the broad evidence provides support for both hypotheses. Therefore in recent years an extensive empirical literature has considered the causal relationship between energy resources and economic growth. This is a crucial element of empirical modelling within the energy consumption-growth agenda because it provides a robust means of addressing the energy consumption-growth relationship in a context that is free of structural linkages. Therefore, the energy-growth cointegration and causality studies provide a means to understand the fundamental relationship between energy consumption and economic growth that can assist in contributing to the economic and energy dimensions of the climate change policy response (Asafu-Adjaye, 2000; Oh and Lee, 2004a).

2.3.2 Energy Consumption-Growth Effects: Cointegration and Causality Results

Some of the theoretical and empirical analyses noted so far have suggested that energy resources may be an important factor of production contributing to the economic growth in a number of countries. At the same time, studies have been noted that support the implications of the neoclassical theory of growth - that heightened energy consumption is simply a consequence of economic expansion. Both of these hypotheses are plausible *a priori* in the case of developed countries such as New Zealand, yet they lend support to opposite directions for energy policy, especially where energy conservation is of concern. The role of causality testing in the energy consumption-economic growth relationship is important because it provides a useable method for exposing the existence and direction of fundamental linkages between energy consumption and economic growth, and hence for guiding policy (Asafu-Adjaye, 2000; Wolde-Rufael, 2005, Fatai *et al.*, 2004).

Investigations of the energy consumption-economic growth relationship that use Granger (following Granger, 1969), Sims (following Sims, 1972), and more recent cointegration (following Engle and Granger, 1987) causal testing techniques go back at least to Kraft and Kraft (1978), who find evidence of a causal link from Gross National Product (GNP) to energy consumption in the United States economy for the period 1947-1974. Over the years many further studies have been conducted utilising the different methodologies for different countries and timeframes (see Guttormsen, 2004). Despite the volume of published research in this area however, various different conclusions have been drawn on the nature of the underlying relationship, even within the same country and/or the similar timeframe that provide no consensus from which to formulate the policy prescriptions.

Four possible energy consumption-economic growth relationships have been implied from the causality testing framework. All the relationships are technically feasible and have found support in the empirical literature. The causality possibilities are as follows:

- unidirectional (Granger) causality from economic growth to energy consumption (see Kraft and Kraft, 1978; Yu and Choi, 1985; Abosedra and Baghestani, 1989; Masih and Masih, 1996; Cheng and Lai, 1997; Soytas and Sari, 2003; Fatai *et al.*, 2004; Oh and Lee, 2004a; Wolde-Rufael, 2005; Narayan and Smyth, 2005);
- unidirectional causality from energy consumption to economic growth (see Yu and Choi, 1985; Erol and Yu, 1987; Stern, 1993, 2000; Masih and Masih, 1996; Soytas and Sari, 2003);
- bi-directional causality between both energy consumption and economic

growth (see Erol and Yu, 1987; Hwang and Gum, 1992; Glasure and Lee, 1997; Masih and Masih, 1997; Asafu-Adjaye, 2000; Soytas and Sari, 2003; Ghali and El-Sakka, 2004; Oh and Lee, 2004b; Wolde-Rufael, 2005); and

- no causality between energy consumption and growth (see Akarca and Long, 1980; Yu and Hwang, 1984; Yu and Choi, 1985; Erol and Yu, 1987; Masih and Masih, 1996; Asafu-Adjaye, 2000; Soytas and Sari, 2003; Altinay and Karagol, 2004; Wolde-Rufael, 2005).[10]

The disparity evident in the results suggests that different approaches to energy and economic policies are required in different economic contexts. Causality from economic growth to energy consumption implies that energy use is an increasing function of economic growth, and that it is not a vital input to production *per se*. This case aligns with the neoclassical view, and places relatively little emphasis on energy in driving the production process. Consequently, energy conservation policies may be feasible with little or no effect on economic growth (Narayan and Smyth, 2005). Similarly, a lack of causality in either direction suggests that no significant relationship exists between energy consumption and growth. This supports the 'neutrality hypothesis' asserted in some studies (Yu and Choi, 1985; Erol and Yu, 1989).

On the other hand, causality from energy consumption to economic growth suggests energy conservation may be difficult to enact without negatively affecting economic growth. Such results lend empirical support to those studies which assert a more fundamental role to energy in the process of economic growth, for example the ecological economics school of thought. See also Beaudreau (2005). As a final possibility, bi-directional causality has been reported in several studies. In these cases, significant signals from energy to growth are present with feedbacks, suggesting that conservation policies may have important economic effects, both directly and indirectly.

Recent comments by Stern (1993; 2000) and Zachariadis (2006) identify several plausible causes for some of the inconsistent results. These include the lack of a multivariate framework, the failure to account for energy quality in the process of aggregation and the econometric problems of not considering the time series properties of the data or the issue of cointegration i.e. long run relationships. Given these

[10] Some multi-country studies are cited more than once where different countries produced different results within the same study.

shortcomings, Table 2.1 presents several studies that employ appropriate methodologies and form a good basis for the discussion that follows.

Table 2.1 Energy Consumption-Economic Growth Causality: Selected Results

Study	Data	Methodology	Causality
Stern (1993)	USA; Annual 1947-1990	Multivariate VAR (Y, E*, K, L)	$E \rightarrow Y$
Darrat *et al.*,(1996)	USA; Quarterly 1960-1993	Multivariate VAR (Y, E, P, MP, FP)	$Y \rightarrow E$
Masih and Masih (1998)	Thailand; Annual 1955-1991	Trivariate VECM (Y, E, P)	$E \rightarrow Y$
	Sri Lanka; Annual 1955-1991	Trivariate VECM (Y, E, P)	$E \rightarrow Y$
Cheng *et al.*, (2001)	Taiwan; Monthly 1982-1997	Trivariate VECM (Y, E, EM)	$E \rightarrow Y$
Oh & Lee (2004a)	South Korea; Quarterly 1981-2004	Multivariate VECM (Y, E, K, L)	$Y \rightarrow E$
	South Korea; Quarterly 1981-2004	Trivariate VECM (Y, E, P)	$Y \rightarrow E$
Oh and Lee (2004b)	South Korea; Annual 1979-1999	Multivariate VECM (Y, E*, K, L)	$Y \leftrightarrow E$
Narayan and Smyth (2005)	Australia; Annual 1966-1999	Trivariate VECM (Y, E, EM)	$Y \rightarrow E$
Sari and Soytas (in press)	Six Developing Asian Countries; Annual 1971-2002	Multivariate VAR (Y, E, K, L)	$E \rightarrow Y$

Notes: 'Methodology' represents the type of model used in the causality testing framework. 'VAR' represents Vector Autoregression and 'VECM' represents Vector Error Correction Model. Letters in brackets reflect the variables contained within each model; 'Y' is economic growth; 'E' is energy; 'E*' is quality-adjusted energy; 'K' is capital; 'L' is labour; 'P' is energy price; 'MP' is monetary policy; 'FP' is fiscal policy; and 'EM' is employment. In the column headed 'Causality', arrows represent the reported direction of Granger causality between the energy and economic growth variables. Two-headed arrows represent bi-directional causality. The six countries studied by Sari and Soytas are: Indonesia, Iran, Malaysia, Pakistan, Singapore, and Tunisia. Individual results are not displayed as qualitatively-similar findings were reported for each country, utilising the impulse response and variance decomposition.

It can be discerned from Table 2.1 that the overall pattern of results is unclear. Altinay and Karagol (2004, p. 986) note that based on the mixed results contained in the literature, "it is improper to make any type of generalizations of the potential relationship between GDP and energy consumption. Thus, in designing a recovery aimed at facilitating energy consumption and promoting economic growth, it is necessary to consider the case of each country separately". There is thus justification for considering the empirical energy-growth nexus for the case of New Zealand.

To the best knowledge of this work, the only study that considers the energy consumption-economic growth relationship for New Zealand is by Fatai *et al.*, (2004). They consider the causal relationship for New Zealand between economic growth and energy consumption in several bivariate models containing disaggregated consumption data for coal, gas, oil, electricity, industrial energy demand and total final energy demand, respectively. Though no evidence is found of a cointegrating relationship between GDP and any of the disaggregated energy resources, the results indicate unidirectional causality from real GDP to industrial energy consumption, therefore "energy conservation policies may not have significant impacts on real GDP growth in...New Zealand" (Fatai *et al.*, 2004, p. 431). The present study will consider the results of Fatai *et al.*,'s (2004) model in the context of a different cointegration test, and longer time series using several demand-side and supply-side models that include energy price, capital and labour variables in the causality testing framework.

The issue of energy resource availability and its relationship with economic growth discussed above relates to another important issue concerning macroeconomic consequences of energy *price* shocks. This is because the demand and supply of most energy resources are highly inelastic in the short run. Consequently, economies have been subject to volatile energy prices on numerous occasions over the post-World War Two period. Prominent periods of heightened price volatility include 1973, 1979-80, 1986, 1990 and 2000-2006 (International Monetary Fund, 2005, 2006a). In the next section, the theoretical and empirical literature on the energy price-economic growth nexus is discussed. Although much work has been conducted for the case of the US and other dominant economies, there is a lack of existing empirical work in this area for the case of New Zealand.

2.4 Macroeconomic Activities, Energy Prices and Economic Growth

Historically, much has been said in the popular media about the economic importance of energy price shocks. However, the conventional neoclassical theory has struggled in attributing macroeconomic significance to such events. This is because of the low energy share of output in most of the developed economies (Finn, 2000). The main interest in energy prices concerns oil prices in particular, given that unlike most other energy resources (e.g. coal, electricity and gas), for most countries the world price of oil is determined exogenously i.e. it is invariant to events and conditions in the domestic economy.

Academic interest in the potential impact of oil price shocks has increased since Hamilton (1983) identified a robust relationship between oil price increases and subsequent economic downturns for the majority of post-war recessions in the US.[11] Subsequent research has focussed on the potential transmission channels by which oil price shocks spill over from the energy sector into the macroeconomy, and on quantifying the magnitude of the hypothesised effects for economic growth, using a range of econometric methodologies. The theory and evidence pertaining to these issues are considered in the remainder of this section.

2.4.1 Macroeconomic Impacts of Oil Price Shocks: Theoretical Debate

Despite the close proximity of the first 'oil crisis' in 1973 to the global recession of 1974, studies by Perry (1977), Tobin (1980), and Nordhaus (1980) present various arguments suggesting that the factor cost share of oil was too low to facilitate the observed reduction in US output growth that followed the oil price hike. Their basic argument relies on simple algebra; given a cost share of oil expenditures in output of around 4 percent (as is standard for the developed economies) and a price increase of 10 percent, output should be expected to decrease by no more than 0.4 percent. However, the observed reduction in output attributed to the recession of 1974 was an order of magnitude larger than that figure, even allowing for the scale of the price increase.

Numerous studies have suggested that coincidental events and various policy responses are the cause of recession noted for 1974 and in subsequent periods of high oil prices. Darby (1982) suggests that events coinciding with the price shocks of 1973-74 may have been important causes of the subsequent recession, including the end of the

[11] With the only exception, the recession of 1960, being preceded by an oil price increase (Mork, 1994).

(Bretton Woods) pegged exchange rate regime, a substantial reduction in the US money supply growth in 1973 and 1974 and the removal of price controls in the US and elsewhere between 1973 and 1975 (see also Pierce and Enzler, 1974; Mork, 1989, 1994; Rogoff, 2005). The co-incidence of these events has cast doubt on a presumed oil price-economic growth relationship.

Following Darby (1982), and Friedman and Schwartz (1963) before him, a number of studies have argued that changes to monetary policy (hereafter MP) has been the source of major recessions of the US economy. Romer and Romer (1989; 1994) present evidence suggesting that 'exogenous' MP tightening has had a considerable impact on subsequent economic performance in the post-war period, even after controlling for potential supply shocks. Bohi (1991) similarly argues that tight MP responses to oil shocks have been the true causes of recession and not the oil shocks themselves. Bernanke *et al.,* (1997; 2004) support this position by presenting evidence that the systematic component of MP responses to oil price shocks has driven the resulting economic recessions, rather than the oil price movements themselves. Their empirical estimate suggests that around 70 percent of the reduction in output following a positive oil price shock is the result of subsequent monetary tightening (see also Darrat *et al.*, 1996; Leduc and Sill, 2001; Barsky and Kilian, 2001; 2004; Kilian, 2006). Recent arguments in support of the insignificance of oil price shocks that are based on methodological arguments are presented by Hooker (1996b; 1996a; 1997; 1999; 2002).

On the other hand, a number of studies have noted these arguments and reiterate that oil prices may indeed be an important factor affecting economic growth in the US and elsewhere. Relevant contributions to this literature include Mork (1989; 1994), Dotsey and Reid (1992), Hoover and Perez (1994a; 1994b), Ferderer (1996), Lee *et al.,* (1995), Hamilton (1988a; 1988b; 1996; 1997) Lee and Ni (2002), Balke *et al.,* (2002), Hamilton and Herrera (2004), Cuñado and Pérez de Gracia (2003), Carlstrom and Fuerst (2005) and Jiménez-Rodríguez and Sánchez (2005). These studies present numerous theoretical perspectives on the oil price shock hypothesis, as well as empirical evidence on the estimated magnitude of such shocks impacting on growth through some of the speculated indirect channels. The implication of this literature is that indirect transmission mechanisms may be the crucial means by which oil price shocks have macroeconomic impacts.

The theoretical debate over the importance of oil prices to economic growth follows the seminal study by Hamilton (1983) that reports a 'statistically significant and non-spurious correlation' between energy price increases and subsequent economic downturns of the US post-war economy, in contrast to the predictions of the mainstream theory. Hamilton's (1983) findings are supported empirically by Gisser and Goodwin (1986) and Burbidge and Harrison (1984), who re-affirm the statistical link between energy price rises and economic growth for a range of countries.[12] None of these studies, however, assert how the energy price shocks might come to have growth impacts in the various countries studied. The subsequent literature has pursued several distinct lines of enquiry that are presented in turn below.

The earliest studies that predict an insignificant impact for oil prices tend to focus on an energy price increase working directly through the production function. Rasche and Tatom (1977a; 1977b; 1981), Dohner (1981), Mork (1981), and Bruno and Sachs (1982; 1985) are among those who consider the macroeconomic impact of oil price hikes as a standard supply shock. In these analyses, an energy price increase reduces the average and marginal productivity of existing capital and labour stocks, causing a shift in the production function and a reduction in potential output. The aggregate supply curve shifts to the left, leading to higher inflation and a lower level of output. If sticky nominal wages are assumed, the reduction in output growth also leads to increased unemployment, and hence further reductions in output growth. Without a reduction in the price of capital goods, investment slows causing additional long run output and real wages losses (Rasche and Tatom, 1981).

Bohi (1991) shows that an algebraic evaluation of the production function introduced in section 2.2 highlights several further channels of transmission that are potentially important for economic growth. For convenience, the production function given by equation (2.6) is re-presented with Q representing gross output, K representing capital inputs, L representing labour inputs, and E representing energy inputs, as follows:

$$Q = F(K, L, E) \quad (2.8)$$

[12] Burbidge and Harrison (1984) find significant economic effects for oil price increases in the US, Canada, Germany, Japan and the UK. Gisser and Goodwin (1986) include oil price, monetary and fiscal policies variables in their model of output growth, and find the coefficient on both policy variables to be statistically insignificant, *per contra* oil prices.

Setting P_E as the relative price of energy and the price of output as the numeraire, net output Y can then be given as:

$$Y = Q - P_E E \tag{2.9}$$

Finally, letting lower-case values represent natural logarithms of the respective variables, the marginal product of each factor input be set equal to its price, and P_K and P_L be the relative prices of capital and labour (Bohi, 1991, pp. 148-49), the effects of an energy input price change can then be illustrated by:

$$\frac{\partial y}{\partial p_E} = \left[\frac{P_K K}{Y}\right] \cdot \frac{\partial k}{dp_E} + \left[\frac{P_L L}{Y}\right] \cdot \frac{\partial l}{\partial p_E} - \left[\frac{P_E E}{Y}\right] \tag{2.10}$$

From the analysis above, equation (2.10) indicates that a direct price effect will cause output to decline, relative to the cost share of energy, because of the higher cost of energy resource inputs. This is reflected by the third term on the right hand side of the above equation, which is the sole avenue of transmission considered in the arguments of Perry (1977) and others. However, there will also be indirect price effects given the substitution of capital and labour inputs for energy. These are given by the first and second terms on the right hand side of equation (2.10), respectively. Regarding these effects, Bohi (1991, p. 149) states that:

> [b]oth substitution relationships are normally thought to be positive...in which case substitution away from energy will offset the negative direct effect of an energy price shock. However, in the short run context of an energy supply disruption both terms could be negative, in which case the indirect effects could exacerbate rather than offset the direct effects. Thus, an energy price shock could be severely damaging to the economy even though the direct impact is small.

Numerous studies have followed this hypothesis in developing several indirect channels for transmission of oil price shocks that could theoretically account for the observed magnitude of GDP growth reduction despite the small cost share of oil. These are discussed in the section below.

2.4.2 Indirect Channels for Energy Prices Shocks

Among the many indirect energy-prices-to-economic-growth transmission mechanisms that have been speculated, macroeconomic adjustment costs appearing in labour and factor markets, and operating through inventory and final demand have been prominent in the literature. One of oldest and most widely-cited arguments is attributed to Lilien (1982), who considers the impact of allocative shocks on labour dispersion across industries. The central idea is that if allocative disturbances can affect the relative productivity of labour in different industries, they may induce workers to shift toward industries where their marginal product is higher (see also Jones and Leiby, 1996; Davis *et al.*, 1996). Such a move may involve a short-term time cost of labour mobility, which at an aggregate level can have a large and negative effect on growth.

Lilien (1982) constructs an employment growth dispersion index to empirically test the dispersion hypothesis, and reports an estimated coefficient for the index that is positively signed and highly significant in explaining movements of the unemployment rate in the US over the period 1948-1980. Loungani (1986) extends this theory to explicitly account for the effects of oil price shocks, and makes an important contribution to this literature by showing that oil price shocks are responsible for a significant part of Lilien's (1982) employment growth dispersion index. In fact, once oil price shocks are accounted for, Lilien's dispersion index has "no explanatory power for unemployment" (Loungani, 1986, p. 536). This result may reflect the fact that energy, and oil in particular, are ubiquitous in developed economies; consequently a price shock to these commodities can affect various factor, goods and financial markets.

The sectoral reallocation argument has been extended by several studies to account for the effect of factor specialisation on unemployment, given that specialisation may increase the costs of labour reallocation across sectors (for example, see Black, 1982). Consideration has also been given to the estimated impacts for capital inputs moving between sectors (see Davis, 1987; Hamilton, 1988a). Hamilton (1988a) argues that the extent to which unemployment will rise following a price shock is dictated by the dollar share of products whose *use* depends on energy, rather than the dollar share of energy *per se*. This crucial conceptual distinction allows for substantial macroeconomic effects to result from a shock to input factors of (assumed) modest importance, such as oil. For example, automobile demand may suffer because of fuel price increases, which could lead to higher unemployment and a reduction in aggregate demand. Furthermore, these impacts would have a much greater impact on growth than the fuel price rise itself (Hamilton, 1988a). See also Keane and Prasad (1996), Davis *et al* (1997), Carruth *et al.*, (1998), Davis and Haltiwanger (2001), and Lee and Ni (2002).

Rotemberg and Woodford (1996) demonstrate how the oil shock dispersion thesis can apply to labour resources directly, given the relationship between inputs in the production process. Their study demonstrates that imperfect competition in product markets can give rise to substantial recessionary effects from an energy price increase by assuming mark-up pricing rather than marginal cost pricing, in which case oil price rises can force a dramatic reduction in labour utilisation. On the other hand, Finn (2000) has derived a perfectly competitive model with quantitatively similar conclusions for real wages and output, modelling capital utilisation as a function of energy prices. This allows a further explicit channel for energy price shocks to transmit into the wider economy that is more-typically considered as a key variable for growth, namely investment.

Several studies have considered the direct impact of oil price changes on the investment decisions of firms and households. In addition to the utilisation of *existing* capital and labour resources, investment in *new* physical and human capital may be affected by allocative shocks. The pioneering work of Bernanke (1983) and others that examines the effect of such shocks on investment decision making argues that allocative shocks, such as energy price movements, can depress some forms of capital investment substantially. This is because of the irreversible nature, and considerable cost, of undertaking specific investment projects (Bernanke, 1983).

Investment decisions within the energy industry itself are particularly sensitive to energy price volatility. Obviously, this is because energy prices have a profound and direct impact on revenue and cost streams. The nature of energy sector investment is typified by substantial initial costs, with financial benefit accruing only after a long lag. Further issues complicate energy sector investment in the face of volatile energy prices; see Paddock *et al.*, (1988), Dixit and Pindyck (1994) and International Monetary Fund (2005) for specific treatment of these issues.

The basic premise behind the investment uncertainty hypothesis derives from the environmental economics concept of 'option value', i.e. in conjunction with new (as-yet unknown) information a resource may deliver a new stream of *potential* benefits in the future that are forgone if the resource is consumed presently. Consequently there is a benefit to deferring consumption of that resource to the next period (see also Weisbrod, 1964; Cicchetti and Freeman III, 1971; Arrow and Fisher, 1974).[13] In a similar manner, where information received each period can substantially alter the cost-benefit calculus of a particular investment project, there is an implicit benefit to deferring an irreversible investment decision until the next period (see also Cukierman, 1980; Pindyck, 1991).[14]

The effects noted above may be pronounced during periods of volatility in financial and commodity markets, and so actions with uncertain long-term effects can "create an investment cycle by temporarily increasing the returns to waiting for information" (Bernanke, 1983, p. 85). Pindyck (1991) suggests that in this fashion oil price shocks can induce aggregate investment instability, with volatile energy prices serving as the catalyst. Pindyck, in fact, asserts that fluctuating economic conditions of this type may bear more influence on investment spending decisions than interest rate movements that are widely viewed as a principal source of influence over business investment activities.

These arguments have also been applied to the issue of inter-industry relative wage uncertainty, and its impact on the labour supply decisions of individuals. The theory states that where allocative shocks alter the marginal productivity of labour across industries, they can also increase uncertainty about the relative wages that will prevail between industries in the future. This can impact on the labour supply decisions of those individuals required to invest in costly industry-specific human capital, by providing an incentive to defer until the next period any decision over which industry to enter (see Topel and Weiss, 1985; Davis, 1987).

Alongside the hypothesised impacts on labour and capital of oil price shocks, it has

[13] Weisbrod draws an analogy with property insurance, which is taken out by many people yet seldom 'consumed'. A call option on a common financial asset is another illustrative analogue.

[14] Cukierman (1980) presents a similar model of investment decision making under uncertainty. He noted that delaying investment in favour of new information may well be a dominant strategy for risk-neutral, as well as risk-averse, investors. However, he does not emphasis the link to macro-level instability to the same degree as Bernanke.

been argued that energy is essential for implementing new technologies, and hence for productivity growth (Jorgenson, 1984). Jorgenson (1984) argues that the productivity slowdown of the 1970s resulted from the negative impact of oil price increases on the uptake of new technologies, demonstrating that technical change in US industries is biased toward energy use. While this avenue may be a very important means for energy to impact on economic growth, it is difficult to assess empirically and consequently has received little further attention in the literature (Stern, 1993).

The various impacts discussed above pertain to the supply-side of the economy, yet there are also a number of plausible demand-side instruments that may be important from an economic perspective (Mork and Hall, 1981; Bruno and Sachs, 1985). For net importers of key energy resources, one crucial possibility concerns the considerable terms of trade effects that can follow periods of energy price movements and heightened volatility. Given a rise in energy prices, the terms of trade effect refers to the transfer of purchasing power from domestic consumers to foreign owners of energy resources. Such transfers are likely to negatively impact on domestic demand, and may be the most important consequence of a price hike for some oil-importing countries given the impact on foreign reserves, exchange rates and the implications for overseas sector (Organisation for Economic Cooperation and Development, 2004).[15] Backus and Crucini (2000) consider this issue empirically for the US economy and note that "given the importance of oil as an internationally traded commodity and the volatility of its price, oil shocks could potentially explain virtually all of the terms of trade variation from the early 1970s to the mid-1980s" (p. 190). Their study finds empirical evidence that heightened terms of trade volatility is significantly related to increased oil price volatility, as opposed to fluctuations in the nominal or real exchange rates that are both insignificant with respect to the terms of trade volatility.

As well as the terms of trade effect, the theoretical result that energy price shocks may trigger an external inflation spike has been pervasive in the literature. Because an inflation spike that results from oil price movements is not caused by an increase in domestic money supply, it can have negative consequences for real balances. In turn this can lead to reduced consumption demand as consumers face a reduction in

[15] The magnitude of this net transfer is dependent, however, on the extent to which export demand increases as a result of greater foreign purchasing power (Dohner, 1981).

purchasing power, just as energy price increases may inhibit greater investment by the owners of physical and human resources (Mork, 1981, 1994). Pierce and Enzler (1974), as well as Gordon (1975), Mork (1981) and Bruno and Sachs (1985) consider this avenue explicitly and find evidence in support of the theory for the US economy over various periods in the 20th century. These studies argue that the burden of this reduction in demand may fall disproportionately on the durable goods sector, which is also potentially vulnerable to demand-side effects of oil price shocks.

One durable good which is intimately related to both oil prices and industrial production is the automobile, which draws on energy (petroleum) to undertake useful work and is a backbone of industrial production in certain developed economies. Lee and Ni (2002) demonstrate that in the US, oil price shocks impact the automobile industry most significantly among a wide range of industries.[16] Further, it has also been shown that significant 'lumpiness' exists for the margins on which US automobile manufacturing firms adjust output, such that production is more volatile than sales (Bresnahan and Ramey, 1994; Jones and Leiby, 1996).[17] In this sense reduced demand, driven by an oil price shock operating through reduced real balances, could have disproportionate unemployment effects.[18] For example, Hamilton (1988a) simulates a reduction in automobile demand, following a rise in oil prices, as a driver of unemployment and finds a large and negative impact on output. The same argument may apply more-or-less to a number of other important sectors where energy resources are closely tied to the production and consumption of that sector's output, such as steel production, chemical manufactures and international air travel.

Combining the various demand-side impacts noted above suggests that an energy price shock can result in higher inflation and higher unemployment. In fact the 'oil crises' of the 1970s and early 1980s gave rise to both of these at the same time, known as the

[16] Industries also considered are: Petroleum refining, Industrial chemicals and synthetic materials, Paper, Rubber and plastic products, Nonferrous metals, Iron and Steel, Lumber products, Apparel, Household furniture, Household appliance, Electronic machinery, Construction machinery, and Office and computing machines.

[17] This 'lumpiness' refers to the "intermittent production and shift margins [which give] a natural explanation for the excess volatility of production. An 80 percent increase in sales can lead to a 100 percent increase in production if the plant responds by adding an extra shift. Likewise, a moderate decrease in sales can lead to a halving of production if a second shift is eliminated" (Bresnahan and Ramey, 1994, p. 610).

[18] Bohi (1991) and Barsky and Kilian (2004) dispute this point.

'stagflation' phenomenon (Bruno and Sachs, 1985; Helliwell, 1988). Such a combination should not happen according to the Keynesian theory of the Phillips curve, where inflation is "supposed to be the cost of good times, whereas recession sometimes has to be tolerated as the cost of loosening the grip of inflation" (Mork, 1994, p. 16). This is an important point, because if the economics underlying the period of stagflation suggest that energy price *increases* could have recessionary macro consequences, then to the extent that demand channels are important, it also suggests that oil price *reductions* should result in sustained economic growth coupled with low inflation (Tatom, 1988).

Such a scenario failed to materialise in the wake of the 1986 oil price crash, however, causing a 'breakdown' in the energy price-economic growth relationship. Many of the studies employing data for the post-1986 period have failed to identify a significant Granger causality from oil prices to economic growth in a similar framework to that of Hamilton (1983). These results suggest that either the oil price-growth relationship was once significant but no longer is, or that the underlying relationship between energy prices and growth is complex and perhaps nonlinear. A number of studies which pursue the second hypothesis are discussed in the section below.

2.4.3 Energy Prices and Economic Growth: An Asymmetric Relationship?

The various reallocation arguments discussed above imply that economic growth will be negatively affected regardless of whether the reallocation is triggered by a positive shock or a negative shock. On the other hand, the demand-side models suggest that the energy price-economic growth relationship is symmetric, i.e. a price decrease should bolster economic growth by operating through the same channels as a price increase, but in the opposite direction. Until the 1980s, the majority of significant price movements were positive, thus preventing an analysis of these theories to understand precisely how and to what extent oil prices would influence the path of economic growth. Towards the end of 1985 the world price of crude decreased from US$30 per barrel to below US$15 per barrel, and this allowed evaluation of numerous oil price shock-growth theories in light of those events.

Mork (1989) adopts a simple means for assessing whether the macroeconomic effects of oil price movements are symmetric by testing whether the coefficients on oil price increase and oil price decrease variables are equivalent when specified separately in a growth regression framework. The important finding reveals that correlations between energy price decreases and economic growth in the US were significantly different from those for energy price increases and "perhaps zero" (Mork, 1989, p. 744) over the post-World War Two period. This implies an asymmetric energy price-economic growth relationship for the US, which is an important finding from the economic policy perspective. Mory (1993) has also found an asymmetric relationship for the US, and argues that the oil-induced dislocations posited by Loungani (1986) and Hamilton (1988a) would be recessionary whether triggered by price increases or decreases.

The basic argument is that an oil price change in either direction may trigger a costly reallocation of labour and capital between industries, and while the direct impact of a price increase would compound these costs, the direct impact of a price decrease might offset them. Such a sequence of events seems plausible, and could render the net effect of a price decrease insignificantly different from zero as reported (see Hamilton, 1988a; 1988b; 1996; Mory, 1993; Jones *et al.*, 2004). Mork *et al.*, (1994) find evidence of asymmetries in several Organisation for Economic Co-operation and Development (OECD) countries, namely West Germany, France, the United Kingdom (UK) and Japan. On the other hand, both oil price increases and decreases are significant for the case of the US and for Canada. Norway, as an oil exporter, is an exception to this trend, with positive price shocks impacting growth positively and negative price shocks impacting growth negatively. This may be expected, however, if demand effects (especially the terms of trade effect) are stronger than supply effects. In a relatively small economy where oil exports are substantial, such an explanation seems reasonable.[19]

The decision to model oil price increase and decrease separately seems to provide the result that is both statistically robust and consistent with the intuition, suggesting that the estimation methodology is appropriate. However, several studies dispute that recasting energy price variables as positive and negative can resolve the breakdown of

[19] Mork *et al.*, (1994, p. 20) note: "For a country of 4 million people that currently produces more than 2 million barrels of crude oil per day, this result is hardly surprising."

the energy price-economic growth relationship. As a case in point, Hooker (1996a) finds Mork (1989) and Mory's (1993) theoretical arguments for an asymmetric relationship inconsistent with the oil price facts. Hooker's argument is that "there appears to have been a dramatic reduction in the importance of [asymmetric, e.g. Mork and Mory's] oil price representations...since [the asymmetry] theories imply that the larger magnitude of oil prices since 1973 should have led to *more* sectoral reallocation and investment uncertainty, the evidence seems to contradict their versions of the mechanisms linking oil prices and the macroeconomy" (1996a, pp. 205-06). On the other hand, more-sophisticated arguments have been put forward to explain the breakdown of the relationship from another perspective. These studies focus on *relative* market conditions at the time of the price shock, and appear to perform well empirically. The studies by Lee *et al.*, (1995) and Hamilton (1996) are particularly important in this context.

The idea that the impact of an oil price shock could be dependent on the prior pattern of oil price movements is taken up by Lee *et al.*, (1995), who suggest that energy price *volatility* may be the important element of oil prices for economic growth, rather than the energy price *level*.[20] This argument seems sensible to the extent that investment avenues are important, as it is well-known that most investors are risk-averse. Lee *et al.*, (1995) utilise oil price indicators normalised by a measure of oil price variability, subsequently referred to as 'Scaled Oil Price Increase' (SOPI) and 'Scaled Oil Price Decrease' (SOPD). These reflect "both the unanticipated component of real oil price movement and the time-varying conditional variance of oil price change forecast" (Lee *et al.*, 1995, p. 42). Furthermore, the estimated coefficient on the positive normalised price shock measure is highly significant in the Vector Autoregression (VAR) growth equation, while the coefficients on the negative normalised price and 'conventional' real price change variables are not. These findings support the thesis that sectoral shifts and investment uncertainty are important channels for transmission of oil price shocks. Several other studies follow this line of analysis.

Ferderer (1996) and Hamilton (1996) both confirm Lee *et al.*,'s (1995) result empirically for the US, emphasising that investment and unemployment channels,

[20] Davis (1987) and Hamilton (1988b) first raise this point.

respectively, are important. Ferderer uses the unconditional variance of real oil price as a proxy for price volatility, while Hamilton employs a 'Net Oil Price Increase' (NOPI) measure that in any period is equal to the maximum of (a) zero, and (b) the difference between the level of the crude oil price for that quarter and the maximum value for the level achieved during the previous four quarters. Such a measure provides an alternative to Lee *et al.*,'s SOPI and emphasises those shocks occurring after a period of relative price stability over those occurring in an already-volatile pricing environment (Hamilton, 1996). Ferderer employs a four variable VAR with output, oil price, oil price variability, and MP variables. The coefficient on oil price variability suggests this variable is significant at 1% in output growth equation, whereas oil price level and the federal funds rate are not.[21] Hamilton's (1996) VAR model contains output growth, NOPI, Treasury bill, inflation, and import price variables. The results for the output growth equation suggest oil price shocks, as measured by the NOPI variable, have a negative and highly significant relationship to GDP over the sample period 1948 to 1994.

Cuñado and Pérez de Gracia (2003) and Jiménez-Rodríguez and Sánchez (2005) present evidence supporting these non-linear approaches from a range of European and OECD countries, respectively.[22] In particular, the latter study finds the asymmetry to be significant in all cases expect Japan and Norway, on the basis of the Lee *et al.*, (1995) and Hamilton (1996) oil price measures. The Norway result mirrors that for Mork *et al.*, (1994) noted earlier, while in the case of Japan it is well known that the country survived the second oil shock relatively unscathed and has subsequently performed relatively robustly to oil price movements (Mork *et al.*, 1994). Consequently it is not surprising that neither oil price increases nor decreases are significant for the case of Japan.

The literature on energy prices and economic growth discussed above suggests that price shocks, especially to oil resources, have been important triggers of recession in a range of countries. A number of different transmission mechanisms have been asserted,

[21] However, the Variance Decompositions suggest each variable has a significant impact on output growth, by showing the estimated percentages of the forecast error variance for the endogenous variable (output) explained by the right-hand-side oil and MP variables (Ferderer, 1996).

[22] These are: Germany, Belgium, Austria, Spain, Finland, France, Ireland, Italy, Luxembourg, Portugal, UK, Netherlands, Denmark, Greece, and Sweden (Cuñado and Pérez de Gracia (2003)); and US, Euro Area, Japan, Canada, France, Italy, Germany, Norway, UK (Jiménez-Rodríguez and Sánchez (2005)).

consistent with the ubiquitous nature of energy in modern economies. Table 2.2 below presents the results of the key empirical studies.

Table 2.2 Macroeconomic Impacts of Energy Price Shocks: Selected Results

Study	Data	Methodology and Variables	Is Energy Significant
Hamilton (1983)	USA; Quarterly 1949-1972	VAR (Y, OP, MP, IP, UN, W, INF)	Yes
Burbidge and Harrison (1984)	US, Japan, Germany, UK, Canada; Monthly 1961-1982	VAR (Y, OP, MP, IP, R, W, INF)	Yes
Gisser and Goodwin (1986)	USA; Quarterly 1961-1982	OLS (Y, OP, MP, FP, UN, I, INF)	Yes
Mork (1989)	USA; Quarterly 1949-1988	VAR (Y, OP, MP, IP, UN, W, INF)	Yes
Mory (1993)	USA; Annual 1952-1990	OLS (Y, OP, MP, GOV)	Yes
Lee *et al.*, (1995)	USA; Quarterly 1949-1992	VAR (Y, OPV, MP, IP, UN, W, INF)	Yes
Ferderer (1996)	USA; Monthly 1970-1990	VAR (Y, OPV, OPV MP)	Yes
Hooker (1996a)	USA; Quarterly 1947-1974	VAR (Y, OP, MP, IP, INF)	Yes
	USA; Quarterly 1974-1994	VAR (Y, OP, MP, IP, INF)	No
Hamilton (1996)	USA; Quarterly 1948-1994	OLS (Y, OPV, MP, INF, IP)	Yes
Darrat *et al.*,(1996)	USA; Quarterly 1960-1993	VAR (Y, OP, MP, FP, W, R)	No
Lee *et al.*, (2001)	Japan; Monthly 1960-1996	VAR (Y, OPV, MP, INF, R, CP, GOV)	Yes
Cuñado and Pérez de Gracia (2003)	15 European Countries; Quarterly 1960-1999	VAR (Y, OP, INF)	Yes
Jiménez-Rodríguez and Sánchez (2005)	9 OECD Countries; Quarterly 1972-2001	VAR (Y, OPV, INF, R, W, EX)	Yes

Notes: 'Methodology' indicates the framework used to test the impact of oil prices on economic growth. VAR is Vector Autoregression as before, Y is economic growth, MP is Monetary Policy, OP is oil prices, IP is import prices, UN is unemployment, W is wages, INF is inflation, R is interest rate, I is investment, OPV is oil price volatility, CP is commodity prices, GOV is Government expenditures, EX is exchange rate. 'Is Energy Significant?' indicates whether the coefficient on the energy price variable is statistically significant within the model described. Note that the ordering of variables within the brackets does note reflect the order of the VAR within the corresponding study.

The results presented in Table 2.2 suggest that oil importing economies are negatively affected by oil price rises. While the structure of the various economies may affect the extent to which economic growth is retarded following a price shock, these findings also imply that oil price shocks contribute to the volatility of most of the model variables for most of the country case-studies (Jiménez-Rodríguez and Sánchez, 2005). In the case of New Zealand, the existing literature suggests that little work has been undertaken on the relationship between oil price shocks and economic growth. As a net importer of oil, New Zealand's domestic economy is likely to be affected by oil price shocks for the same reasons as other countries. However, the overall structure of the economy and the energy system within it are inherently different from most industrialised countries.[23] This reinforces the need for policy inferences to be drawn from a study directly focussed on New Zealand. The present study seeks to empirically evaluate these aspects of the energy-economic growth nexus using recent techniques noted in the literature, and to compare the findings for New Zealand with other studies that have previously evaluated the relative importance of energy price shocks and economic growth nexus.

2.5 Summary and Conclusion

This chapter has considered theoretical and empirical literature concerning two important aspects of the energy-economic growth nexus. These aspects are energy consumption and price signals, as these factors are important elements of economic growth. From an economic perspective, energy consumption and oil price shocks have important long term and short term effects and policy implications for growth.

Given that energy resources are highly inelastic in the short run, this means that energy consumption responds little to price movements. Consequently, much of the historic research interest in energy issues and the macroeconomy has focussed on energy price shocks and economic growth. This literature presents a large number of plausible transmission mechanisms which can explain the occurrence of historic recession following oil price increases yet trivial growth following oil price decreases. Several non-linear measures of oil price movements have been presented in the empirical literature, based on the various theories of oil price shocks noted in section 2.4. The majority of empirical studies that account for the non-linear price shock arguments find evidence that oil price shocks are important macroeconomic events in a number of developed economies, despite the small cost share of oil in the economic output of those countries. Nonetheless, the oil price impacts on New Zealand's economic growth have not been empirically evaluated to date, therefore the policy implications regarding the

[23] These issues are covered in the next chapter.

importance of oil prices and the various linkages with economic growth are undertaken in the subsequent chapters.

The related issue of energy resource consumption and the impacts for economic growth have also been addressed, in light of the contrasting economic theories and the plethora of empirical evidence. On the one hand the ecological economics school of thought argues that entropy concerns will constrain the ability of substitution and technological change to ameliorate energy resource scarcity in the face of supply shortages and/or demand management initiatives. However the neoclassical economists have drawn on factor substitution and technological change arguments to suggest that energy supplies can sustain per capita income growth indefinitely. Concern over the pollution generated by the combustion of energy resources has added a new dimension to this debate, such that tackling the problem of climate change has motivated moves to reduce the consumption of fossil fuels which are compounded, particularly in the US, by geopolitical concerns for 'energy independence' and 'energy security'. Given that coal and oil resources in particular underpin global agriculture, industry and transport processes and will doubtless feature in the economic transformation of developing countries, a crucial empirical evaluation concerns the cointegration and causality linkages between energy consumption and economic growth. As empirical studies considering this nexus find different linkages between energy consumption and economic growth across various developed and developing countries, therefore country-specific analysis based on the specific energy system is required for each case.

In line with the New Zealand Government's objectives on economic growth, this study will examine the impact of energy consumption and price shocks on economic growth. New Zealand is bound by the Kyoto Protocol to the United Nations' Framework Convention on Climate Change to reduce greenhouse gas emissions to 1990 levels during the period 2008-12; this implies a trade-off which will require careful development of energy policies. Such policies will be analysed for New Zealand by examining the energy consumption–economic growth relationships. The findings will shed light on the energy-economic growth nexus for New Zealand. The results will also be useful for comparing the case of New Zealand to other country case-studies. In the next chapter, consideration is given to the role of energy in New Zealand, including an examination of the types of energy used, their role in different sectors, and how these patterns of use have changed over time. Subsequent chapters present an empirical analysis of various hypotheses noted in the energy consumption and price relationships for New Zealand.

Chapter Three

ENERGY RESOURCES IN THE NEW ZEALAND ECONOMY

The efficiency with which New Zealand produces and uses energy impacts directly on its international competitiveness, on its economic growth and on the quality of the environment.

(Statistics New Zealand, 2004, p. 357)

3.1 Introduction

This chapter examines the role of energy in the New Zealand macroeconomy and its usage, by resource and sector, for long term economic growth. Chapter 2 has highlighted the key theories which suggest how energy consumption and price signals may affect the process of economic growth. There is a large amount of empirical evidence that supports the energy-growth hypotheses. As a key factor input in the production process and in the climate of energy scarcity, the importance of energy has gained prominence following the oil crises of the 1970s and the increase in globalisation and integration of the global economy. Before considering various energy-growth nexus empirically for New Zealand in the next two chapters, it is important to discuss the macroeconomy and the energy sector that sets the scene of energy use in New Zealand. The chapter is structured as follows: section 3.2 presents an overview of the New Zealand economy, tracing the important developments in the country's economic history with the timeframe that focuses on the period since 1960. Section 3.3 provides a descriptive analysis of the New Zealand energy sector over the period considered, discussing the main energy resources in turn. Section 3.4 considers the state and direction of energy policy, which provides the important linkages between the energy sector and the macroeconomy. Section 3.5 summarises the important issues that are taken into consideration in the following chapters.

3.2 Overview of the New Zealand Macroeconomy

New Zealand is located in the southwest of the Pacific Ocean. It comprises two large islands, and numerous smaller islands. At 270,000 square kilometres of land surface with a population of 4.1 million in 2006, it has one of the lowest population densities in the world (Statistics New Zealand, 2006). New Zealand's economy consists of the primary, manufacturing, and service sectors. The total value of economic output is most easily gauged by the level of Gross Domestic Product (GDP) which in 2005 was NZ$155 672 million (International Monetary Fund, 2006b). It is a member of the Organisation for Economic Cooperation and Development (OECD) group of nations. Following the patterns of development, domestic agriculture and manufacturing sectors were developed. Exports of food and fibre were particularly to the United Kingdom initially, and thus New Zealand's economic development from the time of colonisation through the 19th and 20th centuries relied heavily on the British Empire. The role of international trade has remained pre-eminent to New Zealand's economic well-being. Since the 1980s, manufacturing and service sectors form major shares of GDP with the service sector contributing more than two-thirds to total GDP. Primary products (i.e. butter, meat, cheese and forestry products) remain key export commodities, contributing around half of the total export receipts (Statistics New Zealand, 2006b).

The period since 1960 has been characterised by sweeping changes to New Zealand's economic outlook. Two important changes in the international trading environment occurred in the early 1970s which rendered the prevailing economic climate, of widespread Government ownership and regulation, unsustainable. First, the entry of Britain into the European Economic Community (EEC) in January 1973 led to decline in exports to the United Kingdom (UK). This was followed closely by the first oil 'price shock' which saw world oil prices triple. These events impacted negatively on the terms of trade, and with a heavy reliance on international trade, the domestic economy suffered. The situation was made worse by a series of setbacks, the origins of which lie in the economic policy orientation of successive administrations that forced the wide-sweeping reforms undertaken by the fourth Labour Government. Between 1984 and 1991, the Government involvement in most areas of the domestic economy was removed, culminating in one of the most free and liberal economies in the world (Henderson, 1995). The post-reform period has seen a slow and steady recovery of the domestic economy, with several structures now in place to facilitate a long-term economic expansion on the basis of free-market principles. Thus, New Zealand's recent economic history can be separated into three different eras. Each period addressed here notes the long run development of New Zealand's economic profile.

3.2.1 Macroeconomy of New Zealand Pre-1960

New Zealand's economic history can be traced back to at least to colonisation movement that originated in Great Britain during the early 19th century.[24] The physical geography helped to shape New Zealand's economic development in several important ways from the time the first European settlers arrived. Endowed year-round rainfall, vast areas suitable for grazing livestock and the combination of temperate climate and low population density allowed early settlers to develop a comparative advantage in the production of agricultural commodities. Demand for wool laid the foundation for economic exchange with the industrialising Britain, and consequently for the development of the fledging New Zealand economy. The advent of refrigerated shipping toward the end of the 19th century entrenched primary production, as the economic backbone of this country; it allowed large-scale farm operations to service the markets of Great Britain which, in the midst of an industrial revolution, was experiencing a domestic movement away from the production of primary commodities towards the manufacturing sector (Hawke, 1985). This situation continued through World War One.

The New Zealand economy entered a buoyant period of economic growth as a result of its ready and willing market for food and wool products, and the means to transport them to market at a relatively low cost. The immediate impact on the farm activities flowed through into manufacturing in freezing works and dairy factories, and subsequently the service industries were established to provide for those involved in the former activities (Hawke, 1985). However, the focal point of expansion remained the development of primary commodity exports to Britain, who by 1932 absorbed nearly 90 percent of all exports. This situation was further developed through several inter-Governmental arrangements which allowed for the export of large amounts of agricultural output to the latter at favourable prices. The 'Commandeers' arranged during the two World Wars, and the development of marketing boards in the wake of World War Two, provided security of food supply to the British at prices favourable to New Zealand exporters, and further solidified the comparative advantage of New

[24] The indigenous people were engaged in sophisticated trade and enterprise for many centuries before the arrival of European settlers. However, in line with the neoclassical approach of this thesis, we begin with the emergence of 'conventional' economic enterprise in the colonial period, which followed large-scale immigration in the years after the signing of the Treaty of Waitangi in 1840.

Zealand primary producers as the basis of wealth creation (Hawke and Lattimore, 1999).

As more money entered the domestic economy, a regime of increased taxation provided the Government with the means to ensure full employment and to undertake substantial investments in education, health and housing. It also gave rise to persistent, though manageable, inflation. The culmination of these factors led the economy through a period of unsteady growth from the 1940s, before settling into a pattern of consistent positive growth in the 1950s that came to be known as the post-war 'long boom'.

3.2.2 The End of the Long Boom: 1960-1972

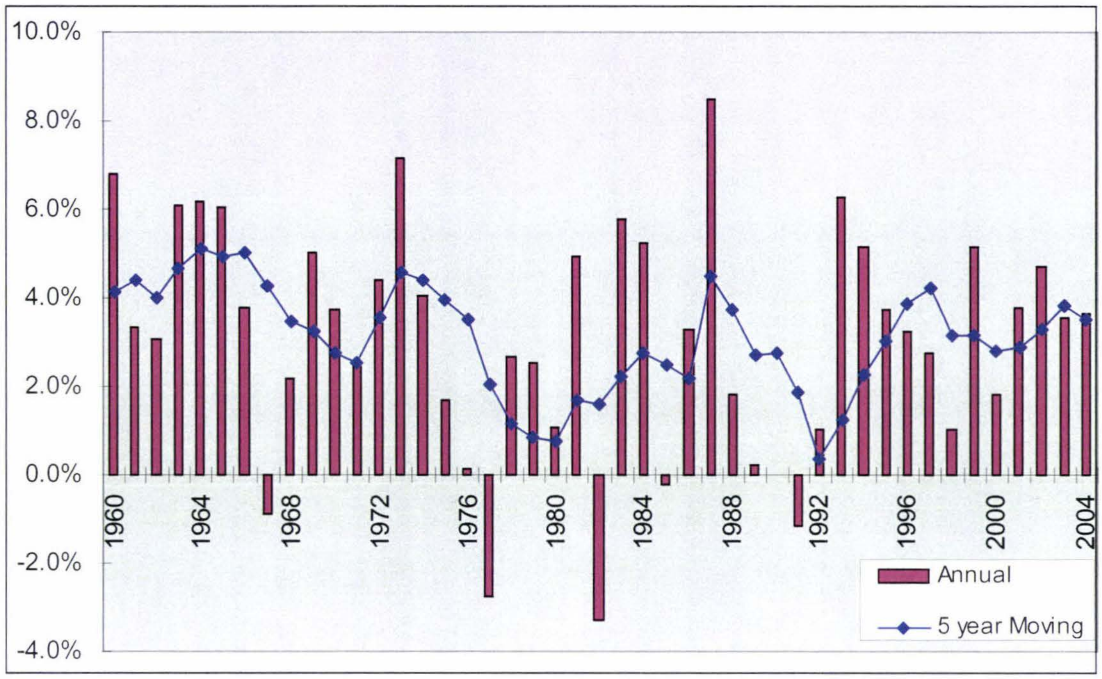
By the 1960s, the welfare state was a well-established ideology in New Zealand. The Government wielded a substantial influence over most sectors of the economy, controlling prices of goods as diverse as milk, electricity, and the exchange rate (i.e. pounds sterling) and provided universal access to health, education, welfare services and most importantly, employment. 'Insulationist' policies adopted during the 1930s continued to actively encourage domestic expansion into non-traditional industries, with such expansion underwritten by the foreign exchange receipts of agricultural exports to Britain.[25] This range of policies promoted an egalitarian society. The nation was successful in delivering economic growth between 3 and 6 percent throughout most of the 1960s (see Figure 3.1). The sharp decrease in GDP growth in 1967 of -1.2 percent was the result of a recession that was caused by a substantial reduction in world wool prices, which fell by over 40 percent between 1966 and 1968. At the time, wool continued to contribute more than 30 percent of New Zealand's total exports, making it an important source of foreign exchange (Dalziel and Lattimore, 2001).

The reaction of the Government (via the Wool Commission) was to purchase excess supply for stockpiling, thus providing a minimum price level to the farmers. The exchange rate was also devalued in a further attempt to reduce adverse impacts on export receipts. These measures were successful in reducing the negative impact on the

[25] The term 'Insulationism' refers to the broad decision taken during the 1930s that New Zealand's economic direction ought to be dictated more by agents and events from within the domestic economy, and less by agents and events from without.

farmers' incomes and the wider economy, and assisted in the rise in real GDP in the later years.

Figure 3.1 Growth Rate of New Zealand's Real GDP, 1960-2004 (production basis)



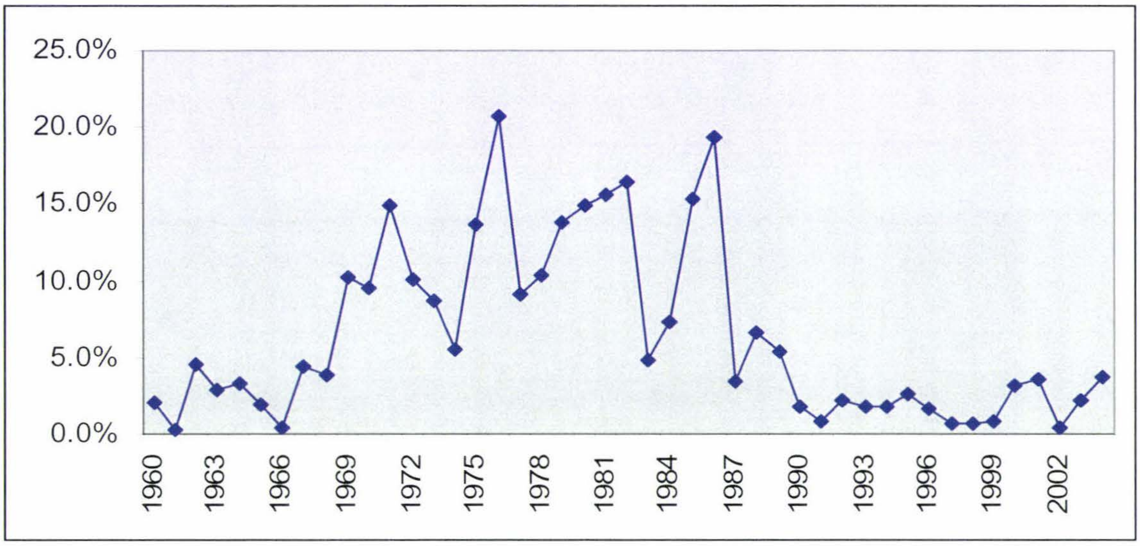
Source: *International Financial Statistics* (line 19699B.CZF...)

The series of events should have revealed the short-sightedness of a trading regime reliant almost exclusively on the export of a small range of commodities to a single market. However, several events that occurred in the early 1970s adversely affected international commodity markets.[26] These caused an upsurge in commodity prices that lifted New Zealand's terms of trade, to once again spur economic growth (see Fig 3.1). Nonetheless, economic events abroad also forewarned the deterioration of important economic indicators. For example, at the end of the Bretton Woods arrangement in 1971 relative currency values were allowed to equalise at their own accord, affecting inflation rates world wide. Unsurprisingly, New Zealand's rate of inflation that had been steady at around 2 percent since the end of World War Two rose significantly, impacting adversely on the macroeconomic activities; by 1971 the rate of inflation had reached 10 percent (see Figure 3.2). The Government responded by revaluing the currency and increasing export subsidies which reduced inflation the following year. However, they also affected the Balance of Payments deficit. The resulting combination of narrow

[26] These included a massive increase in demand for grain from the Soviet Union, resulting from a change in feeding policy; a poor anchovy harvest in Peru, resulting from El Nino weather effects; and significant crop failures in 1973 and 1974 (Dalziel and Lattimore, 2001).

export focus, insular domestic economy, and Balance of Payments deficit left New Zealand in a precarious position in the early-1970s.

Figure 3.2 Annual Rate of GDP Deflator Inflation, 1960-2004



Source: *International Financial Statistics* (line 19699BIRZF...)

3.2.3 Macroeconomic Developments: 1973-1983

In New Zealand's economic history, 1973 marked many changes that led to several economic downturns. Britain's entrance into the EEC undermined the existing export strategy, and this was followed later in the year by an international 'oil shock' which caused a three-fold increase in the world price of oil.[27] The combination of factors put New Zealand's foreign sector under enormous pressure. Not only was the traditional export market substantially weaker than at any time since the late 1930s, but the exporters' ability to penetrate alternative markets was affected by the increased cost of transportation. The rise in cost of transporting goods also considerably increased the prices of imports. The net result of these events was a 30 percent reduction in the terms of trade that constrained several domestic growth conditions. The Government borrowed from overseas in an attempt to maintain economic growth and full employment. As a consequence of this policy, the Current Account deficit reached

[27] This 'oil shock' resulted from an agreement within the Organisation of the Petroleum Exporting Countries (OPEC) to reduce output and embargo Western countries following the Yom Kippur war. The presence of oil price controls in many countries exacerbated the macroeconomic effect of the OPEC actions, which were followed by wide-felt recession in the developed economies.

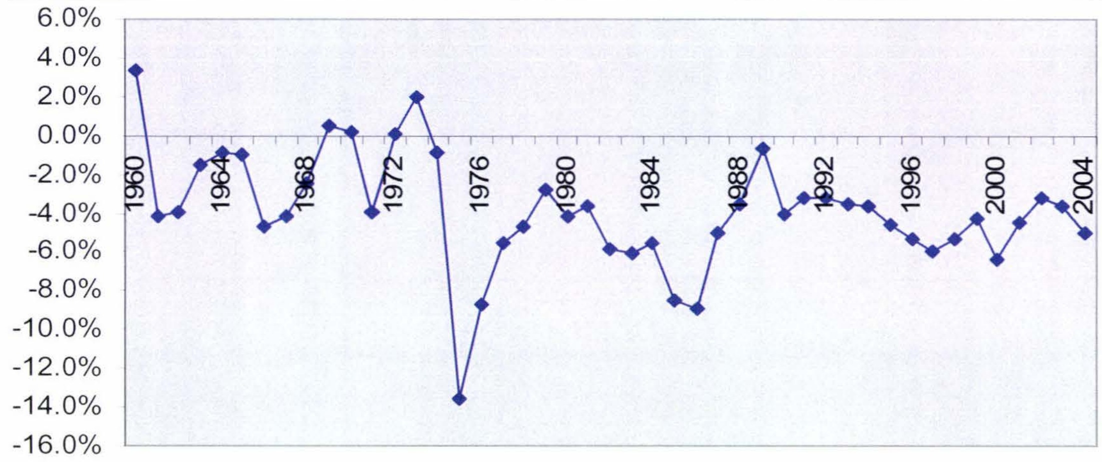
almost 15 percent of GDP in 1975. This level of public debt was unprecedented during the period, and further worsened the domestic situation.

One side-effect of the heightened public borrowing was the import of inflation from abroad. By 1976 the domestic inflation rate had reached 14 percent per annum. This presented an unsustainable environment for the continuation of the Government's 'welfare state' policies. Large amounts of intermediate goods and capital, imported by local manufacturers operating under heavy Government protection, continued to provide employment and wages. The cost of such policies, however, was reduced Government liquidity and heightened inflation. These pressures forced the 1976 Budget to include the removal of various price and interest rate controls and subsidies "in the interests of future solvency" (Dalziel and Lattimore, 2001, p. 17). This move was followed by a second oil shock in 1979-80, and thereafter unemployment rose from 2 percent in 1980 to 6 percent in 1984. These figures were unprecedented in the post-war New Zealand. The position of the Government at the time forced a change of direction in subsequent economic legislation, with two particular policy decisions spurring the subsequent developments of 1984.

A series of new policies, aimed at reducing dependency on foreign oil, the burgeoning current account deficit, rising unemployment and inflation, known collectively as 'Think Big', was floated in the early 1980s. This involved the construction of numerous energy sector installations in the Taranaki region and was motivated by international oil prices surging well-above their long run levels.[28] Importing the requisite capital and equipment from overseas increased the current account deficit from 4 percent of GDP in 1981 to 7 percent in the following year (see Figure 3.3); and inflation increased to 16 percent. The collapse of world oil prices in 1986 quashed the viability of the scheme, but not before leaving the Government $6 billion in arrears (Dalziel and Lattimore, 2001).

[28] These included an ammonia-urea plant at Kapuni; a synthetic fuel plant at Motonui; a methanol production plant at Waitara; and the expansion of the oil refining operation at Marsden Point and of the steel mill at Glenbrook. The key driver of the Think Big project was a desire to reduce foreign oil dependence, given the dearth of domestic petroleum processing infrastructure, and an implicit assumption that prices would permanently remain above their long run average level.

Figure 3.3 Balance of Payments Current Account Balance (Surplus/Deficit as a Percentage of GDP), 1960- 2004



Source: Statistics New Zealand (INFOS series BOPA.S4AC3, BOPA.S5AC3, SNAA.SH9, SNBA.SB9, SNCA.S1NB15)

The disastrous economic collapse occurred in 1982 when the Muldoon Government froze all domestic prices, wages and interest rates on the one hand, and reduced income tax (but not Government expenditure) on the other. These measures were aimed at reducing inflation, which by 1982 had surpassed the 15 percent rate. However, the means of artificially containing inflation by freezing prices resulted in heightened unemployment (6 percent in 1984) while overseas debt continued to climb (Dalziel and Lattimore, 2004). Muldoon's final act to support the NZ Dollar in the face of such pressures cost nearly $800 million, or 2.5 percent of GDP and the 1984 election delivered a new Labour regime intent on repealing successive layers of regulation, protection and control that had put the economic wellbeing of New Zealanders in jeopardy (Dalziel and Lattimore, 2004).

3.2.4 The Period of Reforms and Their Legacy: 1984-2004

The fourth Labour Government had a strong mandate to implement structural reform and liberalisation. The Labour Party was bought to power in the 1984 election with a majority of parliamentary seats, and subsequent Economic Development, Maori Development and Employment Summits re-affirmed the strong public sentiment for economic change. It subsequently tailored a package of reforms based around an integrated theoretical framework that included new microeconomic theories of contestability, principal-agency and public choice alongside conventional theories underpinning macroeconomic restructuring (Silverstone *et al.*, 1996). The immediate targets of reform were capital markets, the financial sector, industrial regulations, and international trade. However, the process was expanded progressively. By 1991, successive governments had undertaken further reforms of factor markets, monetary policy, taxation, Government entity performance, public expenditure, labour markets, natural resource use and social services (Bollard, 1994; Henderson, 1995; Silverstone *et al.*, 1996). These can be broadly grouped into 'financial and market reform', 'public sector reform' and 'social welfare reform'.

Financial sector liberalisation began with the removal of interest rate controls. This was promptly followed by the removal of all price, wage, foreign exchange and bank ratio controls in early 1985. The New Zealand dollar was floated in the same year, leaving the determination of exchange rates to international market forces. All of these actions were in line with the new Government's desire to achieve a competitive environment wherever possible (Evans *et al.*, 1996). This desire also motivated international trade reforms announced in August 1984, involving the removal of all major export subsidies and a reduction in import protection by 1987; a significant broadening of the tax base, including a reduction in income tax rates; and the narrowing of monetary policy to focus exclusively on reducing and containing inflation. Deregulation of the petroleum industry in 1988 stripped back Government's involvement in the determination of production levels and prices, allowing the domestic price to reflect international trading conditions. This had implications for the subsequent path of economic growth, which are discussed below.

Public sector reform involved the corporatisation of various Government departments into State Owned Enterprises (SOEs), which were to function in the manner of businesses. Accountability and performance were instilled as objectives under the new regime of 'user pays', replacing the obligation of Government Departments to provide social services for the community. This corporatisation process was extended into privatisation from 1988; the Government's pursuit of efficiency leading to the sale of former Departments to private sector interests.[29] This improved the Government's

[29] As Evans *et al.*, (1996) note, though SOEs are similar to private businesses there remain important differences such as untested limited liability status; reduced monitoring, as shares are non-transferable;

financial position, and assisted to transform the Budget deficit into a surplus by 1994. The process saw government interests as diverse as NZ Steel, Petrocorp, Development Finance Corporation, Air New Zealand, PostBank, Shipping Corp, Landcorp, Rural Bank, Government Printing Office, National Film Unit, State Insurance, Tourist Hotel Corporation, Maui/Synfuels, Telecom and the Export Guarantee Office being transformed (Robinson, 1994, pp. 20-21).

The reform of social welfare and labour market legislation followed the other elements of reform by some years, occurring when unemployment was high and the economy was in recession. One plausible reason for this delay may have been the likelihood that heightened unemployment would follow the initial period of structural change, which could only be exacerbated by targeting social assistance packages simultaneously.[30] In any case, social welfare spending was cut dramatically in 1990, some six years after financial market reform. Family benefits were abolished, most other benefits were reduced considerably, and the subsidisation of health and other services was replaced with the 'user pays' approach to social service provision. Labour market reform followed shortly thereafter, the key element of change being the replacement of centralised bargaining, typically through unions, with the Employments Contracts Act 1991 (Silverstone *et al.*, 1996). This legislation provided for individual employment contracts to be negotiated between employee and employer directly, crippling the power of the union movement to force firms into collective pay settlement arrangements. Contrary to popular predictions at the time, these reforms preceded a period of positive income and employment growth that suggest the net effect on the labour market may have been beneficial for both sides (Evans *et al.*, 1996).

By the mid-1990s, New Zealand had completed wide-sweeping reforms to the underlying structure of the macroeconomy in less than a decade. Figure 3.1 reveals a generally strong growth performance throughout the period since 1991, which suggests the overall impact of the reform package has been favourable. The continuation of pro-growth policies is reinforced by recent policy initiatives and legislation, such as the Government's Growth and Innovation Framework for Economic Transformation (New

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and a weak, though on-going relationship with Government. These arguments provided justification for eventual privatisation of a large number of entities formerly controlled by the Government.

[30] The reason why unemployment may be expected following liberalisation stems from the sectoral shifts hypothesis, which has been discussed at length in section 2.4 of chapter 2.

Zealand Government, 2002), which sets the over-arching objective of economic policy of returning New Zealand to the top half of the OECD rankings in per capita income terms. Nonetheless, several questions have arisen from the liberalisation programme, which suggest the path of future growth may have been adversely affected.

As a small open economy, New Zealand is insignificant with respect to the world market for crude oil. Consequently, since liberalisation of the petroleum industry in 1988 and the removal of price controls, New Zealand firms and the economy generally have been price-takers for crude oil and refined petroleum. This makes the economy susceptible to price 'shocks' as from the New Zealand perspective, oil prices movements are exogenous. An important question then, in light of the discussion in chapter 2, is whether oil price shocks are important macroeconomic events in the case of New Zealand. This is related to the further issue of whether energy, as a factor of production, is important to New Zealand's economic growth. This is relevant because elements of New Zealand's energy, environmental, and economic policies, in the wake of structural reforms, are driven by inherently conflicting objectives. This conflict may impact on future economic growth, depending on the nature of the energy consumption-economic growth relationship. In order to explore these issues in detail in chapters 4 and 5, the next section provides a descriptive analysis of New Zealand's energy sector, before considering the broader issues of energy policy which are important to economic growth in New Zealand.

3.3 The Energy Sector in New Zealand

Energy is a vital input to the New Zealand economy. It impacts directly on the primary, manufacturing and service sectors, and indirectly in the foreign sector where New Zealand interacts with other economic agents abroad. This section examines the supply and demand characteristics of the energy resources that support the economic activities in New Zealand and their implications for economic growth over the period 1960 to 2004. The penultimate section outlines the energy policy environment, which later develops the empirical investigation of various short-term and long-term energy-growth nexus in subsequent chapters.

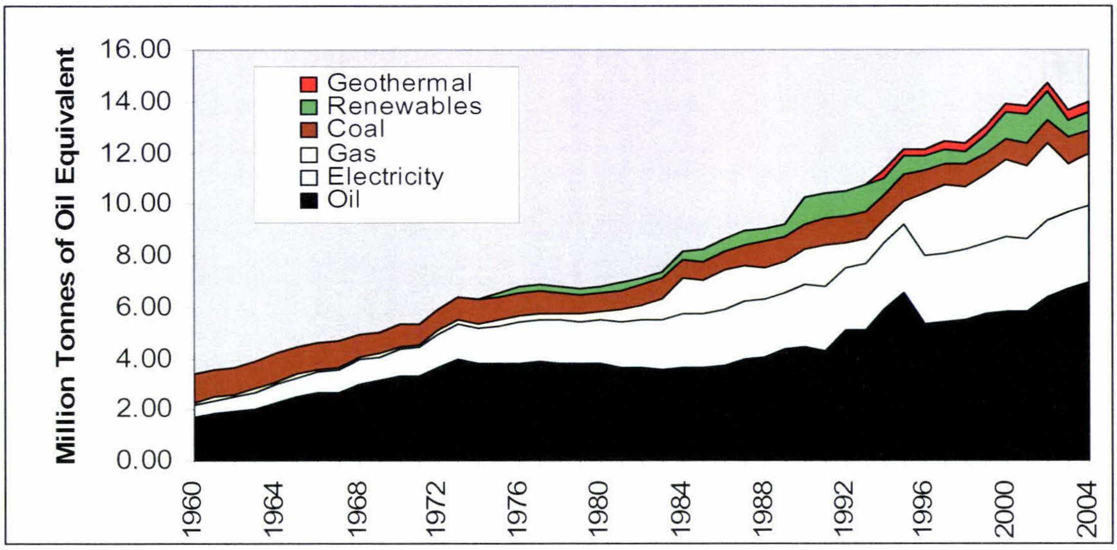
The energy sector in New Zealand is comprised of a small number of traditional resources. The fossil fuels, oil and gas, are crucial energy resources utilised in New Zealand, as are renewable hydro, geothermal and wind resources which generate majority of New Zealand's electricity supply.[31] Together, these resources account for majority of consumer energy utilised in New Zealand, which is largely channelled into the transport, agriculture and industrial sectors.[32] Coal resources have diminished in the relative importance over time, while the renewable energy resources (i.e. solar, wind and wood) have become increasingly vital for consumption purposes, given the world environment for alternative energy use. The annual final demand of these six resources (i.e. oil, electricity, gas, coal, renewables and geothermal) comprise the total consumer energy in New Zealand (see Figure 3.4 for the six energy resources demanded over the period 1960 to 2004). Consumer energy refers to the total quantity of energy used each year by final consumers. For the purposes of this thesis, consumer energy is measured in million tonnes of oil equivalent (MTOE). That is, the various energy resources are converted to an equivalent quantity of oil, based on their relative thermal efficiency.[33] This conversion is important because of the problems of aggregating across energy resources (as noted in section 2.3 of chapter 2 and section 4.3 of chapter 4).

The New Zealand physical profile of a long, thin structure and its temperate climate reflect the composition of energy resource demand of the nation. Figure 3.4 depicts annual consumer energy demand in New Zealand over the period 1960–2004. It clearly shows that oil is, in quantitative terms, the most important energy resource in New Zealand. This is consistent with New Zealand's large transport fleet.[34] Geothermal, coal and renewable energy resources contribute to energy consumption besides imports of crude oil and refined petroleum products. Electricity is the second leading energy resource, and is mainly derived from hydro, wind, coal and gas-fed generation

[31] Use of the term 'oil' is somewhat of a misnomer. While crude oil is the feedstock into refinery production, a more accurate term for refinery outputs might be 'petroleum products', to reflect the diversity of products comprising consumer 'oil' demand. These include petrol, diesel, fuel oil, aviation fuel, kerosene, and others. Consequently the terms 'oil' and 'petroleum' or 'petroleum products' will be used interchangeably, where appropriate.
[32] Consumer energy refers to the energy used by final consumers. It excludes energy used or lost in transformation and in bringing the energy to the final consumers (Ministry of Economic Development, 2006a).
[33] This follows the convention of the International Energy Agency (IEA), whose data are used directly in this analysis.
[34] Historically, demand from the transport sector has accounted for between 60 percent and 80 percent of total petroleum production. This is discussed further below.

processes. Together, oil and electricity resources have traditionally comprised around 75 percent of total consumer energy.

Figure 3.4 Total Annual Consumer Energy Demand in New Zealand, 1960-2004



Source: IEA *Energy Balances of OECD Countries*, various

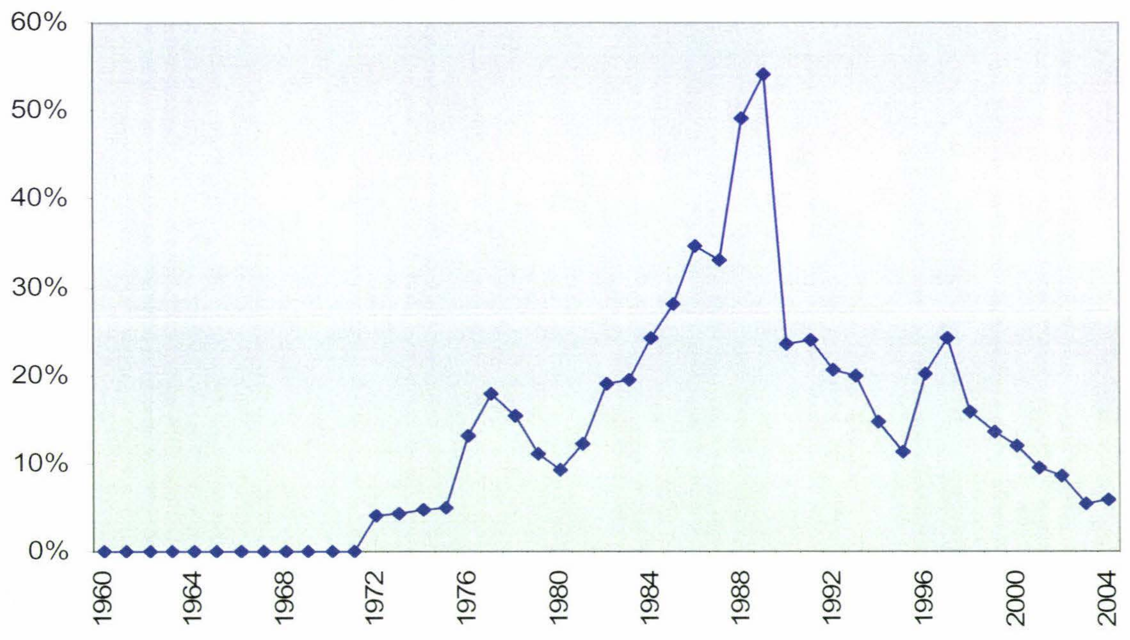
The renewable energy resources are increasingly vital sources of final consumer energy, and have contributed a similar amount as that of coal over the period 1990-2004. In conjunction with geothermal resources, these energy resources have contributed around 25 percent to New Zealand's annual energy demand. The pattern of energy consumption is important when New Zealand's endowment of energy resources and the impact of processes for producing final energy, are considered. Gas, coal and combustible renewables require little transformation from their natural state before consumption, compared to oil and electricity that are relatively high-quality energy resources that require transformation from crude inputs. The sections below consider the supply and demand characteristics of each resource in turn. In line with the focus of this study, the attention is given to the characteristics of New Zealand's oil industry over time.

3.3.1 Oil Resource Use in New Zealand

New Zealand has limited domestic oil resources and imports of oil (in both crude and refined forms) have traditionally contributed to the majority of New Zealand's oil supply. Petroleum products have been sold in New Zealand since Vacuum Oil Pty Ltd of Melbourne, Australia, (now Mobil) established a New Zealand operation in 1892.

However, New Zealand's only refining facility located at Marsden Point near Whangarei, commenced operation in 1964 and expanded substantially as part of the 'Think Big' project in 1986. New Zealand's oldest oil field, Kapuni, began production in 1969 and only the development of the Maui field in 1979 has added significantly to the domestic production base.[35] The 'Think Big' project led to an increase in economic activities that resulted in an increased proportion of final demand being met by domestic oil resources. However, a continued level of economic growth in the post-reform period coupled with a dramatic fall in the world price of oil and a change in Government oil policy have seen the proportion of domestic oil resources comprising total oil consumption decrease since 1990 (see Figure 3.5). Consequently, New Zealand continues to remain heavily reliant on oil imports to meet domestic demand.

Figure 3.5 Domestic Crude Oil as a Proportion of Total Consumer Oil, 1960-2004



Source: IEA *Energy Balances of OECD Countries*, various

Total annual consumer demand for petroleum products has increased from 1.67 MTOE in 1960 to 6.93 MTOE in 2004. The rate of increase in demand (as seen in Figure 3.4) has been relatively constant over the period (1960 to 2004), while the proportion of domestic crude and condensate refined into petroleum products has decreased

[35] That is, significant relative to the preceding quantity of domestic crude output. For example, Maui's maximum output of 2.22 MTOE occurred in 1997, contributing 77 percent of total domestic production in that year. Nonetheless, after allowing for exports, total domestic crude accounted for only 20 percent of Marsden point's refinery intake. The contribution of Kapuni similarly peaked in 1977 at 26 percent of total refinery intake. McKee's maximum contribution of 8 percent occurred in 1989.

substantially over the past 20 years. From an economic perspective, an interesting implication of such a high level of import-reliance is that the macroeconomy may be susceptible to oil price shocks. This is especially the case in New Zealand which, as a small open economy, has no real influence on world oil prices and where, following deregulation of the petroleum industry in 1988, the price of oil has been allowed to vacillate according to the international conditions. This issue will be discussed in detail in the next section which also forms the basis of the empirical analysis in chapter 5.

The bulk of New Zealand's crude imports are sourced from the Middle Eastern markets of Oman, United Arab Emirates, Saudi Arabia and Qatar, and the Asian markets of Australia, Indonesia and Malaysia. Currently around 5 million tonnes of crude oil per year is processed at the New Zealand Refining Company's (NZRC) Marsden Point facility. The major oil companies in New Zealand are Beyond Petroleum (BP), Caltex, Mobil and Shell. These companies are all significant shareholders as well as customers of NZRC.

The Marsden Point refinery produces around 70 percent of New Zealand's petrol supply, 85 percent of total diesel supply, 83 percent of total jet fuel supply, 100 percent of fuel oil supply and 75 percent of roading bitumen (New Zealand Refining Company, 2005). The residual domestic demand for petroleum products is met by imports of refined products, primarily from the large Singapore market that supplies around 20 percent of total consumer oil each year, in addition to a small amount of domestic crude and condensate gas (Ministry of Economic Development, 2006a).[36]

Geographically, all of New Zealand's developed oil resources are found in the Taranaki region, which is on the West coast of the North Island.[37] The Maui and Kapuni fields continue to dominate domestic crude oil production; however the smaller McKee and Waihapa/Ngaere/Piakau/Stratford fields also made sizable contributions to domestic production from the mid-1980s to the mid-1990s.[38] The contribution of domestic crude oil reserves to the supply of refined petroleum products has ranged from 0 percent

[36] Condensate is the name given to reservoir gas that condenses into light crude at atmospheric temperatures.

[37] Most crude oil resources are located together with gas resources in single deposits. This is the case for New Zealand; all (presently) developed gas reserves are also situated offshore and onshore Taranaki.

[38] At their peak, each of these fields contributed about 25 percent to total production. Neither has made an important contribution since the mid-1990s. See footnote 73 above.

between 1960 to 1972, to a peak of 54 percent in 1989 (International Energy Agency, various). The trend for the post-reform period has been a sharp decrease in domestic resources to below 10 percent of total production by 2004 (International Energy Agency, various). This is consistent with the industry deregulation and the running-down of both Maui and Kapuni fields as they reach the end of their useful lives. The future prospects for domestic production include the Pohokura, Maari, and Kupe fields that are situated in the offshore Taranaki region, though the Maui field will likely remain the most important field over the medium term. Around 75 percent of domestic crude oil production is exported annually, with only the remainder used as a feedstock to refinery operations at Marsden Point. This is because of the specific characteristics of the domestic crude, which do not align with refinery requirements.[39]

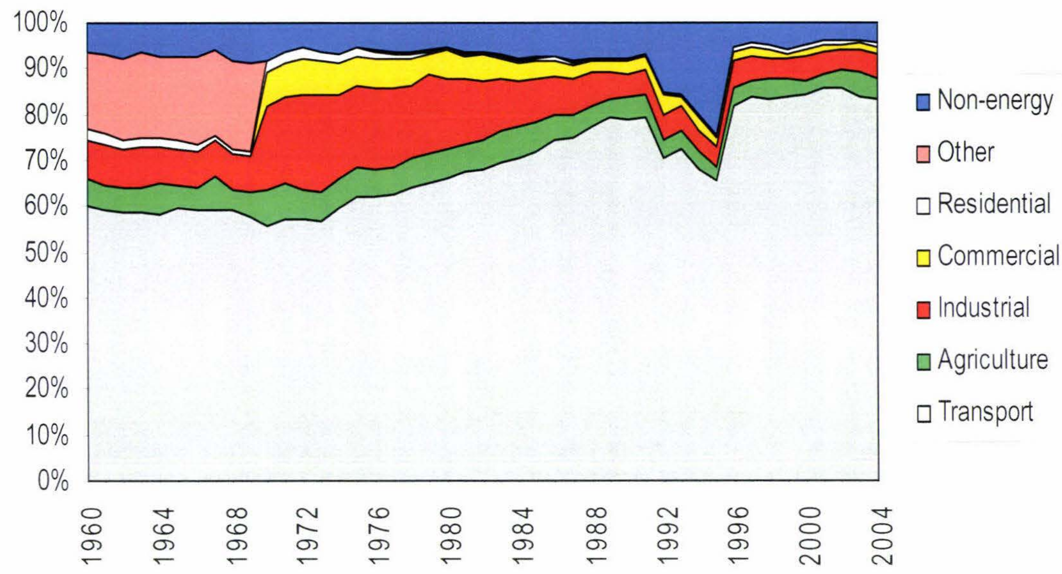
The retailing of petroleum products is dominated in New Zealand by a small number of long-established multinational companies. These companies are all vertically integrated in the petroleum industry, though only Shell is actively involved in the domestic exploration and production activities. The first company established in New Zealand was Mobil (in 1892), followed by Shell (1912), Caltex (1920), and BP (1946). The Australian firm Gull and Challenge (the Fletcher Challenge offshoot), entered New Zealand's retailing market in 1998, though the latter was bought out by Caltex in 2001 (Pickford and Wheeler, 2001). Prior to deregulation wholesaling licenses were required, however these were abolished in 1988.

The contributions of oil demand by each sector are indicated by Figure 3.6. The demand for petroleum products in New Zealand is dominated by the transport sector, which has increased its share of consumer oil demand from 60 percent in 1960 to around 85 percent since 1996 (International Energy Agency, various). In this context, transport includes international and domestic aviation, and road and rail. While it is common for the transport sector to dominate consumer oil demand in developed economies, demand from New Zealand's transport sector is particularly high. The main reasons for high consumption are the nation's long, narrow geographical structure and the low population base that necessitate lengthy travel between the major destinations. Other

[39] New Zealand's production is typically around 50 percent condensate, 20 percent crude and 30 percent naphtha. These characteristics restrict the usefulness of this resource as an input to refinery operations, which generally rely on 'lighter' products for processing.

relevant factors include the high ratio of automobile ownership amongst the population, and the importance of the service industry vis-à-vis primary and manufacturing sectors in New Zealand; in the developed economies where industry and or agriculture are the dominant sectors, the energy resources coal and electricity tend to have a higher relative share of consumer energy. Other important sectors that comprise of consumer oil demand include agriculture, industry, commerce, and residential. The level of oil demand over time implies targeting in the context of climate change and the related policy responses. Policy issues are discussed in section 3.4.

Figure 3.6 Composition of Consumer Oil Demand in New Zealand, 1960-2004

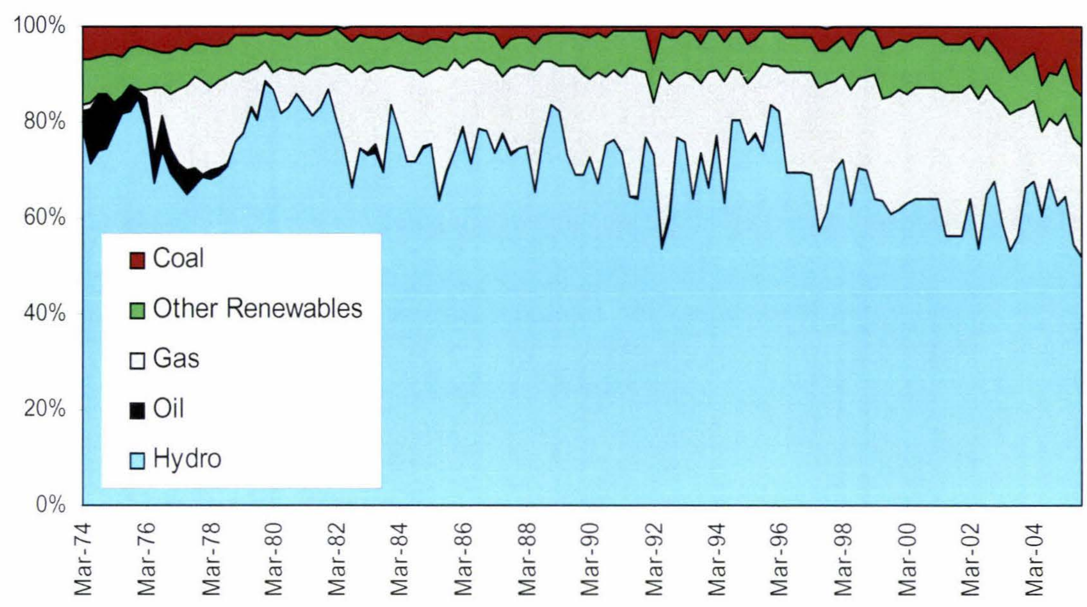


Source: IEA *Energy Balances of OECD Countries*, various

3.3.2 Electricity Utilisation

Electricity is the second leading resource in terms of final consumption in New Zealand. However, New Zealand's electricity sector differs markedly from the oil industry in a number of important ways due to a combination of physical and geographical factors peculiar to New Zealand. Electricity differs from most other energy resources in that it cannot be stored for any length of time. This makes the international transportation of electricity difficult, and in the case of New Zealand, practically impossible. New Zealand is entirely self-sufficient in electricity production, the majority of which is based on renewable hydro and geothermal resources.[40] Gas, coal, and the renewables biogas, steam, wood, and wind make up the balance of electricity generation feedstocks, with limited diesel-powered generation available in the instance of a supply shortage (see Figure 3.7).

Figure 3.7 Relative Contributions of Various Resources to Electricity Generation in New Zealand, 1974-2006[41]



Source: Ministry of Economic Development (2006)

Electricity generation dates back to 1861, with early developments initiated by numerous private companies and local authorities (Parliamentary Commisioner for the Environment, 2003). The Government's involvement in electricity generation in New Zealand began with the 45 Megawatt (MW) hydro-electric plant at Lake Coleridge in 1914. Hydro schemes, taking advantage of topography in the South Island, remained the means of expanding generation capacity for 40 years until the construction of a coal-fired station at Meremere and a geothermal station at Wairakei in 1958 (Statistics New Zealand, 1988). Population pressures and economic growth have continued to drive consistent increases in electricity consumption, and this higher demand has led to a rise in electricity generating capacity. In 2006, 60 plants with installed capacity exceeding

[40] In fact, New Zealand is self-sufficient in all energy resources except for oil, and is a net exporter of coal.

[41] Data for the breakdown of electricity generation by source have only been reported since 1974. These data are taken from the Ministry of Economic Development, as they are not reported in the IEA's *'Energy Balances'* publications.

10MW contributed to the national supply, with a further 14 plants planned for commission by 2009 (Ministry of Economic Development, 2006a). The majority of this new supply is based on wind, hydro, and geothermal sources, as well as limited gas developments.

The provision of electricity generation and distribution in New Zealand has been dominated by the Government involvement, and has been seen as a 'natural monopoly'. The Electricity Division was re-organised in 1987 as the State Owned Enterprise (SOE) Electricity Corporation of New Zealand (ECNZ). Prior to the industry separation in 1996, the Electricity Division of the Ministry of Energy was responsible for generation most of the country's electricity and operating the national grid. Electricity was then transmitted in bulk to 60 supply authorities who distributed and sold to the end-users. The industry separation took place in 1996 when Contact Energy was separated from ECNZ. The market separation was further extended in 1999 when ECNZ was split into the SOEs Meridian Energy, Genesis Power, and Might River Power. In the same year, Contact Energy was privatised. Since 1999 these four companies have provided more than 80 percent of the total annual electricity generation.[42] The balance of consumer electricity demand is supplied by smaller generating schemes and co-generation.[43]

Following the industry separation, the structure of the electricity industry has expanded from the flat 'two-tier' model described above to a more market-oriented format with a number of discrete processes. A wholesale electricity market allows generators to sell to retailers at a half-hourly interval. This system is operated by Transpower under a regime of 'uniform pricing' (Came and Dupuy, 2005). Generators bid their minimum price for supplying a certain quantity of electricity (to meet the forecasted electricity demand); these bids are ranked from cheapest to most expensive with the market price set by the marginal unit (see Came and Dupuy, 2005; Dupuy, 2006). The electricity is transmitted via the national grid by Transpower to the distribution companies and 10 industrial

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[42] Meridian dominates generation in the post-corporatisation era, with 32 percent of the generation market, followed by Contact (24 percent), Genesis (18 percent), and Mighty River Power (14 percent) (Ministry of Economic Development, 2006a).

[43] Co-generation refers to the simultaneous production of multiple forms of useful energy from a single primary source. Typically it involved the production of electricity in conjunction with heat or steam for industrial or commercial heating or cooling purposes.

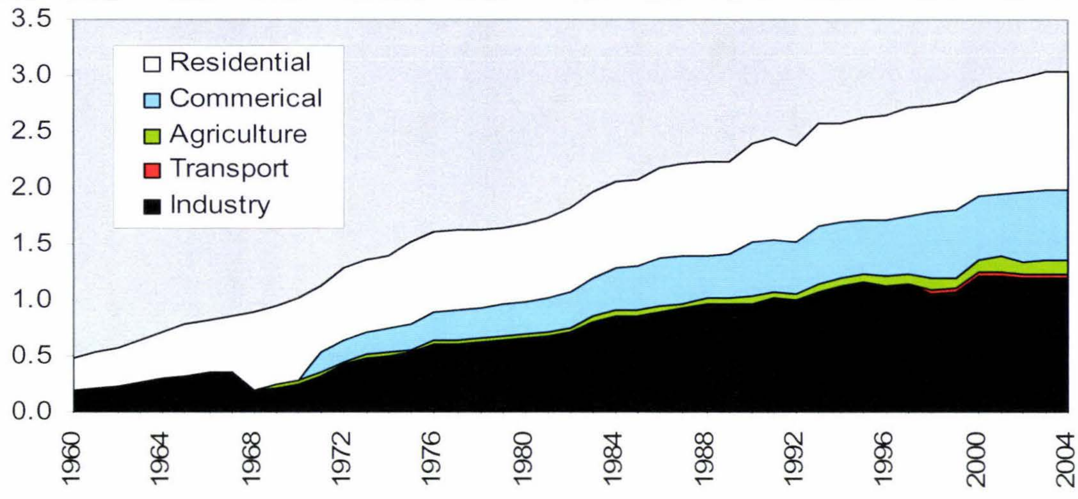
consumers.[44] Transmission between New Zealand's North and South Islands is via a High Voltage Direct Current link that runs below the Cook Strait.

The Commerce Commission and the Electricity Commission are responsible for overseeing different aspects of New Zealand's electricity market. The Commerce Commission overseas the distribution and transmission pricing to ensure an equitable balance between 'fair pricing' and 'fair incentives for investment'. The Electricity Commission is responsible for retail and wholesale markets, and transmission contracts. Its role is to ensure adequacy of supply in the electricity market and the management of price risk in what is an inherently volatile market (Ministry of Economic Development, 2006a). This is necessary because the cost of preventing supply failure by maintaining 'back-up' generation capacity is substantial and falls solely on the individual operators in the market. In such circumstances, market forces signal a level of production that is socially sub-optimal.

Figure 3.8 reveals the composition of final electricity demand among the different sectors of the economy. Electricity demand in New Zealand is dominated by residential, industrial, and commercial demands. The current annual demand is around 3.1 MTOE, slightly less than half of the final demands for petroleum products. The initial growth in electricity demand was driven by the post-war residential activities, however since the early 1970s, this has been mainly propelled by increasing industrial demand, and to a lesser extent commercial demand. The demand in the agricultural sector has increased marginally in the post-1996 period. The electricity demand of the industrial and commercial sectors has remained relatively constant, with modest increases in residential demand since 2000. This is attributable to a combination of net immigration and a sustained economic boom triggered by residential investment activity in the period 2000 to 2004 (Statistics New Zealand, 2006b).

[44] The 10 current direct supply customers are NZ Steel, CHH Pulp and Paper, Comalco Power, Fonterra, Methanex NZ, Norske Skog Tasman, Ontrack NZ, Pan Pacific Forest Industries, Rayonier MDF, and Winstone Pulp International.

Figure 3.8 Annual Final Demand for Electricity in New Zealand, 1960-2004 (Million Tonnes of Oil Equivalent)



Source: *IEA Energy Balances of OECD Countries*, various

3.3.3 Gas Sector Profile

New Zealand's gas industry is geographically confined to the Taranaki region of the North Island, where 11 gas fields produce gas for reticulation. Production has been mainly dominated by the Maui and Kapuni fields for more than two decades, followed by nine other small fields.[45] Total gas supply increased from 0.1 MTOE in 1960 to 3.0 MTOE in 2002. That had reduced to around 2.0 MTOE by 2004 (International Energy Agency, various). The final gas consumption is comprised of the residential, commercial, and industrial users. The consumption is dominated by industrial users (including electricity generators) who consume around 90 percent of the total annual amount. The commercial users account for around 8 percent of the total demand, with a large number of residential consumers making up the remaining 2 percent (Ministry of Economic Development, 2006a).

The electricity generators (i.e. Contact Energy and Genesis Power) utilise gas to operate the Otahuhu, Taranaki Combined Cycle, New Plymouth and Huntly thermal power stations, respectively, that demand around 40 percent of total final gas consumption. The petrochemical industry is also a large industrial consumer of gas, dominated by the demands of the Methanex chemical methanol plants at Motunui and Waitara Valley and Ballance Agri-Nutrients's ammonia/urea plant at Kapuni. Traditionally, these plants

[45] These fields are Kaimiro, Mangahewa, McKee, Ngatoro, Rimu, Tariki/Ahuroa, and Waihapa/Ngaere

have used around 30 percent of annual final consumption in the time since the 'Think Big' project.[46] The balance of industrial consumption is made up by a number of major industrial users (i.e. NZ Steel, Cater Holt Harvey, Fonterra and Tasman Pulp and Paper). The remainder of final gas demand is reticulated to commercial and residential consumers through more-than 3000 kilometres of transmission pipelines.[47] The pipeline system functions similarly to the national electricity grid, and is operated by Natural Gas Corporation (more commonly known as NGC).

The Government's involvement is the gas industry has been limited since the industry reform began in 1987. Deregulation of the industry occurred in 1993 with the removal of gas franchises and cessation of the wholesale price controls. The Government's current policy objective for the gas industry is "to ensure that gas is delivered to existing and new customers in a safe, efficient, fair, reliable, and environmentally sustainable manner" (Ministry of Economic Development, 2004b, p. 2). The regulatory aspects of the gas industry are the responsibility of the Government and the Gas Industry Company (GIC), an industry body established in late 2004.[48] The development initiatives and exploration activities (such as favourable royalty rates and development permits) have been undertaken to increase future gas resources following a downward revision of Maui reserves in 2004. The future gas developments include the Kupe and Pohokura fields located offshore Taranaki, to provide long-term supply given the impending rundown of the Maui field (Steeman, 2006).

3.3.4 Coal Resources

New Zealand is endowed with enormous coal resources, estimated at around 15 billion tonnes in total.[49] These are concentrated in the Waikato region of the North Island, and the west Coast and Southland regions of the South Island. The majority of coal reserves (around 80 percent) are of low-grade lignite variety, 15 percent is sub-bituminous and

[46] Their contribution to final consumption has decreased in recent years, following the closure of the Motunui plant.
[47] Maui gas is fed directly to the Huntly power station via the Maui pipeline, which is owned and operated by Maui Development Limited.
[48] However, the Government has recently subjected Vector and Powerco to price control, mandating price reductions of 9.5 percent and 9 percent respectively in October 2005. This was in response to the Commerce Commission's (2004) report which suggested the pipeline businesses may have been taking advantage of their monopoly position.
[49] Of which around 8.5 billion tonnes is deemed economically recoverable.

only 5 percent is of the high-grade bituminous variety (Ministry of Economic Development, 2006a). The coal resources in New Zealand have dwindled since 1960, from nearly 35 percent of consumer energy to below 10 percent in the recent years (see Figure 3.4). The current output is around 5 million tonnes, or slightly less than 1.0 MTOE. Around 85 percent of this production is undertaken by a large SOE - Solid Energy - while a number of small private mining companies account for the remaining 15 percent of coal output.

Sub-bituminous coal is used for the electricity generation, while bituminous coal is used in steel production. In 2003, the 1000 MW Huntly power station switched from gas to coal as the pre-dominant feedstock, and demand for sub-bituminous coal has risen in the years since. Domestic production has not been able to keep up with this higher level of demand, and imports of sub-bituminous coal have increased to cover the domestic shortfall. The change in the feedstock was necessitated by gas shortages (see discussion above), however Government policy is in favour of seeking non-thermal alternatives to coal as a longer-term replacement for the gas supplies (Ministry of Economic Development, 2005). This is because of the implications for New Zealand's greenhouse gas emissions reduction commitments of the carbon dioxide emissions from the combustion of coal resources.[50] Electricity consumption dominates domestic coal demand, comprising around 55 percent of total final consumption. The other major domestic coal users are Pacific Steel and NZ Steel, who utilise 20 percent of final consumption, while its use as a feedstock in a wide range of other industrial processing operations accounts for a further 20 percent. The remaining 5 percent is utilised as a source of heat energy in the commercial sector (Ministry of Economic Development, 2006a).

Exports of large quantities of coal (mainly bituminous) continue to increase in the recent years. These account for around 35-45 percent of annual production, so that the coal sector is a net exporter. The majority of these exports are sent to steel-producing countries, such as Japan, India, South Africa, China and Australia. As global growth continues, so too does global steel production and hence export demand for bituminous coal in particular has increased (Ministry of Economic Development, 2006a).

[50] The increase in coal demand is therefore likely to be temporary, once generation technologies become available.

The Government's involvement in the coal industry follows a familiar pattern to the other energy resources. Government ownership of most mines dominated the post-World War Two period, facilitating employment opportunities and the provision of cheap coal to spur the post-war period of recovery. The Department of Mines became State Coal in 1983, before becoming the SOE CoalCorp in 1987. In 1997, CoalCorp was re-named Solid Energy, which continues to dominate domestic production activities as a commercial company with the Government as the only shareholder (Statistics New Zealand, 2004).

3.3.5 Geothermal and Other Renewables

The geothermal and renewable resources directly contribute a small amount to final consumer energy. However this understates their role in the wider energy industry, as both make important contributions as feedstocks to the electricity generation.[51] The direct use of renewable resources is in the form of woody biomass, which is utilised in the wood processing industry and for residential heating, while a small amount of geothermal energy is also used directly for heating purposes. Renewable energy activities centre around the development of wind energy technologies, which has the potential to make a large contribution to New Zealand's energy supply. Various aspects of the Government's sustainable growth and sustainable energy policies surround the development of large-scale wind energy resources (Ministry of Economic Development, 2004). These broader issues are discussed in the next section.

3.4 The Energy Policy Environment

The importance of energy resources for the economic growth process, and the presence of externalities, natural monopolies, and other complex characteristics of energy markets have justified its regulation and policies for the nation's development goals. Together, these issues imply that the state and direction of Governmental policies toward energy consumption and pricing may have an important bearing on the growth path of the macroeconomy. The preceding sections of this chapter have described New Zealand's general economic environment and the role of various energy resources by

[51] Which, following the definition of consumer energy given earlier, is counted under their 'final' demand, i.e. electricity and not renewables.

sector. The economic reforms discussed in section 3.2 point out the changes in policy direction that had a direct impact on the energy sector. These changes include deregulation of the petroleum industry in 1988, the corporatisation of ECNZ in 1987 and Petrocorp in 1988, and so on. An important, though less-visible, element of the progression toward free-market orientation after 1984 has been the strain caused by heightened environmental concern; for example, the Resource Management Act 1991 and the increasing focus on climate change in various acts of legislation since 1992 that have culminated in the Climate Change Review Act 2002.

Prior to deregulation, Government involvement in, and control of, the petroleum industry was pervasive, and the industry was relatively inefficient. The Petroleum Sector Review Act 1988 removed nearly all existing regulations across the industry's core refining, wholesaling and retailing elements. It abolished domestic wholesalers' obligation to utilise the refining facilities at Marsden Point, allowing the refining costs to fluctuate according to international conditions. Government support of the Marsden Point refining facility, extended through the 'Think Big' initiative, was also removed, leaving future investment to be funded privately. As well as being free to source refining services offshore, wholesaler licensing requirements were abolished, price and rate-of-return controls were removed, and companies were free to vertically integrate into retailing (as was the norm overseas). Retailers benefited from the removal of licenses, though some argued this would lead to predation on the part of multi-national wholesalers against independent retailers who had advantages of location under the prior regime.[52]

The resulting energy industry is essentially a free market, with the proviso that petroleum products remain subject to heavy taxation.[53] Fluctuations in the international price of crude flow through to retail prices as domestic wholesalers compete with foreign competition for crude and refined products. In the current climate of strong

[52] The Ministry of Economic Development commissioned a study by the New Zealand Institute of Economic Research in 2002 after the Motor Trade Association, the industry body for independent retailers, claimed large companies were utilising wholesale pricing to drive independents out of the industry. The report found that competition between the established large companies was sufficient to ensure consumers were not disadvantaged by the predatory behaviour of the larger firms, and advised that government protection of independent retailers was not appropriate or justified (New Zealand Institute of Economic Research, 2002).

[53] The low price elasticity of demand makes petroleum taxes an efficient means of revenue generation.

global demand and a limited idle refining capacity, the time taken for foreign impact to reach the domestic market can be measured in hours.[54] This leaves individuals and businesses in New Zealand's small open economy as price-takers with respect to petroleum products. In light of the literature on energy price and consumption effects, it may be important to analyse what effect if any this has on economic growth.

The Government Policy Statement on Electricity Governance calls for an electricity system that will deliver the Government's growth and sustainability objectives, highlighting the link between the energy sector, the environment and economic growth (Ministry of Economic Development, 2004a). The Electricity Commission is charged with ensuring a secure supply of electricity that is generated with environmental responsibility and is priced efficiently and fairly. In conjunction with climate change policy, the Resource Management Act 1991, and the National Energy Efficiency and Conservation Strategy, these requirements imply that both the means of generation and the level of electricity supply may be affected in future. This may be important from an economic growth perspective, given the primacy of electricity to most production processes.

Climate change policy in New Zealand reflects the conflict between economic and environmental objectives that motivates further analysis in chapter 4. New Zealand is bound by the Kyoto Protocol to reduce Greenhouse Gas (GHG) emissions to 1990 levels during the period 2008-2012. Such actions have economic costs that may harm the competitiveness of domestic businesses and the export industries. The current goal of climate change policy is that "New Zealand should have made significant greenhouse gas reductions on business as usual and be set towards a permanent downward path for total gross emissions by 2012" (Ministry for the Environment, 2005, p. 75). The main contributors to emissions in New Zealand are the primary, energy and transport sectors. Methane emissions from the primary sector account for around 54 percent of all greenhouse emissions, while the energy and transport sectors generates around 25 percent and 10 percent, respectively (Gillespie, 1997; Ministry for the Environment, 2005).

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[54] That is, in the case of price increases. As is well known, the relationship between crude and retail price movements is asymmetric; see Gately and Huntington (2002) for a useful discussion.

The transport sector is particularly important from a climate change perspective because it is growing rapidly and is based almost exclusively on non-renewable fuels. The national transport fleet is relatively old, so average fuel efficiency is relatively poor, while the general rate of taxation on petrol and diesel is low by international standards (Xie *et al.*, 2005; Ministry of Economic Development, 2006a). These factors both contribute to the higher rates of fuel use that are behind the growing rate of GHG emissions (Ministry of Economic Development, 2005). Furthermore, the Government is averse to targeting agricultural methane emissions as this may penalise agricultural exporters unduly and there are few practicable technologies presently available. On the other hand, there are limited opportunities for efficiency gains in the energy sector given that a high proportion of electricity is already generated by renewable sources and that oil, which dominates consumer energy, is without close substitutes. In 2005, the Government decided not to go ahead with a proposed carbon tax for some sectors of the economy, which would have imposed a carbon price signal into the market for energy. Such a move was considered in line with the general liberalisation of energy policy, and seen as a cost-effective way of reducing total greenhouse gas emissions that are forecasted by the International Energy Agency (IEA) to exceed the Kyoto Protocol target by 21 percent during the first commitment period 2008-2012 (International Energy Agency, 2006a).

Energy efficiency measures are often considered to be of principal importance to climate change response strategies. While an increasing emphasis on efficiency measures may assist with the long-term development of sustainable energy measures, the present rate of increase in efficiency – currently less than 1.5 percent per annum – suggests this is an unrealistic short term solution, and highly unlikely to meet the National Energy Efficiency and Conservation Strategy's target of a 20 percent improvement by 2020 (Energy Efficiency and Conservation Authority, 2001). The central implication of climate change policy from the perspective of this study is that energy conservation measures may impact on macroeconomic performance. These effects may be compounded by the Resource Management Act 1991 (RMA) constraining growth in the energy supply, particularly with respect to New Zealand's electricity generation options.

The RMA is based on the principal of sustainable resource management. In this context, sustainability refers to the idea of maintaining environmental quality so that the present developments do not impede the productivity of the environment for future generations. Under the RMA, actions which may impact on the environment first require the consent of the local body authority, and are subject to their subsequent regulation. There is potential for conflict under this regime, especially with regard to energy sector developments, between economic and environmental objectives. Electricity generators have identified difficulties in the RMA regarding resource consents, fulfilling land requirements, and processes surrounding emergency scenarios that make the expansion of electricity infrastructure a complex process for the companies involved in generation; a pertinent example of this is the 2004 proposal for Meridian Energy's 'Project Aqua'.[55] The development of future coal-based electricity generation is also constrained by the negative environmental consequences of coal combustion, and the likely impact of such operations on environmental values. This is noted, for example, in the Ministry of Economic Development's (2005) *Briefing to Incoming Ministers*. These arguments suggest that renewable energy may be required to substitute for the relatively less-clean components of final demand in the future on the basis of environmental constraints. This is particularly important for electricity, where annual demand continues to increase steadily (see Figure 3.8).

Meridian Energy's policy for future electricity generation developments is an exclusive focus on renewable resources as the source of generation. However, there are practical problems with any policies which aim to alter the present composition of final consumer energy. On the one hand, while government policies are supportive of the renewables industry, the current contribution of renewables (excluding hydro) to final energy consumption is small.[56] Furthermore, there seems little chance of substantial increases in energy generation from renewable sources over the medium term, given currently available technologies. These points suggest that environmental and economic policies may need to be reconsidered if the competing policy objectives are not to conflict. An empirical analysis of the fundamental relationship between energy consumption and

[55] Project Aqua proposed the construction of six power stations along a 60 km stretch of the Waitaki River in North Otago, capable of generating up to 3200 GWh (0.3 MTOE) of electricity per year. That is equal to around 8 percent of annual final energy demands. Meridian eventually decided to abort the proposal, faced with problems acquiring land and the difficulties of gaining resource consent to divert the river's water flow.

[56] For a review of Meridian's renewables policies, see www.meridianenergy.co.nz.

economic growth may yield useful insights for policy-makers concerned with this task. This argument motivates the analysis of the next chapter, which uses a cointegration and causality framework to examine the relationship between the key energy consumption and macroeconomic variables.

3.5 Summary and Conclusion

This chapter has considered the path of New Zealand's macroeconomic and energy sector developments, focussing on the period since 1960. It has also noted the characteristics of the five resources which comprise consumer energy in New Zealand, namely oil, electricity, gas, coal, geothermal and other renewables. The market structures and the energy market trends over the period 1960-2004 indicate oil and electricity as vital energy components. The liberalisation reform package delivered in the wake of the 1984 election, extended to most sectors of the economy, included deregulation of the petroleum industry. This in turn exposed the post-reform domestic economy experiencing the fluctuations in the world price of oil. From the economic growth perspective energy resources are vital for many sectors and the impact of oil price movements on economic growth is important for overall output of the economy.

In the wake of the deregulation period, the objectives of economic and environmental legislation have placed compounding pressures on New Zealand's energy resources. One implication is that a reduction in the quantity, or a change in the composition, of energy used in the production process may be required in the future to fulfil the environmental obligations of energy policy. The implications of such energy conservation for economic growth are worthy of consideration, because of the theoretical bi-causality implied *a priori* that energy consumption may cause economic growth and vice versa (as discussed in chapter 2). The importance of climate change to the future direction of the economy, the environment, and the energy sector are vital. These issues are developed further in the following chapters, where the empirical analysis adds to the depth of the arguments presented here.

Chapter Four

ENERGY CONSUMPTION AND ECONOMIC GROWTH: INVESTIGATIONS OF COINTEGRATION AND CAUSALITY

Is energy consumption a stimulus for economic growth or does economic growth lead to energy consumption? Evidence in either direction may have significant bearings upon policy.

(Masih and Masih, 1996, p. 166)

4.1 Introduction

The relationship between energy consumption and economic growth has received much attention in the applied economics literature. Economic theory is ambiguous regarding the direction of causality between these variables, as contrasting theoretical considerations suggest that energy consumption precedes economic growth and vice versa. On the one hand, theory states that energy resources are an important factor of production, implying that energy consumption drives economic growth. But on the other hand, the demand for energy is a derived demand. That is, energy consumption is a function of macroeconomic conditions (Lermit and Jollands, 2001). From this perspective, the state of the economy bears heavily on the demand for energy. Given the high level of public awareness surrounding environmental issues, reflected in part by national and international climate change legislation, analysing this complex relationship is an important policy issue for both the developed and the developing countries. In the instance that energy is a vital causal factor of economic growth, energy conservation policies may be more difficult to enact than in a situation where economic growth causes energy consumption, or no causal relationship exists between these variables.

"In the field of energy economics an issue that has remained empirically elusive and controversial is that of the causal relationship between energy consumption and economic growth. At the heart of the issue arises the question as to which variable takes precedence over the other – is energy consumption a stimulus for economic growth or does economic growth lead to energy consumption?" (Masih and Masih, 1996, p. 166). The aim of this chapter is to consider the energy consumption-economic growth relationship for the case of New Zealand, utilising the cointegration and causality methodologies in evaluating three specific relationships in the demand-side and supply-side hypotheses of energy consumption.

The literature of energy-growth nexus is important given the various economic growth policies that New Zealand is addressing in an attempt to conserve energy and utilise renewable energy resources, so as not to impinge on economic growth. Using the advanced multivariate approach this study differs from that of Fatai *et al.*, (2004) on causal linkages between energy consumption and gross domestic product (GDP) in New Zealand. This study also applies three specifications of testing for causality using the Autoregressive Distributed Lag (ARDL) approach to cointegration and vector error correction models (VECMs) in estimating the long run and short run causal relationships between relevant variables.

The chapter is structured as follows: section 4.2 discusses the economic theory and empirical evidence of the energy consumption-economic growth issues. Section 4.3 discusses the data and models employed in the present study. Given that the models are estimated over the period 1960-2004, using the recently developed ARDL approach has the advantage of good small sample properties relative to other methodologies used in energy-growth nexus studies where the estimation period has been short. Section 4.4 presents the results for three trivariate and multivariate demand and supply models for the unit root tests, the bounds test of cointegration, and the Wald F-tests of short run causality for these models. The implications for New Zealand's economic policies are discussed. The final section concludes the chapter.

4.2 Energy Consumption and Economic Growth Relationship: Economic Theories and Empirical Evidence

This section draws together the relevant issues and ideas from chapters 2 and 3 that discussed the theoretical aspects of energy consumption-growth nexus and the empirical studies for several countries. The principal objective of this chapter is to identify the long run and short run impacts of the energy consumption-economic growth relationship for New Zealand, using the recently developed time series cointegration methodologies to avoid spurious results. Identifying the nature of the key relationship over the short run and the long run will assist the policy-makers about the impact of energy consumption and economic growth, and also identify the policy implications for greenhouse gas emissions requirements to meet the broader environmental targets.

The neoclassical theory of economic growth (discussed in detail in chapter 2) models economic output primarily as a function of capital and labour inputs. Economic growth is fundamentally driven by investment, population growth, and exogenous technological change. The original Solow (1956) model of economic growth has been expanded to take explicit account of the role of energy resources in production; subsequent neoclassical literature highlights several mechanisms by which economic growth can continue despite a finite base of energy resources. The vital elements include the substitution of capital and labour inputs for energy, and the ability for technological progress to use existing energy resources more efficiently, as well as delivering new energy resources that are not subject to binding supply constraints (Solow, 1974a; 1997; Stiglitz, 1997).

In light of these considerations, the neoclassical theory predicts energy resources to be non-essential inputs to production. This implies that while energy resources contribute to production, causality runs from economic growth to energy consumption. Accordingly, energy supply constraints need not impact on the growth path of the macroeconomy. The important policy conclusion from this perspective is that energy conservation policies may be realistically pursued without constraining economic growth. This is a crucial result given the international attention levelled at the issues of global warming and climate change, and the related issue of impending fossil fuel scarcity. Such an implication also suggests that the global living standards need not decrease in the course of tackling the important environmental issue. However, there is an alternative theoretical perspective, commonly attributed to the ecological economics school of thought, which asserts that energy resources are a limiting factor in the growth of modern economies (Stern and Cleveland 2004).

The ecological economics school of thought draws on various scientific laws and properties to argue that energy, broadly defined, is the sole factor of production in economic systems (Georgescu-Roegen, 1975). It focuses on the material basis of economic production, and from this perspective a number of limits arise in the neoclassical theory's substitution and technological change arguments. To the extent that these limits imply that economic growth is dependent on energy resource inputs, the prospects for sustained economic growth under a regime of energy conservation policies differ wildly to those predicted by the mainstream theory. The main counter-arguments to substitution and technological progress are noted below.

A crucial argument in the ecological economics literature suggests capital-energy substitutability is limited by the physical interdependence of various inputs. That is, the construction and maintenance of capital items require a flow of energy and materials; producing more of the substitute therefore requires more of that which it is substituting for (Stern and Cleveland, 2004).[57] Another line of enquiry suggests thermodynamic restrictions can inhibit factor substitution possibilities. This argument states that there are limitations to transforming materials from one thermodynamic state to another, and limitations on the use of energy to facilitate such transformations (Ruth, 1993). Arguably, a more compelling critique of the neoclassical role for technological progress is that such progress simply reflects substitution from less efficient production techniques to more efficient production techniques, based on the acquisition of new knowledge. This knowledge is embodied in improved capital and more highly-skilled workers. Stern and Cleveland (2004) argue that even the improved capital and labour inputs still require energy and ecosystem services to produce economic outputs, so that the argument of thermodynamic restrictions to substitution (in this case, between knowledge and other factors of production) remains valid. Given that knowledge, in this sense, is only one of several factor inputs, the marginal productivity of knowledge remains constrained by the quantities of the other inputs (Stern and Cleveland, 2004).

Despite the divergent views of the neoclassical and ecological economics schools of thought, both perspectives imply that a long run relationship may exist between energy resources and economic output. However, the direction of causality in both the short run and long run has been disputed. Empirical studies that examine the relationship between these variables have utilised Granger causality techniques to test for the direction of causal relationship, if any, that exist for several developed and developing countries (see

[57] However, this argument only seems to apply at the very macro-level; evidence from many regions (even nations, in the case of resource dependent countries such as Kuwait and Qatar) suggests that the depletion of natural resources can be augmented with manufactured capital to sustain economic growth.

Chapter 2, sections 2.3.2 and 2.5.1 for discussion of the empirical literature). However, the majority of studies disagree about the identified causal relationship, even within the same country context. This may be because of inappropriate statistical methodologies being used in many cases (Asafu-Adjaye, 2000; Stern, 2000). Therefore, the central issue of causality remains largely unresolved. The country-specific examination is crucial to analyse these impacts given that there is no consensus in the literature.

The two studies by Fatai *et al.*, (2001; 2004) examined the causality between energy and economic variables for New Zealand and the causality between disaggregated components of energy and growth. They considered the bivariate relationships between energy consumption and employment, and energy consumption and real Gross Domestic Product (GDP), respectively. In the 2001 study Fatai *et al.,* utilise the Johansen-Juselius (hereafter referred to as JJ) approach to examine the cointegration properties of energy consumption by disaggregating total energy consumption into coal, electricity, gas, oil, total final energy consumption (household plus commercial energy consumption) and commercial energy consumption components with total employment, for the period 1960-1999. Their results provide evidence of a cointegrating relationship for electricity consumption and employment, and oil consumption and employment. The direction of causality shows that energy resources (i.e. electricity and oil) Granger cause employment. The results for the other energy resources are not significant thus no short run causal relationships exist for the other energy resource variables. These results hold for both the standard Granger causality test and the alternative Toda and Yamamoto (TY) test.[58] The ARDL bounds test results show similar significant causal relationships for the electricity and oil variables with employment. However, the implied direction of causality between electricity and employment is from employment to electricity consumption, which is in contrast to the results of the standard Granger and TY causality tests.

In the 2004 study, Fatai *et al.,* consider the bivariate causality between disaggregated energy (coal, gas, electricity, and oil) and real GDP; total final consumption (household plus commercial energy consumption) and real GDP; and commercial energy and real

[58] The TY test is conducted on a VAR($p + d$) model estimated in the levels of the variables, where p is the optimal VAR order and d is the maximum order of integration of the variables. See Toda and Yamamoto (1995) for a detailed description of this approach to causality.

GDP for the period 1960-1999. They find no evidence of cointegration between any of the variables using the JJ approach. The short term causality results using the reduced-form Vector Autoregression (VAR) model indicate no causality from the consumption of disaggregated energy resources to economic growth but significant univariate causality from economic growth to commercial energy consumption, and from economic growth to total final consumption. Qualitatively-similar conclusions are also presented, based on the alternative TY approach to causality.

The studies of Fatai *et al.*, (2001; 2004) reveal important information about the New Zealand energy consumption-economic growth nexus, suggesting that energy conservation policies may not have significant impacts on real GDP growth. However, the theoretical arguments presented by Stern (1993; 2000), Stern and Cleveland (2004), and Zachariadis (2006) call for the consideration of other important variables in the modelling framework to ensure that the detection of (non-) causality between the variables is not spurious. This is because the inclusion of variables representing, for example, capital and labour may alter the statistical relationship between energy consumption and economic growth in the cointegration and causality framework. The data, methodology and models presented in the next section address the energy consumption-economic growth relationships from a number of perspectives, drawing on the existing body of literature to consider several important theoretical issues.

4.3 Empirical Investigation: Data, Methodology and Models

Given the contrasting theoretical perspectives on the relationship between energy resource consumption and economic growth (as noted above), empirical assessments of the underlying nexus ought to be free of specific structural linkages between energy and output which may bias the analysis towards a particular theory (Stern and Cleveland, 2004). Therefore, reduce-form time-series models are often used to address the notion of causality. There are several different approaches that can be utilised in this context to address the issues of cointegration and causality, all of which have been utilised in the empirical energy-growth causality literature. The relative merits of various approaches are discussed in the following sections.

4.3.1 Energy Consumption-Economic Growth Data

This section defines and discusses the various variables that are included in the models and their sources, and notes the impact of energy quality on the aggregation of consumption data for the diverse energy resources. The annual data compiled for the variables used in the models are for the period 1960-2004. The International Energy Agency (IEA), the branch of the Organisation for Economic Cooperation and Development (OECD) responsible for energy data collection and dissemination, does not compile energy consumption data for the period prior to 1960. Thus the research period is constrained by the non-availability of energy data for the earlier period. However, many time series studies have used much smaller sample sizes to infer correlation and causality in the energy literature and in the wider economic growth literature. Given the number of observations, the decision to adopt the ARDL cointegration methodology over the JJ approach is to avoid any spurious results.

The models estimated here include variables representing three main energy consumption-growth hypotheses. The variables used are output, capital stock, total labour force, energy price and total energy consumption. Output is given by real Gross Domestic Product (real GDP), which is the nominal GDP series 19699B.CZF taken from the International Monetary Fund's *International Financial Statistics* (IFS) database, deflated by the GDP deflator series 19699.BIRZF from the same database. Capital is proxied by real gross fixed capital formation (real GFK), which is given by the IFS nominal gross fixed capital formation series 19693E.CZF, similarly deflated by the IFS GDP deflator series 19699.BIRZF. This definition follows Sari and Soytas (in press), Jin and Yu (1996) and Shan and Sun (1998) among others in assuming a constant rate of capital depreciation, such that the variance in the capital stock is essentially related to changes in investment. Labour is measured by total labour force (TLF) and is taken from line 'tempnzl' of the well-known Groningen Growth and Development Centre's *Total Economy Database*. This measure is preferred to the IFS equivalent, which is only available back to 1986. Energy prices (EP) are proxied by the energy component of the Consumers Price Index (CPI (Energy)), which is a weighted measure of the cost of various fuel, electricity and gasoline resources. These data are taken from the OECD *Main Economic Indicators* series NZL.CPGREN01..4. See Appendix 4.1, Table A4.1 for details of the variables and data sources.

The energy consumption is defined as total consumer energy (TCE) and measured in Million Tonnes of Oil Equivalent (MTOE), for the various energy sources (i.e. oil, coal, gas, electricity, geothermal and renewables). The energy data are sourced from the IEA's 'Energy Balances of OECD Countries' (various), and are already converted to MTOE.[59] This allows comparison of the contribution that each fuel makes to the economy and their interrelationships through the conversion of one fuel into another (International Energy Agency, 1992, p. 6). Conversions to MTOE values are based on various country-specific factors; see International Energy Agency (various) for further discussion. The decision to select this measure of energy consumption over a quality-adjusted measure is discussed below.

In aggregating the consumption data of various energy resources several authors suggest weighting total energy for the change in energy use composition, rather than simply aggregating on the basis of thermal equivalence. Stern (1993) proposes that the gross energy input should be adjusted for changes in the mix of fuels comprising total energy. This is because much of the growth in energy consumption is due to the substitution of high quality energy resources, namely electricity, for low quality energy resources, such as coal. Economic theory suggests that the value marginal product of a thermal unit of the energy resource should be reflected in its price, and it is clear that the price of various fuels per heat equivalent differ greatly (for example, see Cleveland *et al.*, 2000). This implies that the marginal product of various energy resources differ, in which case energy quality may be a relevant concern for energy consumption-economic growth evaluation. This raises the important issue of how to accurately account for energy quality in the process of aggregation.

There are several alternative methods for aggregating the consumption of various energy resources other than simple thermal equivalence measures, including several economic and thermodynamic approaches. These approaches are discussed extensively by Cleveland *et al.*, (2000). They point out that advanced economic approaches are more appropriate means of aggregation than the thermodynamic concepts of exergy and

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[59] The IEA data reported in MTOE is one of the main sources utilised in the empirical energy literature (for example, see Narayan and Smyth (2005); Fatai *et al.*, (2004)).

emergy.[60] The economic approaches to aggregating quantities consumed of different energy resources all utilise the idea that marginal prices reveal information about energy quality to weight the various consumption data. While the simple numeraire price methods are sensitive to the (arbitrary) choice of numeraire price, and also assume that fuels are perfect substitutes, on the other hand, an approximation to the Divisia index has been utilised by Stern (1993; 2000) and Oh and Lee (2004b) to comprise 'quality adjusted energy consumption' data. This avoids the problems associated with numeraire methods (see Cleveland *et al.*, 2000, for detailed discussion).

Despite the apparent usefulness of the Divisia approach, its reliance on energy resource prices to comprise the weights for the quality-adjusted data creates several problems that make it difficult to implement in the context of this study. Chapter 3 notes that for much of the period in question, energy resource prices in New Zealand were subject to varying degrees of regulation. During that time, the prices did not necessarily reflect the value marginal product of the various energy resources. Furthermore, reliable data are not available for all energy resources for a longer time series going back to 1960, notwithstanding the influence of price regulation in New Zealand. Given some of these drawbacks, the application of Divisia index methodology does not seem to be appropriate.[61] As the use of energy consumption data in physical units is a standard measure within the literature, and has the benefits of being simple and well defined, the MTOE measure is selected as the most-appropriate gauge of New Zealand's total consumer energy to conduct this analysis.

4.3.2 Cointegration and Causality: Methodology

The econometric concept of cointegration refers to a long run trend amongst several time series that are individually non-stationary, such that a stable (i.e. stationary) long run relationship exists between those series. Where the lagged values of a time series x

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[60] See Cleveland *et al.*, (2000) for a full discussion of the various approaches to aggregating the consumption of various energy resources.

[61] Alternative quality coefficients are presented in Lermit and Jollands (2001) for the electricity, gas, geothermal, solid fuel, and liquid fuel resources for the period 1987-2000. These coefficients are derived by solving a system of simultaneous equations representing New Zealand's energy flows, which do not rely on energy price data. However this series has not been used in this study due to a lack of data, i.e. only 14 observations were available for each resource. Also, the numerous assumptions made about the relative improvements in the efficiency of different processes and the changes in quantities and types of energy used to provide each service are not clearly stated.

provide statistically significant information about the future values of another time series y, the series x is said to Granger cause the series y. The presence of cointegration between several variables implies that causality must exist between the series in at least one direction. This has been established by the Engle-Granger Representation Theorem (see Engle and Granger, 1987). When cointegration is present between two or more variables, the error correction models (ECM) can be estimated to address the issues of short run and long run causality. The ECM approach is advantageous relative to the traditional reduced-form VAR models, which can only consider the short run causality.[62] Hence, testing for the presence of cointegration usually precedes the tests of causality in recent time series studies.

Depending on the order of integration of the individual series, there exist several methodologies for undertaking cointegration and causality investigations for systems of economic variables. These include the Engle-Granger (EG) approach, the JJ approach, and the ARDL approach to cointegration. The EG approach to cointegration exploits the idea that a linear combination of two cointegrated series must be stationary, using a simple two-step methodology based on Ordinary Least Squares (OLS) estimation. To examine whether a long run relationship exists between two series, y_t and x_t, the following cointegrating relationship is first estimated:

$$y_t = \alpha + \beta x_t + \varepsilon_t \tag{4.1}$$

The time series properties of the residuals $\hat{\varepsilon}_t$ from the above regression are then examined using a modified Dickey-Fuller test.[63] If the null hypothesis of unit root can be rejected, the implication is that y_t and x_t, are cointegrated. In such cases causality can be addressed using an ECM; see Engle and Granger (1987). Despite the simplicity of the EG approach to cointegration, however, it has been shown that this approach has several serious short comings.[64] Therefore, the alternative approaches are often preferred.

[62] This is because the long run information is lost through differencing.
[63] The Dickey-Fuller test is discussed in section 4.3.3.
[64] Most notably, the EG method is not suitable for addressing cointegration where more than one cointegrating relationship exists. Other short-comings of the EG approach are that firstly, selection of the direction of the cointegrating regression (equation 4.1 above) is usually arbitrarily, and can lead to different and inconsistent results. Secondly, the EG approach is static and cannot account for the dynamic interrelationship of the variables (Kugler and Lenz, 1993).

The JJ methodology uses a maximum likelihood procedure to determine the cointegration properties of multivariate vector autoregressive models, based on studies by Johansen (1988; 1991) and Johansen and Juselius (1990). This methodology requires all variables to be integrated of order one, I(1), and determines the number of cointegrating vectors within the model - the cointegrating rank, r - by means of Likelihood Ratio tests. These are based on the maximal eigenvalue and the trace test, with the maximal eigenvalue test considered superior (Johansen and Juselius, 1990).[65] The cointegrating rank indicates the number of restrictions to be placed within each cointegrating vector to form the ECM, from which the long run and short run causality can be tested. Though the JJ approach estimates the multiple long run relationships, however, it is known to suffer from low power, especially in small samples (Maddala and Kim, 1998). Furthermore, the need for all variables to be I(1) requires pre-testing procedures that introduce added uncertainty into the long run analysis (Pesaran *et al.*, 2001).

An alternative methodology is the ARDL approach to cointegration, which has better small sample properties (Pesaran and Pesaran, 1997), and can be applied whether the underlying regressors are I(0), I(1), or mutually cointegrated (Pesaran and Shin, 1998). Some of the recent studies that have utilised the ARDL methodology in the context of country-specific time series data for developed and developing countries are Gounder (2001; 2002), Getnet *et al.*, (2005) and Narayan and Smyth (2004). This approach has also been used in the recent studies of the energy consumption-economic growth nexus (i.e. Narayan and Smyth, 2005). Given the small sample size of the present empirical study, the ARDL approach has been utilised to estimate the models.

The ARDL models estimated here reflect different considerations of the energy literature. They include a trivariate demand-model with real GDP, total energy consumption, and energy prices as a third variable, and several production function approaches including labour and capital variables. The multivariate models have been utilised to avoid the omitted variable bias in the cointegrating regression equations (Stern, 1993; 2000).[66] The crucial theoretical concern is that labour and capital may act

[65] See Johansen (1988) for a detailed econometric specification of these two statistics.

[66] Several studies have utilised a trivariate demand side approach, including energy price variables in the consumption-growth model. Examples include Masih and Masih (1997; 1998), Asafu-Adjaye (2000), and Narayan and Smyth (2005).

as substitutes for energy in the production process, which can result in an insignificant impact for energy consumption on economic growth in a bivariate model. The demand side specification estimates the indirect relationship between consumption and real GDP to occur through the channel of energy prices. A number of recent studies have adopted similar approaches to estimate the energy-growth nexus for various country studies.[67]

4.3.3 Energy Consumption- Economic Growth Nexus: Empirical Models

This section outlines the models estimated to analyse the energy consumption–economic growth nexus. The equations are presented algebraically for the trivariate demand-side model, trivariate supply-side model and the multivariate supply-side model. The first set of models to be estimated augment the traditional bivariate energy consumption-real GDP analysis with a composite energy price measure, as in Asafu-Adjaye (2000) and Oh and Lee (2004a). Defining lnGDP as the natural log of real GDP, lnTCE as the natural log of total consumer energy, lnEP as the natural log of energy price and ε the error term, the specifications take the following forms:

$$\ln GDP_t = \alpha_0 + \alpha_1 \ln TCE_t + \alpha_2 \ln EP_t \; \varepsilon_{1t} \tag{4.2}$$

$$\ln TCE_t = \beta_0 + \beta_1 \ln GDP_t + \beta_2 \ln EP_t \; \varepsilon_{2t} \tag{4.3}$$

$$\ln EP_t = \chi_0 + \chi_1 \ln GDP_t + \chi_2 \ln TCE_t \; \varepsilon_{3t} \tag{4.4}$$

The next set of estimated equations comprise the trivariate supply-side model, which incorporates the employment variable similar to the studies of Fatai *et al.*, (2001) and Narayan and Smyth (2005). Defining lnTLF as the natural log of total labour force, μ as the error term and all of the other variables as given previously, the equations take the following structural forms:

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[67] For examples of the demand side approach, refer to Asafu-Adjaye (2000) and Oh and Lee (2004a); the supply model with real GDP, energy consumption and employment is used by Fatai *et al.*, (2001) and Narayan and Smyth (2005); and the production function approach with real GDP, energy consumption, capital and labour is employed by Stern (1993; 2000), Ghali and El-Sakka (2004), Oh and Lee (2004a; 2004b), and Sari and Soytas (in press).

$$\ln GDP_t = \phi_0 + \phi_1 \ln TCE_t + \phi_2 \ln TLF_t + \mu_{1t} \tag{4.5}$$

$$\ln TCE_t = \varphi_0 + \varphi_1 \ln GDP_t + \varphi_2 \ln TLF_t + \mu_{2t} \tag{4.6}$$

$$\ln TLF_t = \gamma_0 + \gamma_1 \ln GDP_t + \gamma_2 \ln TCE_t + \mu_{3t} \tag{4.7}$$

The final model to be estimated augments the system represented by equations (4.5), (4.6) and (4.7) with a capital variable. This allows for the long run and short run causality issues to be considered in the context of an expanded production function, consistent with studies by Ghali and El-Sakka (2004), Sari and Soytas (in press), Stern (1993; 2000), and Oh and Lee (2004a; 2004b). Defining lnGFK as the natural log of real gross fixed capital formation, η as the error term, and all of the other variables as before, the relevant equations are given as follows:

$$\ln GDP_t = \kappa_0 + \kappa_1 \ln TCE_t + \kappa_2 \ln GFK_t + \kappa_3 \ln TLF_t + \eta_{1t} \tag{4.8}$$

$$\ln TCE_t = \lambda_0 + \lambda_1 \ln GDP_t + \lambda_2 \ln GFK_t + \lambda_3 \ln TLF_t + \eta_{2t} \tag{4.9}$$

$$\ln GFK_t = \pi_0 + \pi_1 \ln GDP_t + \pi_2 \ln TCE_t + \pi_3 \ln TLF_t + \eta_{3t} \tag{4.10}$$

$$\ln TLF_t = \theta_0 + \theta_1 \ln GDP_t + \theta_2 \ln TCE_t + \theta_3 \ln GFK_t + \eta_{4t} \tag{4.11}$$

In each of the above models, the focus is on the causality analysis between real GDP and total energy consumption. The initial step is to establish the long run properties for the groups of variables. The ARDL approach to cointegration developed by Pesaran (1997), Pesaran and Shin (1998b) and Pesaran *et al.*, (2001) involves two distinct stages. The first stage involves establishing the existence of a long run relationship between the variables using a bounds test (i.e. 'F-test') procedure. If the long run relationship is identified, then in the second stage the short run and long run Granger causality tests are considered in the context of a VECM that includes a lagged error correction term derived from the long run relationship. On the other hand, if no cointegration exists then short run causality is investigated utilising the conventional Granger causality test based on the reduced-form VAR model. This methodology has been discussed by Narayan (2004) in detail as applied to this analysis.

Although the ARDL methodology is invariant to the ordering of the series, examining the time series properties of the variables is a requirement of the Granger causality tests

(Narayan and Smyth, 2005). This is because implementation of the Granger causality tests described in this section requires all of the series to be integrated of order one, I(1). The Augmented Dickey-Fuller (ADF) and Kwiatkowski-Phillips-Schmidt-Shin (KPSS) tests have been used for this purpose, and are briefly described below.

Stage One: Unit Root Tests

The ADF test and the KPSS test establish the order of integration of the various time series variables here, and take contrasting approaches to establish the time series properties of the data. The ADF null hypothesis tests that the series under consideration contains a unit root, whereas the KPSS tests the null hypothesis that the series is stationary. Using the combination of these tests to determine the order of integration of the data series is preferable to a reliance on individual tests as they are known to suffer from low power. The ADF test is based on the following regression:

$$\Delta y_t = \alpha + \beta t + (\rho - 1) y_{t-1} + \sum_{i=1}^{k-1} \theta_i \Delta y_{t-i} + e_t \qquad (4.12)$$

where y_t is the time series under consideration, Δy_t is the first-difference of y_t, t is a trend, and e is a white noise error term. The ADF test examines the parameter ρ based on its regression t-ratio.[68] The null hypothesis is given by $H_0 : \rho = 1$ and if this cannot be rejected, the implication is that the mean and autocovariances of the series are time-dependent, i.e. y_t is a nonstationary process. Such a series needs to be differenced at least once to induce stationarity before standard inference procedures can be applied to regressions containing that variable (Quantitative Micro Software, 2004). By defining x_t as a random walk process and z_t as a stationary process, the KPSS test specification is given as follows:

$$y_t = x_t + z_t \qquad (4.13)$$

The KPSS procedure tests the null hypothesis H_0: $\sigma_v^2 = 0$ against the alternative hypothesis H_A: $\sigma_v^2 > 0$. Rejection of the null implies that variance of random walk

[68] However, the t-ratio does not follow the usual t-distribution (Dickey and Fuller, 1979). Consequently, a range of asymptotic critical values from MacKinnon (1996) will be used for this test.

process is greater than zero; therefore the process is deemed to be nonstationary. Economic theory predicts that all five series (Real GDP, Real GFK, TCE, TLF and EP) defined earlier should each be integrated of I(1). If the results of ADF and KPSS tests establish this, the Granger causality tests can be employed on the stationary first-differences. The second stage of the analysis involves the bounds test procedure outlined by Pesaran and Pesaran (1997) and Pesaran *et al.* (2001) which can be used to identify the existence of a cointegrating relationship between the variables.

Stage Two: The Bounds Test

The bounds testing approach to cointegration estimates an F-statistic to determine the significance of the lagged levels of the variables under consideration, in an unrestricted error correction model (ECM). Using the demand-side model given by equations (4.2), (4.3) and (4.4) as an example, the bounds test procedure is based on the following ECM specifications:

$$\begin{aligned}\Delta \ln GDP_t = a_0 + \sum_{i=1}^{n} b_i \Delta \ln GDP_{t-i} + \sum_{i=1}^{n} c_i \Delta \ln TCE_{t-i} + \sum_{i=1}^{n} d_i \Delta \ln EP_{t-i} \\ + e \ln GDP_{t-1} + f \ln TCE_{t-1}\ g \ln EP_{t-1} + \mu_{1t}\end{aligned} \quad (4.14)$$

$$\begin{aligned}\Delta \ln TCE_t = \alpha_0 + \sum_{i=1}^{n} \beta_i \Delta \ln GDP_{t-i} + \sum_{i=1}^{n} \chi_i \Delta \ln TCE_{t-i} + \sum_{i=1}^{n} \delta_i \Delta \ln EP_{t-i} \\ + \varepsilon \ln GDP_{t-1} + \phi \ln TCE_{t-1} + \varphi \ln EP_{t-1} + \mu_{2t}\end{aligned} \quad (4.15)$$

$$\begin{aligned}\Delta \ln EP_t = \mathrm{A}_0 + \sum_{i=1}^{n} \mathrm{B}_i \Delta \ln GDP_{t-i} + \sum_{i=1}^{n} \mathrm{X}_i \Delta \ln TCE_{t-i} + \sum_{i=1}^{n} \mathrm{E}_i \Delta \ln EP_{t-i} \\ + \Phi \ln GDP_{t-1} + \Gamma \ln TCE_{t-1} + \mathrm{H} \ln EP_{t-1} + \mu_{3t}\end{aligned} \quad (4.16)$$

In the above equations, Δ is difference operator, μ is a random error term and all variables are as defined earlier. The computed F-statistics have non-standard distribution, and are compared to appropriate critical values tabulated in Pesaran and Pesaran (1997) and Pesaran *et al.*, (2001). The critical bound values for the classification of the regressors are either purely I(1), purely I(0), or mutually cointegrated. If the computed F-statistics fall outside the critical bounds, a conclusion can be made regarding cointegration without the need for pre-testing of the time series properties of the individual variables. If the estimated F-statistic exceeds the upper critical band, the null hypothesis of no cointegration can be rejected (Pesaran and Pesaran, 1997).

The F-test procedure outlined above is performed for each equation with the relevant variables in turn. If a long run relationship exists, the F-test results indicate which variable should be normalised as the dependent variable in the third stage. As the long run relationship between energy consumption and economic growth is established, the long run and short run causality can be estimated using a Vector Error Correction Model (VECM) which includes a lagged Error Correction Term (ECT) derived from the long run relationship when cointegration is identified. The ECT is not included where no cointegration is identified in the second stage.

Stage Three: Granger Causality

The third stage of the modelling process involves the Granger causality analysis of the groups of variables. If the presence of cointegration is established by the bounds test, the standard Granger-type test is considered in the context of a VECM based on first differences, where a lagged ECT is included to incorporate the long run dynamics. Referring to the trivariate demand model given by equations (4.2), (4.3) and (4.4), and defining τ as the random error term, the VECM to estimate the Granger causality relationships algebraically is as follows:

$$\Delta \ln GDP_t = a_0 + \sum_{i=1}^{n} b_i \Delta \ln GDP_{t-i} + \sum_{i=1}^{n} c_i \Delta \ln TCE_{t-i} + \sum_{i=1}^{n} d_i \Delta \ln EP_{t-i} + e_1 ECT_{t-1} + \tau_{1t} \quad (4.17)$$

$$\Delta \ln TCE_t = \alpha_0 + \sum_{i=1}^{n} \beta_i \Delta \ln GDP_{t-i} + \sum_{i=1}^{n} \chi_i \Delta \ln TCE_{t-i} + \sum_{i=1}^{n} \delta_i \Delta \ln EP_{t-i} + \varphi_1 ECT_{t-1} + \tau_{2t} \quad (4.18)$$

$$\Delta \ln EP_t = \mathrm{A}_0 + \sum_{i=1}^{n} \mathrm{B}_i \Delta \ln GDP_{t-i} + \sum_{i=1}^{n} \mathrm{X}_i \Delta \ln TCE_{t-i} + \sum_{i=1}^{n} \Phi_i \Delta \ln EP_{t-i} + \Gamma_1 ECT_{t-1} + \tau_{3t} \quad (4.19)$$

The optimal lag length n is selected according to a Schwarz Bayesian Information Criterion (SBC) and Akaike Information Criterion (AIC).

The trivariate supply and multivariate supply models take the following specifications, respectively, to estimate the causality between the variables. The trivariate supply model is given as:

$$\Delta\ln GDP_t = f_0 + \sum_{i=1}^{n} g_i \Delta\ln GDP_{t-i} + \sum_{i=1}^{n} h_i \Delta\ln TCE_{t-i} + \sum_{i=1}^{n} i_i \Delta\ln TLF_{t-i} + j_1 ECT_{t-1} + \omega_{1t} \quad (4.20)$$

$$\Delta\ln TCE_t = \phi_0 + \sum_{i=1}^{n} \varphi_i \Delta\ln GDP_{t-i} + \sum_{i=1}^{n} \gamma_i \Delta\ln TCE_{t-i} + \sum_{i=1}^{n} \eta_i \Delta\ln TLF_{t-i} + \iota_1 ECT_{t-1} + \omega_{2t} \quad (4.21)$$

$$\Delta\ln TLF_t = \Phi_0 + \sum_{i=1}^{n} \Gamma_i \Delta\ln GDP_{t-i} + \sum_{i=1}^{n} \mathrm{H}_i \Delta\ln TCE_{t-i} + \sum_{i=1}^{n} \mathrm{I}_i \Delta\ln TLF_{t-i} + \mathrm{K}_1 ECT_{t-1} + \omega_{3t} \quad (4.22)$$

The multivariate supply model is given as:

$$\Delta\ln GDP_t = t_0 + \sum_{i=1}^{n} u_i \Delta\ln GDP_{t-i} + \sum_{i=1}^{n} v_i \Delta\ln TCE_{t-i} + \sum_{i=1}^{n} w_i \Delta\ln TLF_{t-i} + \sum_{i=1}^{n} x_i \Delta\ln GFK_{t-1} + y_i ECT_{t-1} + \mu_{1t} \quad (4.23)$$

$$\Delta\ln TCE_t = \tau_0 + \sum_{i=1}^{n} \upsilon_i \Delta\ln GDP_{t-i} + \sum_{i=1}^{n} {}_i \Delta\ln TCE_{t-i} + \sum_{i=1}^{n} \xi_i \Delta\ln TLF_{t-i} + \sum_{i=1}^{n} \psi_i \Delta\ln GFK_{t-1} + \zeta_1 ECT_{t-1} + \mu_{2t} \quad (4.24)$$

$$\Delta\ln GDP_t = T_0 + \sum_{i=1}^{n} U_i \Delta\ln GDP_{t-i} + \sum_{i=1}^{n} V_i \Delta\ln TCE_{t-i} + \sum_{i=1}^{n} W_i \Delta\ln TLF_{t-i} + \sum_{i=1}^{n} X_i \Delta\ln GFK_{t-1} + Y_1 ECT_{t-1} + \mu_{3t} \quad (4.25)$$

$$\Delta\ln GDP_t = \mathrm{T}_0 + \sum_{i=1}^{n} \Upsilon_i \Delta\ln GDP_{t-i} + \sum_{i=1}^{n} \Omega_i \Delta\ln TCE_{t-i} + \sum_{i=1}^{n} \Xi_i \Delta\ln TLF_{t-i} + \sum_{i=1}^{n} \Psi_i \Delta\ln GFK_{t-1} + \mathrm{Z}_1 ECT_{t-1} + \mu_{4t} \quad (4.26)$$

The short run causality can then be tested by examining the standard Wald statistics pertaining to each of the lagged explanatory variables, while the long run causality can be inferred from the estimated t-statistic value on the lagged ECT term.[69] These resulting test statistics and associated p-values allow for various theoretical hypotheses, relating to the short run and long run causality directions from the energy consumption to economic growth and vice versa. The policy considerations have been formed based on the implied causal relationship.

[69] Asafu-Adjaye (20000) and Oh and Lee (2004a) among others also consider the joint significance of the individual regressors with the ECT. The resulting F-statistics can, these studies argue, indicate which variables bear the short term burden of readjustment to equilibrium.

4.4 Empirical Results

This section presents the results of the stages of analysis explained above. The results of the unit root tests are presented first, followed by the stages of the ARDL approach to cointegration and causality, i.e. the bounds tests and long run and short run causalities for the demand-side and supply-side energy consumption-growth nexus. Comparisons with several studies are made here to have some bearings on the energy policy. The important implications for energy and economic growth policies are vital given the current situation of climate change, Kyoto Protocol policies and New Zealand's domestic energy policies. The models are estimated over the period 1960 to 2004 utilising annual data in constant (2000 NZ$) prices for the real GDP and real GFK variables, million tonnes of oil equivalent for the TCE variable and TLF.

4.4.1 Unit Root Test Results: ADF and KPSS Tests

The estimated t-statistics of the ADF and Lagrange Multiplier (LM-) statistics of the KPSS unit root tests are presented in Table 4.1 for each of the variables used in the models, i.e. real GDP, real GFK, TCE and EP variables in both the log-level and log-difference form. Critical values for the ADF test are from Mackinnon (1996), and the asymptotic critical values for the KPSS test are from Kwiatkowski *et al.*, (1992). The KPSS LM-statistics can be compared with the asymptotic critical value at the 10 percent level as a robustness check of the ADF test results. The results indicate that all of the variables in levels are non-stationary processes that are integrated of order one. In the case of each variable, the ADF t-statistic is less (in absolute terms) than the ADF test critical value at the 10 percent level, which is -3.188. Therefore the null hypothesis of the test, that the series under consideration contains a unit root (i.e. is not integrated of order zero, I(0)), cannot be rejected. Transforming each level variable to the first-difference form renders the individual series stationary, or I(0).

In the case of the log of real GDP (LRGDP), log of total labour force (LTLF) and log of energy price (LEP) variables, the KPSS test statistic exceeds the critical value. This implies that the null hypothesis of stationarity (i.e. the series is I(0)) can be rejected for these variables at the 10 percent level.[70] Although the LM-statistics for the log of real GFK (LRGFK) and log of total consumer energy (LTCE) variables do not exceed the critical value, they are close to the 10 percent critical value. Overall, the KPSS results for the level variables provide statistical support for the ADF test results.

Table 4.1 Results of the ADF and KPSS Unit Root Tests

Variable	ADF t-statistic	KPSS LM-statistic	Conclusion
LRGDP	-2.508	0.119*	Not I(0)
LRGFK	-2.895	0.109	Not I(0)
LTCE	-2.345	0.103	Not I(0)
LTLF	-2.132	0.142*	Not I(0)
LEP	-1.227	0.153**	Not I(0)
ΔLRGDP	-5.492***	0.113	I(0)
ΔLRGFK	-5.357***	0.060	I(0)
ΔLTCE	-6.946***	0.261	I(0)
ΔLTLF	-3.887***	0.172	I(0)
ΔLEP	-1.905	0.251	I(0)

Notes: LRGDP is log of real GDP, LRGFK is log of real GFK, LTCE is log of total consumer energy, LTLF is log of total labour force and LEP is log of energy price. Δ is difference operator. The 10 percent critical values for the levels of the variables are -3.188 for the ADF test and 0.119 for the KPSS test. For the first-differences of the variables the 10 percent critical values are -2.604 for the ADF test and 0.347 for the KPSS test. *,**,*** indicate statistical significance at the 10, 5, and 1 percent levels, respectively.

The ADF results for the differenced data indicate that the null hypothesis of unit root can be rejected at the 1 percent level for each of the LRGDP, LRGFK, LTCE and LTLF variables. Taken together with the ADF test results for the levels of the variables, these imply that levels of each series are integrated of order one, I(1). The same implication is reached when the KPSS results for the differenced data are inspected. The null hypothesis of stationarity cannot be rejected for any of the five differenced variables when the estimated LM-statistics are compared to the asymptotic critical value at 10 percent level. While the ADF test statistic for the ΔLEP variable is not significant at the 10 percent level, the estimated KPSS LM-statistic indicates this differenced series is stationary. Given the *a priori* expectation that the LEP series would be difference-stationary, as is implied by the KPSS result, the ADF inference that the series may be

[70] The null hypothesis can be rejected at the 5 percent level for LEP.

I(2) is dismissed in favour of the alternative. On this basis, the levels of LRGDP, LRGFK, LTCE, LTLF and LEP variables are indicated to be all I(1).

4.4.2 Results for Model I: Trivariate Demand Model

This section presents the results of the model given by equations (4.2), (4.3) and (4.4). First, the estimated F-statistics (i.e. bounds tests) for the unrestricted error correction model given by the system of equations (4.14), (4.15) and (4.16) are discussed and presented in Table 4.2. Second, the issues of long run and short run causality between energy consumption and economic growth are addressed. The results of the error correction model given by equations (4.17), (4.18) and (4.19) are discussed, where the inclusion of the ECT is contingent on ascertaining a significant long run relationship between the variables.

Results of the Bounds Test of Cointegration

The estimated F-statistics for the unrestricted error correction model given by equations (4.2), (4.3) and (4.4) are presented in Table 4.2. The results do not identify the existence of a cointegrating relationship between the variables when LRGDP and LEP are set as the dependent variable. A cointegrating relationship is identified when LTCE is cast as the dependent variable. These observations are made on the basis of the computed F-statistics, which indicate the estimated value of 4.701 that falls outside the critical bound values. The results for New Zealand suggest that there exists a single long run relationship between total consumer energy, real GDP and energy prices. The results obtained here can be considered in light of the similar recent results of Asafu-Adjaye (2000) and Oh and Lee (2004a). They considered the demand-side models for the cases of India, Indonesia, Thailand and the Philippines (Asafu-Adjaye, 2000), and South Korea (Oh and Lee 2004a). Asafu-Adjaye (2000) utilised the JJ approach to cointegration for the period 1971-1995. He established the existence of a single cointegrating vector for long run relationship in the case of India, Thailand and the Philippines, and two cointegrating vectors in the case of Indonesia.[71] In the case of South Korea, Oh and Lee (2004a) likewise establish the existence of a single

[71] These results are based on the estimated maximal eigenvalue and trace statistics.

cointegrating vector between the real GDP, energy consumption, and energy prices using the JJ methodology. However, unlike Asafu-Adjaye (2000) and the present study, Oh and Lee's analysis is based on quarterly data for the period 1981-2001. It must be noted that the JJ approach does not inform which variable should be normalised upon in the cointegrating vector, while the ARDL estimations indicate that total consumer energy is the dependent variable in the long run relationship.

Table 4.2 Results of the Bounds Tests: Trivariate Demand Model

Equation	F-statistic	5 percent critical value bounds		Evidence of Cointegration
		I(0)	I(1)	
F_{LRGDP} (LRGDP|LTCE, LEP)	0.936	3.10	3.87	No
F_{LTCE} (LTCE|LRGDP, LEP)	4.701	3.10	3.87	Yes
F_{LEP} (LEP|LRGDP, LTCE)	1.276	3.10	3.87	No

Notes: Critical values are for the model with intercept but no trend, identified as 'Case II' by Pesaran *et al.*, (2001) with k = 2 regressors. LRGDP is log of real GDP, LTCE is log of total consumer energy and LEP is log of energy price.

To address the issues of long run and short run causality between the variables, an ECM that takes the form of equations (4.17), (4.18) and (4.19) is estimated next. The short run and long run causality for the LTCE equation are presented, as well as the short run causality results for the LRGDP and LEP equations.

Results of the Granger Causality Tests: Trivariate Demand Model

The results of the Granger causality tests for the trivariate demand model are presented in Table 4.3. The short run causality is reported for all of the variables, based on the F-statistics of the lagged explanatory variables. Long run causality is assessed based on the t-statistic on the lagged ECT term, and is only included in the equation for TCE. The estimated Wald F-statistic of 0.021 reported for the equation (4.17) in column 2 addresses the causality issue from the log-difference of TCE to the log-difference of real GDP. The result indicates that TCE does not Granger cause real GDP growth in the short run. This result suggests that the emphasis placed on the role of energy in production processes by the ecological economics school of thought is not supported by the evidence for New Zealand. On the other hand, the result is consistent with the neoclassical proposition that the demand for energy is a derived demand, and as such has had no causal bearing on the path of real GDP growth.

The estimated Wald F-statistic of 2.665 in column 3 of equation (4.17) indicates that the null hypothesis of 'no causality from EP to real GDP' cannot be rejected at the conventional levels of significance. Concerning the estimated result for the EP variable (column 3), given that most of the energy resources consumed in New Zealand are domestic resources, it is entirely plausible that price changes should be a function of domestic economic conditions, rather than leading real GDP growth.[72] Therefore, the finding that EP is not significant in the real GDP equation is consistent with the theory. Thus, in the short run neither of the energy variables (i.e. TCE or EP) Granger cause real GDP growth at the conventional levels of significance.

Table 4.3 Results of Granger Causality Tests: Trivariate Demand Model

Equation / Dependent Variable		Short run effects: Wald F-statistics			ECT_{t-1} (t-statistic) (4)
		$\Delta LRGDP_t$ (1)	$\Delta LTCE_t$ (2)	ΔLEP_t (3)	
Eq. (4.17)	$\Delta LRGDP_t$	-	0.021	2.665	-
Eq. (4.18)	$\Delta LTCE_t$	4.928**	-	2.359	-0.319 (-2.761)***
Eq. (4.19)	ΔLEP_t	4.407	1.399	-	-

Notes: ΔLRGDP is log-difference of real GDP, ΔLTCE is log-difference of total consumer energy and ΔLEP is log-difference of energy price. Wald test critical values with 2 degrees of freedom are 4.605, 5.991 and 9.210 at the 10, 5 and 1 percent levels. *, **, *** indicate 10, 5, and 1 percent significance level, respectively.

The estimated results for equation (4.18) indicate the short run causality from real GDP to TCE; from EP to TCE; and the significance of the lagged ECT. The estimated F-statistic in column 1 shows a statistically significant causal relationship exists between energy consumption and economic growth, i.e. real GDP Granger causes TCE. This

[72] An important exception, of course, concerns oil prices which are set in international markets and thus can be considered exogenous with respect to the domestic economy. The relationship between oil prices and economic growth is addressed in chapter 5 of this study.

result is significant at the 5 percent level, and provides evidence in support of the neoclassical theory. The result in column 3 indicates that no short run causal relationship exists from EP to TCE. This is consistent with the view that energy demands are inelastic with respect to prices, given the difficulties involved with substituting some forms of capital and labour for energy resources in the short run.

Long run causality indicated by the lagged ECT is statistically significant at the 1 percent level, with an estimated coefficient value of -0.319. This confirms the result of the bounds test (Table 4.2), and suggests a fairly rapid return to equilibrium following an energy consumption shock. The Wald F-statistics for the interaction of the explanatory variables with the ECT in the equation for TCE (not reported) are both significant at the 2 percent level, indicating that both explanatory variables (i.e real GDP and EP) adjust in the short run as a result of a shock to the underlying long run relationship.

Equation (4.19) reports the short run causality results between real GDP and EP; and TCE and EP. The estimated Wald F-statistic in column 1 is 4.407, indicating a weak Granger causality from the real GDP variable to the EP variable at the 11 percent level. This result implies that energy prices are a function of the state of the domestic economy, and likely to move in step with economic activity. As the demand for energy resources is essentially a derived demand, the result is entirely consistent with the theory. The estimated Wald test statistic for the TCE variable in column 2 indicates that changes in energy consumption do not Granger cause changes in the energy prices in the short run. This can be explained by the extensive use of forward and fixed contracts, particularly amongst industrial and commercial users of energy, which allow for the purchase of energy resources at constant or near-constant prices. Consequently, the changes in consumption patterns may not have a significant short run impact on energy prices, except through the channel of real GDP (to the extent that changes in consumption reflect broader economic conditions).

The results presented above can be compared with the existing literature for New Zealand and other country studies. The results of the bivariate model reported by Fatai *et al.*, (2004) for New Zealand indicate that no Granger causal link from energy, in disaggregated forms (coal, electricity, gas, oil, total final consumption and commercial consumption), to real GDP exists. However, Fatai *et al.,* (2004) find unidirectional causality from real GDP to commercial energy consumption and from real GDP to total final consumption. These results are similar to those presented in Table 4.3 above, however this study further detects a long run relationship between the variables in the presence of a composite energy price variable, which is novel. The results of the short run and long run causality support the neoclassical view that energy consumption is not a limiting factor for New Zealand's economic growth.

A similar result is reported by Oh and Lee (2004a) for the Korean demand-side model, where neither the energy consumption variable, the ECT, nor an interactive term comprising of the energy consumption variable with ECT, are statistically significant in the real GDP equation, implying that energy consumption does not Granger cause GDP in the case of Korea. Asafu-Adjaye's (2000) study of the four Asian developing countries reveals mixed results. The proxy for energy prices is not significant in the GDP equations for India, Indonesia and Thailand, while neither the energy consumption nor the price variables are significant in the case of Indonesia. Thus, energy consumption does not Granger cause GDP in the case of India, Indonesia and Thailand. Only in the case of the Philippines are both terms significant at the 10 percent level. The next section reconsiders the consumption-real GDP nexus from the perspective that employment may be an important element in the short run and long run relationship. The ARDL approach is adopted utilising the consumption, real GDP, and employment variables, to consider the robustness of the results presented in this section.

4.4.3 Model II: Trivariate Supply Model

This section presents the results of the trivariate supply model shown in the system of equations (4.20), (4.21) and (4.22). The model takes the supply-side approach as estimated by Fatai *et al.*, (2001), Chang *et al.,* (2001) and Narayan and Smyth (2005) who examine the link between energy and employment in a macroeconomic setting. The theory suggests that energy and labour may be linked in the production process, and various empirical evidences of this literature support both complement and substitute relationships for several countries. The changes in the level of employment may therefore play an indirect role in the causal relationship between energy consumption and economic growth, which also means that employment policies are vital and act as a means of achieving economic growth and energy-related objectives. The evaluation here starts with the bounds test to establish if there exists any long run relationship, followed by the results of the causality analysis. The results are considered in light of theoretical expectations, and are compared to other such studies.

Results of the Bounds Test of Cointegration: Trivariate Supply Model

The results of the bounds tests for cointegration between real GDP, TCE and TLF variables are presented in Table 4.4. The results indicate that a single cointegrating relationship exists between the variables, where TCE is the dependent variable and the real GDP and TLF variables are long run forcing variables. This estimated F-statistic value is 3.958 for the unrestricted ECM for TCE. The estimated F-statistic values for the real GDP and TLF equations are below the 5 percent critical bounds, indicating the existence of a single long run relationship between these variables.

Regarding the existing evidence for New Zealand, Fatai *et al.*, (2001) find evidence of cointegration in the bivariate disaggregated energy-employment relationships for electricity and oil resources only and not for coal, gas, or total final consumption. They also find evidence of cointegration in the bivariate relationship between employment and real GDP using the bounds test approach. Similarly, Narayan and Smyth (2005) identify the existence of a single long run relationship between electricity consumption, manufacturing employment and real GDP for Australia, using the same cointegration test. In that case, the long run relationship is apparent when the energy consumption variable is normalised. Chang *et al.*, (2001) find one cointegrating relationship between the same three variables using the JJ approach to cointegration in the case of Taiwan for the period 1982-1997 based on monthly data. The findings in the present study are consistent with the above mentioned studies. The enquiry is further broadened to consider the short run and long run causal relationships between the variables below.

Table 4.4 Results of the Bounds Tests: Trivariate Supply Model

Equation	Estimated F-statistic	5 percent critical value bounds I(0)	I(1)	Evidence of Cointegration
F_{LRGDP} (LRGDP|LTCE, LTLF)	1.028	3.10	3.87	No
F_{LTCE} (LTCE|LRGDP, LTLF)	3.958	3.10	3.87	Yes
F_{LTLF} (LTLF|LRGDP, LTCE)	1.433	3.10	3.87	No

Notes: The estimated F-statistics are reported as well as the 5 percent critical bounds taken from Pesaran *et al.*, (2001). The critical values are for the model with intercept but no trend, identified as 'Case II' with k = 2 regressors. LRGDP is log of real GDP, LTCE is log of total consumer energy and LTLF is log of total labour force.

Results of the Granger Causality Tests: Trivariate Supply Model

The estimated Wald F-statistics for the tests of short run causality, as well as the t-statistic of the long run lagged ECT in the trivariate supply model are presented in Table 4.5. The estimated results for equation (4.20) indicate the short run Granger causality results from TCE to real GDP; and from the LTF variable to real GDP. The estimated Wald statistics are not statistically significant, indicating that the null hypothesis of no causality cannot be rejected. That is, neither total consumer energy nor total labour force Granger causes real GDP. These results are consistent with the neoclassical arguments concerning the short run relationship between energy resources and real GDP that energy resources contribute to production and that causality may run from GDP to energy consumption. Given the relatively small cost share of energy in New Zealand's GDP, it is perhaps unsurprising that changes in the level of energy consumption do not have a significant causal flow onto the changes in real GDP. If disequilibrium in the energy relationship is capable of causing a significant impact on real GDP, it may be through one or more indirect channels (such as capital or labour inputs) which could be expected to take a period of time to indicate any effect. This is consistent with not being able to reject the null hypothesis of no short run causality from TCE to real GDP.

The estimated results for equation (4.21) link the causal relationship between real GDP and TCE; and TLF and TCE. In this case, real GDP Granger causes TCE and the result is significant at the one percent level, while TLF also Granger causes TCE. The link between changes in real GDP and changes in TCE confirms the unidirectional flow of causality in the short run from real GDP to energy consumption. The estimated test statistic for the labour force variable suggests that this has a causal bearing on the quantity of energy consumed. The coefficient on the TLF variable in the long run ARDL equation for energy consumption is -0.989 and is significant at the 7 percent level.[73] This result suggests that the variables are close substitutes and implies that a production function approach, including an additional capital variable, may reveal richer energy consumption-economic growth dynamics. The long run relationship implied by the lagged ECT is statistically significant at the 1 percent level, and the coefficient on the ECT is -0.282. This suggests a similar speed of adjustment to the demand model presented in section 4.4.2. The Wald test for the joint significance of real GDP with the lagged ECT is 9.41, statistically significant at the one percent level. Also, the TLF variable with the lagged ECT is 10.993, also significant at the 1 percent level. These results imply both real GDP and labour adjust in the short term to re-establish the long run equilibrium in the energy consumption equation. The results for equation (4.22) reported in Table 4.5 show that neither real GDP nor TCE has a significant causal effect on TLF.

These results indicate that labour force is not affected in the short run by energy market or broader macroeconomic conditions. Such a finding is consistent with the presence of fixed term contracts and other sources of friction that would prevent macroeconomic impacts from having an immediate effect on the labour market. Qualitatively similar results to those presented in Table 4.5 have been reported in the related empirical literature. In a study of the electricity consumption-GDP-employment nexus for Australia, Narayan and Smyth (2005) find no causality in the short term from either employment or electricity consumption to real GDP. On the other hand Chang *et al.*, (2001) in the case of Taiwan find a significant causal link between the central variables, with causality flowing from energy consumption to GDP. This result is likely due to significant industrialisation that has occurred in Taiwan during the 1980s and 1990s which saw a substantial increase in the consumption of energy resources over that period. Similar results have also been reported for Korea and the other 'tiger' economies (for example, see Masih and Masih, 1997).

[73] Estimated long run ARDL model is: LTCE = -8.108 + 1.562LRGDP – 0.989 LTLF
(t-statistics) (-4.76)*** (7.32)*** (-1.88)*

Table 4.5 Results of Granger Causality Tests: Trivariate Supply Model

Equation / Dependent Variable	Short run effects: Wald F-statistics			ECT_{t-1} (t-statistic)
	$\Delta LRGDP_t$ (1)	$\Delta LTCE_t$ (2)	$\Delta LTLF_t$ (3)	(4)
Eq. (4.20) $\Delta LRGDP_t$	-	2.909	0.117	-
Eq. (4.21) $\Delta LTCE_t$	9.316***	-	5.152**	-0.282 (-2.723)***
Eq. (4.22) $\Delta LTLF_t$	1.176	1.401	-	-

Notes: ΔLRGDP is log-difference of real GDP, ΔLTCE is log-difference of total consumer energy and ΔLTLF is log-difference of total labour force. Wald F-test critical values with 2 degrees of freedom are 4.605, 5.991 and 9.210 at the 10, 5 and 1 percent levels. *, **, *** indicate 10, 5, and 1 percent significance level, respectively.

The similarity between Australia and New Zealand, in terms of their respective stages of economic development, may explain why the results of these nations show no significant causal link of energy consumption to real GDP. As both these countries are relatively highly-developed, with a large service sector that dominates GDP contribution, thus the relatively-low energy intensive sector consumption does not Granger cause GDP (see also chapter 3). Therefore, accumulation of wealth in Australia and New Zealand over the recent years is based, to a larger extent, on the high value-added and low energy intensity activities in which developed countries tend to have a comparative advantage.[74] On the other hand, the export of energy-intensive manufacturing and primary sector activities to developing countries could also explain the higher incidence of significant causal relationships noted in the literature for those economies (see Chapter 2 - section 2.4).

The finding that GDP does not impact on labour force in the short run differs from the recent studies of Narayan and Smyth (2005), Chang *et al.*, (2001) and Fatai *et al.*, (2001) who find a highly significant relationship from real GDP to employment in a bivariate framework. Divergence of the present result provides a justification for considering a capital variable to be included in the model. It may be that the labour-

[74] Examples include finance, banking and insurance industries. See also Stern (1993) for the US economy. Sari and Soytas (in press) present evidence for several developing countries that provides contrasting evidence in support of this thesis.

capital relationship, which is not identified explicitly in this equation, is impacting on the labour-real GDP result (see Table 4.5 – equation 4.20). These relationships are considered in the next section, where the addition of a capital variable to the present model allows for the energy consumption-real GDP relationship to be addressed within a production function specification.

4.4.4 Model III: Multivariate Supply Model

This section presents the results of the model given by the system of equations (4.23) to (4.26) noted above. The model takes the supply-side approach of Stern (1993; 2000), Ghali and El-Sakka (2004), and Oh and Lee (2004b) *inter alia*, in examining the important energy consumption relationships in an expanded production function framework. Given the economic link between labour and energy noted in the literature, the inclusion of the capital variable seems appropriate. This is because the theory predicts a central role of capital in the economic growth process, as well as a potential substitute (and complement) for energy and labour factors in the production process. Estimated results are discussed next for the multivariate supply model for energy-growth nexus.

Results of the Bounds Test of Cointegration: Multivariate Supply Model

The results of the bounds tests for cointegration between the real GDP, TCE, TLF and real GFK variables are presented in Table 4.6. The results suggest that a single cointegrating relationship exists between the four variables. This is identified when real GFK is the long run dependent variable. Oh and Lee (2004b) also establish the existence of one cointegrating relationship in the case of South Korea. On the other hand, Ghali and El-Sakka (2004) identify two cointegrating vectors for the case of Canada 1961-1997, normalised on real GDP and energy consumption. Stern (2000) also identifies two relationships, with real GDP and labour supply selected as the normalised variables in the two vectors. This suggests a range of long run relationships are feasible, that are dependent on various country-specific factors.

Table 4.6 Results of the Bounds Tests: Multivariate Supply Model

Equation	Estimated F-statistic	5 percent critical value bounds		Evidence of Cointegration
		I(0)	I(1)	
F_{LRGDP} (LRGDP|LTCE, LTLF)	1.231	2.79	3.67	No
F_{LTCE} (LTCE|LRGDP, LTLF)	3.342	2.79	3.67	No
F_{LTLF} (LTLF|LRGDP, LTCE)	1.412	2.79	3.67	No
F_{LRGFK} (LTLF|LRGDP, LTCE)	4.409	2.79	3.67	Yes

Notes: Critical values are for the model with intercept but no trend, identified as 'Case II' by Pesaran *et al.*, (2001) with k = 3 regressors. LRGDP is log of real GDP, LTCE is log of total consumer energy, LTLF is log of total labour force and LRGFK is log of real Gross Fixed Capital Formation.

Results of the Granger Causality Tests: Multivariate Supply Model

This section presents the results of the Granger causality tests between the various variables. The estimated F-statistics for the Granger causality tests are presented in Table 4.7. The results for equation (4.23) show that TCE does not Granger cause real GDP, which supports the earlier findings for the trivariate models. Thus, it can be said that energy consumption does not precede, in the Granger sense, real GDP in New Zealand. This result, established by Fatai *et al.*, (2004) is shown to be robust to a number of specifications including the important factors of production. Statistical support for the notion that changes in TLF do not Granger cause real GDP changes in the short run also continues to hold in the equation (4.23). The estimated Wald F-statistic for the real GFK variable (i.e. capital) is insignificant, thus there exists no causal link to real GDP. This may be because of the time lags involved for new capital and equipment acquisitions to impact on the real output.

The estimated results for equation (4.24) test the Granger causality results for the TCE equation. The estimated Wald F-statistic in column 1 indicates that real GDP Granger causes TCE in New Zealand. Similarly, the result in the column 4 indicates that changes to real GFK Granger cause changes to TCE at the 5 percent level. This implies a significant causal link as suggested in the theoretical discussions noted in chapter 2 (see sections 2.2 to 2.4). The coefficient on TCE in the estimated long run ARDL equation for real GFK is negative and statistically significant at the 1 percent level.[75] This implies that these two factors are substitutes, such that increases in energy consumption reduce the level of capital in the long run. On the other hand, the corresponding coefficient on the TLF variable is positive and significant at the 5 percent level, suggesting the labour and capital are complements in the production process. To the extent that more workers require more capital and machinery this is as predicted by the production theory for the long run. Turning to the equation for TLF, the results for equation (4.25) reveal that none of the variables, i.e. real GDP, TCE or real GFK Granger cause changes in total labour force in the short term. This suggests that short run employment patterns are not caused by changes in the energy sector, investment decisions or short term macroeconomic fluctuations. This is an interesting result that warrants further investigation, however the labour dynamics are not the central focus of this study so this issue is not explored further here.

Table 4.7 Results of Granger Causality Tests: Multivariate Supply Model

Equation / Dependent Variable	Short run effects: Wald F-statistics				ECT_{t-1} (t-statistic)
	$\Delta LRGDP$ (1)	$\Delta LTCE_t$ (2)	$\Delta LTLF_t$ (3)	$\Delta LRGFK_t$ (4)	(5)
Eq. (4.23) $\Delta LRGDP_t$	-	3.508	0.218	0.617	-
Eq. (4.24) $\Delta LTCE_t$	6.942**	-	1.298	6.714**	-
Eq. (4.25) $\Delta LTLF_t$	0.517	3.821	-	3.912	-
Eq. (4.26) $\Delta LRGFK_t$	14.632***	0.022	12.511***	-	-0.538 (-4.358)***

Notes: ΔLRGDP is log-difference of real GDP, ΔLTCE is log-difference of total consumer energy, ΔLTLF is log-difference of total labour force and ΔLRGFK is log-difference of gross fixed capital formation. Wald F-test critical values with 3 degrees of freedom are 6.251, 7.815 and 11.345 at the 10, 5 and 1 percent levels. *, **, *** indicate 10, 5, and 1 percent significance level, respectively.

The results for equation (4.26) indicate that changes in real GDP and TLF have significant predictive power for changes in real GFK (i.e. capital). On the other hand, the short run TCE fluctuations do not significantly affect the real GFK variable. These results provide further evidence in support of the neoclassical theory that gives primacy

[75] Estimated long run ARDL model is: LRGFK = -20.46 + 2.1985LRGDP – 1.445LTCE + 1.169LTLF
(t-statistics) (-3.61)*** (2.81)*** (-2.73)*** (2.18)**

to capital and labour in the relationship to economic growth, while energy resources are commonly viewed as non essential in the context of other variables. The long run causality result, for the ECT in column 5, reaffirms the result of the bounds test and suggests that the estimated speed of adjustment (-0.538) is highly significant. This ECT coefficient is much higher than those reported for the earlier cointegrating relationships, which suggests that disequilibrium in the capital equation is rectified at a faster speed. Moreover, the burden of rectification is shared by all three explanatory variables. This is based on the F-statistics on the interactive terms (not reported), which are all significant at the 1 percent level. The important implications of these results are that first, the unidirectional causality identified from real GDP to TCE is consistent and robust to labour and capital relationships; second, the cointegration and causality results presented here suggest that long run considerations of the energy consumption relationship with real GDP ought to take account for capital and labour in the estimation frameworks, as the inclusion of these two variables reveals important information about the direct and indirect causality between these variables. A discussion of the implications of these results for energy consumption and economic policies are presented in chapter 6.

4.5 Conclusion

This chapter has addressed the important issues of cointegration and causality between energy consumption and real GDP. The trivariate and multivariate econometric models were utilised to consider the nature of the underlying relationship between energy-growth nexus. The motivation for this analysis is that the existing literature for New Zealand is based on bivariate models of causality, which numerous studies have argued to be problematic. This is because of potential bias due to omitting key variables.

A trivariate model based on the theory of energy demand was first estimated, including a composite energy price variable. A single long run relationship between the three variables was established, revealing long run causality when energy consumption (TCE) was the dependent variable. Significant short run Granger causality was identified from real GDP to TCE, providing empirical support for the neoclassical theory that energy is non essential to production. These results were subjected to several alternative model specifications, the form of which was derived based on the theory of production and economic growth.

The second model adopted a supply-side approach, including labour force (TLF) as a third variable. The bounds test procedure identified a single long run relationship between the variables, with the estimated F-statistic for the TCE variable indicating it to be the dependent variable in the long run relationship. Short run Granger causality from real GDP to TCE was significant at the 1 percent level, providing further evidence in support of the neoclassical theory that energy consumption is a result of economic activity, rather than being an essential input to production *per se*. Granger causality from TLF to TCE was also established on the basis of the estimated Wald F-statistic. This result, which is significant at the 5 percent level, suggests a relationship between labour and energy as factors of production. Further examination of the estimated long run relationship using the ARDL equation revealed that a relationship exists between these variables as substitute factors of production.

A final model based on the production function approach included variables for labour and capital (real GFK) in the energy consumption-real GDP framework. The estimated Wald F-statistics from the bounds tests indicated the existence of one cointegrating relationship, with real GFK (i.e. capital) the dependent long run variable. The estimated Granger causality test statistics indicated short run causality from real GDP to TCE but not vice versa, as well as indicating significant short run causality from real GFK to TCE. Significant short run causality was also inferred by the estimated Wald F-statistics for the real GDP and TLF variables Granger causing real GFK.

The estimated results of the three models reveal important information about the relationships between the energy, growth, labour and capital variables. The key result that real GDP Granger causes energy consumption without feedback is robust to the choice of modelling framework, and reinforces the results of Fatai *et al.*, (2004) who established the same causality relationship in a bivariate setting. The second major finding that capital and labour variables are important elements of the cointegration and causality implies that the breadth of policy options may not be limited to energy and macroeconomic instruments. These issues are discussed in chapter 6 that outlines the full implications of the results from the perspective of relevant economic and energy policies. The next chapter empirically considers the related issue of oil price shocks and economic growth, which is another vital aspect of the energy-economic growth nexus that has received little attention in the case of New Zealand.

Appendix 4.1

DETAILS OF VARIABLES AND DATA SOURCES

Table A4.1 Energy Consumption-Economic Growth Models: Variable Details and Data Sources

Variable	Description	Source
Output / Real Gross Domestic Product (GDP).	Nominal GDP deflated by GDP deflator. Constant 2000 prices.	IFS line 19699B.CZF (Nominal GDP); IFS line 19699.BIRZF (GDP Deflator).
Capital / Real Gross Fixed Capital Formation (GFK).	Nominal GFK deflated by GDP deflator. Constant 2000 prices.	IFS line 19693E.CZF (Nominal GFK); IFS line 19699.BIRZF (GDP Deflator)
Labour / Total Labour Force (TLF).	Thousands of people in the labour force.	Groningen Growth and Development Centre *Total Economy Database* line 'tempnzl'.
Energy Consumption / Total Consumer Energy (TCE).	Consumption of oil, gas, coal, electricity, geothermal and other renewables in final consumption, measured in million tonnes of oil equivalent (MTOE).	IEA *Energy Balances of OECD Countries*, various.
Energy Prices	Energy component of Consumer Price Index.	OECD *Main Economic Indicators* series NZL.CPGREN01..4.

Notes: IFS is the International Monetary Fund's *'International Financial Statistics'*, IEA is the International Energy Agency, OECD is the Organisation for Economic Cooperation and Development.

Chapter Five

OIL PRICE SHOCKS AND ECONOMIC GROWTH: EMPIRICAL EVIDENCE

Oil price shocks are important macroeconomic events.

(Mork, 1994, p. 35)

5.1 Introduction

As an importer of oil and petroleum products, New Zealand's economy is potentially vulnerable to fluctuations in the world price of crude oil. The objective of this chapter is to examine what impact the changes in the world price of oil had on New Zealand's economic growth over the period 1989-2004, which also takes into consideration the period since deregulation of the petroleum markets. It will draw on the theoretical arguments developed in chapters 2 and 3 to construct several empirical models of oil price shocks and economic growth that focus on the short run.

The key policy objectives for successive Governments have been crucial for achieving higher rates of economic growth, as noted in chapter 3, particularly since the implementation of structural reforms in 1984.[76] This package of reforms included the restructuring of the petroleum industry in 1987-1988, and thus over time various price control measures have been lifted. A key implication of this transformation has been the movement of domestic retail and commercial prices in line with international market prices for crude and refined products. The literature on oil price shocks, as noted in chapter 2, considered a number of direct and indirect channels through which these oil price fluctuations can have macroeconomic consequences, and also the estimated magnitude of historical oil price disruptions for economic growth in a range of country case-studies. This chapter seeks to empirically analyse the impacts for the case of New Zealand, as no study has been undertaken to address the oil price shock and growth nexus. The chapter is structured as follows: Section 5.2 details the theoretical and

[76] The continued pre-eminence of this goal to recent Governmental policy-making can be seen, for example, in the framework document 'Growing an Innovative New Zealand' (New Zealand Government, 2002), and in the Governor General's (2005) Speech from the Throne.

empirical setting for the analysis, discussing the key theories and results from the earlier chapters. Section 5.3 discusses the main data and methodological issues concerning the econometric analysis, followed by the estimated results in section 5.4. Finally, section 5.5 presents the conclusions of the chapter.

5.2 Macroeconomic Impacts of Oil Price Changes: Theory and Evidence

This section briefly synthesises the macroeconomic impact of oil price changes (of chapters 2 and 3) that motivate the empirical investigation undertaken here. The primary basis for interest in the effect of oil prices on the real economy stems from oil's role as a central factor of production in the industrialised countries. An increase in the price of oil causes production costs to rise, which the theory posits will provoke firms to reduce output. On the other hand there are various demand-side responses to consumption and investment that are predicted by economic theory, the presence of which imply that an oil price-shock may constrain output in numerous ways. These considerations have induced several studies which provide empirical estimates of the economic growth impact of oil prices shocks in the developed economies. Most of the studies focus on the United States (US) macroeconomy, and are broadly consistent in finding a cumulative effect in the range of 0.7-1.4 percentage points decrease in the year following a 10 percent increase in oil prices (see Labonte, 2004; Jones and Leiby, 1996, and references contained therein). Alternatively, Jimenez-Rodriguez and Sanchez (2005) estimate elasticities in the region of -0.03 to -0.05 for several European Union (EU) countries, which may be better analogues for the case of New Zealand.[77] These estimates suggest that the short run impact on economic growth may be non-trivial. The various underlying theories are discussed in more detail below.

The important supply-side effects of oil price shocks stem from the presence of short-term rigidities in factor markets. Given an exogenous shock to oil prices, markets are prevented from instantly adjusting to the new conditions by information costs, pre-existing contracts, menu costs, and heightened uncertainty. Because other factor prices do not fall simultaneously, overall production costs rise. This cost increase can lead

[77] This is because of the size of their economies, and their roles as developed net importers of oil products. They include France, Italy, and Germany.

producers to reduce output. This can force periods of adjustment and re-allocation in factor and product markets that give rise to bouts of economic recession and unemployment. Because other prices cannot adjust instantly, the overall level of inflation also tends to increase in the wake of an oil price increase. The perception of economic agents is important in determining whether or not this effect permeates into core inflation, and is reflected by the flow-on effects on wage demands and other factor prices. Such a situation is difficult for policy-makers to respond to, because the coincidence of recession and inflation renders the use of monetary policy a double-edged sword. On the one hand tight monetary policy tends to contain inflation but exacerbate recession, while the loosening of monetary policy, to encourage economic recovery, is likely to also reinforce the initial inflationary impact (Labonte, 2004). In conjunction with these varied supply effects, to gauge the full impact of an oil price shock, it is necessary to look at the implications for the demand side of the economy.

The important demand-side impacts of an oil price shock can be separated into three groups. The first effect predicted by economic theory is a heightened transfer of aggregate wealth from countries that import oil to the main oil exporters. This will reduce the disposable income of consumers in the former nations and increase producers' incomes in the latter. Recent evidence suggests the majority of these transfers, which are essentially windfall gains, are saved in the producer countries, leading to a reduced level of consumer spending in the countries that import oil products (International Monetary Fund, 2005). Secondly, heightened inflation will also erode the real balances of consumers facing higher oil prices. Guo and Kliesen (2005, p. 677) refer to this impact of oil price increases as a "tax on consumption". The third important demand-side effect is the heightened uncertainty surrounding investment and consumption decisions that is created by price shocks.

To the extent that volatility in oil prices results in firms and individuals delaying costly investment and consumption decisions, this effect may be pronounced for economic growth. The recent literature has focussed on this aspect of the theory in particular, and a number of studies consider non-linear oil price measures in an attempt to capture these effects on the macroeconomy (e.g. Ferderer, 1996; Hamilton, 1996). The use of these various non-linear measures tends to recover the causal relationship between oil prices and economic indicators first identified by Hamilton (1983), which is not supported by the majority of recent studies relying on linear price change measures.[78] Economic theory suggests that the inclusion of key macroeconomic variables in the modelling framework is important, given the potential presence of indirect channels of transmission for oil price shocks to affect economic growth. These are via the financial and factor markets in particular.

Many empirical studies include price level, interest rate, real wage and exchange rate variables in their analysis, and variables representing various other channels have also been considered in the literature (see Table 5.1 below). These variables are primarily included because they may be able to reconcile the non-trivial impact of price shocks on the macroeconomy with the relatively small cost share of oil noted by Perry (1977), Nordhaus (1980) and others in the late 1970s. On the other hand, from an econometric perspective these variables are also crucial for mitigating the omitted variable bias in the regression framework. The realisation that oil prices could impact economic growth through numerous channels, coupled with the recognition that oil prices' impact on economic growth would be felt with a lag, has motivated the majority of empirical oil price-economic growth studies following Hamilton (1983) to utilise the reduced-form Vector Autoregression (VAR) methodology. This methodology includes for each variable a dynamic equation based on lags of itself and the other variables within the model. The VAR system of equations can be represented in the following matrix form:

$$y_t = c + \sum_{i=1}^{p} \phi_i . y_{t-i} + \varepsilon_t \qquad (5.1)$$

where y_t is a (n x 1) vector of endogenous variables, c = (c1, ..., cn)' is the (n x 1) intercept vector of the VAR, ϕ_i is the ith (n x n) matrix of autoregressive coefficients for i = 1, 2, ..., p, and $\varepsilon_t = (\varepsilon_{1t},...,\varepsilon_{nt})'$ is the (n x 1) vector of innovations. As this framework will be utilised for the present study, the next section discusses the models in more detail.

[78] This issue is taken up further in the chapter, when the methodology used in the present study is discussed.

5.3 Empirical Investigation: Models, Data and Methodology

The process of modelling the dynamic economic impact of oil price shocks on the real economy has taken several different modelling forms over time. There are a number of important factors to consider which can guide the choice of one methodology over another, though as noted above most studies have utilised the VAR methodology in recent years. This preference may be because VAR models do not require the arbitrary restrictions of the more-tightly structured models. Such restrictions do not seem to be appropriate in the present context, given the various plausible transmission channels suggested by economic theory (Burbidge and Harrison, 1984). The subsections below briefly discuss some of the different types of models presented in the literature, before justifying the choice of model in the present study. The closely-related issues of data and model selection are then considered, along with a discussion on various stages involved in the modelling process.

5.3.1 Economic Growth Models of Oil Price Shocks

Before the VAR methodology became established in the literature, several studies used simulation-type models to address the question of oil shocks from an economic perspective. For example, Pierce and Enzler (1974) view the oil price shock as predominantly a demand shock and utilise simulation methods based on the MIT-Penn-SSRC (MPS) model of the U.S. macroeconomy. They find a permanent threefold rise in the price of imported oil causes a US$ 76 billion decrease in Gross National Product (GNP, current 1976 prices) over the period, i.e. 1967-1973.[79] Rasche and Tatom (1977a) similarly consider the problem as a permanent increase in oil prices, however they focus on the reduction in potential GNP. They estimate the long run impact of the 1973-74 price shock at 7 percent of potential output, although their methodology has been criticised by a number of studies, for example Tobin (1980) and Mork (1994).

The use of the VAR method is attractive in the context of oil price shocks and economic growth because it does not require the tight structure of a complete model, which would limit the number of maintained hypotheses that could be incorporated in the empirical

[79] The simulated loss, which holds money supply and fiscal policy constant, is spread across consumption expenditure and disposable income. It also results in an increase in unemployment from 0.1 percent to 2 percent after 28 quarters, and a 2.4 percent reduction in the Treasury Bill rate over that timeframe.

setting (Sims, 1980; Burbidge and Harrison, 1984). Typically, the empirical oil price-shock models also include a number of the macroeconomic variables identified by Sims (1980) as important determinants of economic growth, however the final form of each model is subject to the specific nature of the question being addressed. There are also practical concerns such as the degrees of freedom available with the time series at hand. Table 5.1 below presents the key variables that have been included in several of the VAR studies that model the economic growth impact of oil price shocks in different contexts.

Table 5.1 VAR Analyses of Oil Price Shocks on Economic Growth: Selected Studies

Study	Sample	Data Frequency	Variables Included
Hamilton (1983)	United States	Quarterly 1949-1972	GNP, UNE, DPI, W, IPI, M, Oil
Mork (1989)	United States	Quarterly 1949-1988	GNP, UNE, DPI, W, IPI, R, Oil
Bernanke *et al.*, (1997)	United States	Monthly 1965-1995	GDP, DPI, Com, R, Oil
Lee *et al.*, (2001)	Japan	Monthly 1960-1996	IPI, DPI, Com, R, Oil
Cunado and Pérez de Gracia (2003)	15 European countries	Quarterly 1960-1999	IPI, DPI, Oil
Jiménez-Rodríguez and Sánchez (2005)	8 OECD countries	Quarterly 1972-2001	GDP, DPI, REER, R, W, Oil

Notes: The variable identifiers listed in column four are as follows – **GDP/GNP** Gross Domestic/ National Product; **UNE** Unemployment; **DPI** Domestic Prices / Inflation; **W** Wages / Labour Costs; **IPI** Industrial Production; **M** Money Supply; **Oil** Oil Prices; **R** Interest Rate; **Com** Commodity Prices; **REER** Effective Exchange Rate.

It is clear from Table 5.1 above that a number of the crucial variables are common to all or most of the studies. These include inflation and interest rate measures and various wage and exchange rate variables, all of which are theoretically-important determinants of economic growth. The next section outlines the form of the models to be used in the empirical analysis of the present chapter. It discusses the central variables in detail, drawing on the economic theories to justify their role in the empirical models, before progressing to outline the various stages of the analysis that follows in section 5.4.

5.3.2 Oil Price and Macroeconomic Data Issues

This section discusses the models and data to be employed in empirically testing the relationship between oil prices and economic growth in New Zealand. It begins by considering the important issues surrounding the data, justifying the choice of variables included in the models, the frequency of data, and the period to be researched. It then describes the structure of the empirical methodology.

Having identified the VAR methodology as the appropriate framework for undertaking this analysis, there are three important issues to consider with respect to variable selection. Firstly, while the primary relationship of interest here is between oil prices and economic growth, there exist many different 'oil prices' across various markets and countries. Consequently, a decision must be made as to which measure is most appropriate for the case of New Zealand. Secondly, the previous discussion has noted that oil price changes may affect economic growth through indirect channels; this suggests that decisions need to be made as to which other variables to include to capture the indirect linkages. Finally, various transformations of the linear price change variable that address the sectoral reallocation and price uncertainty effects are discussed and justified.

The existing literature on oil prices and economic growth utilises a variety of oil price measures. These include producer price indices for crude oil (for example, see Hooker, 1996a; Lee *et al.*, 1995; Cuñado and Pérez de Gracia, 2003), refiner acquisition costs for imported crude oil (see Mork, 1989), spot prices for individual crude and refined petroleum markets (see Carlstrom and Fuerst, 2005; Ferderer, 1996; Backus and Crucini, 2000; Jiménez-Rodríguez and Sánchez, 2004, 2005), and indices comprising several different market prices. Of the various price measures available, the Dubai spot price (in US$) per barrel of crude oil will be considered, deflated by the US Producer Price Index (PPI). This is because Dubai is an internationally-traded variety of medium crude oil that is relevant to the New Zealand economy, and is the crude oil price that is regularly reported by the Ministry of Economic Development in their *Energy Data File*. Defining the variable in real terms avoids the problem relating to nominal price definitions that, owing to positive inflation, a comparable shock to the nominal price would induce a decreasing effect on real variables over the sample period (Jiménez-

Rodríguez and Sánchez, 2004). This definition also means that changes in the level of the variable should be exogenous 'shocks' with respect to the New Zealand economic variables, since the nation is a price taker for this commodity in the international markets. This international price variable is preferred to a domestic price because such a measure would necessarily include tax and retailer margin elements. Changes to a variable so-defined could arise from innovations in fiscal policy or monopolistic behaviour, not necessarily the underlying product market. This would make it difficult to meaningfully interpret any results. Lastly, the chosen definition has the benefit of having consistent results that are comparable to the majority of previous studies (see for example, the studies listed in Table 5.1).

The second important decision concerns the other variables included in the regression models. This is guided by the theoretical issues raised in chapter 2, where it has been highlighted that inflation and exchange rate channels, as well as interest rates and labour markets, may play crucial roles in transmitting oil price-shocks into the macroeconomy. Therefore, and in line with much of the reported literature, the models below include a real exchange rate variable, proxied by the New Zealand Trade Weighted Index; a real wage variable, proxied by the economy-wide average wage; and an inflation measure, proxied by the Consumer Price Index. Under the Reserve Bank Act 1991's Policy Target Agreement, the sole aim of the Monetary Policy is to maintain Consumer Price inflation between 0 and 3 percent on an annual basis. Accordingly, the inflation variable should also capture innovations in official interest rates. This assumption allows the model to address a range of indirect effects with a parsimonious structure, which is beneficial given the relatively modest size of the time series data. The data are taken from two sources: Statistics New Zealand's PC INFOS database for Nominal GDP (INFOS series SNCQ.S1NB15 – expenditure approach); Nominal Wages (INFOS series EESQ.SASZ9Z – average hourly earnings for both sexes, all sectors); Consumer Price Index (INFOS series CPIQ.SE9A – all groups); and Nominal Effective Exchange Rate data (Trade Weighted Index - Reserve Bank of New Zealand and Statistics New Zealand). These data are supplemented by International Monetary Fund's International Financial Statistics (IFS) database for the Nominal Dubai oil price (Line 46676AAZZF…); New Zealand GDP deflator (Line 19699BIRZF...) and the US Producer's Price Index (Line 11163...ZF…). See Appendix 5.1, Table A5.1 for details of the variables and the data sources.

The important choice of the period of estimation has been governed by the timing of the reform package noted earlier. Since the price regulation of the petroleum factor and product markets existed prior to the structural reforms, thus the post-reform period (i.e. post-1988) is a vital period to consider the impact of oil price shocks on economic growth. Quarterly data are used as this is the highest resolution at which common economic aggregates are readily-available, and has been conventionally used in the literature. The number of observations for the quarterly period March 1989 to March 2006 (i.e. 70 observations) is sufficient to avoid the various pitfalls associated with econometric estimation based on short time series. See Kennedy (2003) for a discussion on this issue.

The final data issue to address concerns the various oil price transformations that are considered in the models below. These oil price representations are motivated by the break-down of the causal relationship between linear oil price change variables and growth in Gross Domestic Product (GDP) that is found in many of the recent (i.e. post-1986) studies. Two such non-linear price measures utilised in the present study follow Mork's (1989) asymmetric oil price change and Hamilton's (1996) net oil price change. The asymmetric price specification models the positive and negative oil price changes separately. That is, the oil price shock variable is included in the regression framework as follows, where o_t is the rate of change of oil price in period t:

$$o_t^+ = \begin{cases} o_t & if\ o_t > 0 \\ 0 & otherwise \end{cases} \tag{5.2a}$$

$$o_t^- = \begin{cases} o_t & if\ o_t < 0 \\ 0 & otherwise \end{cases} \tag{5.2b}$$

The distinction in equations (5.2a) and (5.2b) has a theoretical basis in the sectoral shifts hypothesis developed by Lilien (1982), which suggests that both positive and negative price changes may alter the marginal product of factor inputs and spur the sectoral reallocation of various resources on the supply side of the economy. This effect would reinforce the negative direct demand effects of a positive increase but offset the positive demand effects of a price decrease, giving rise to asymmetric effects on economic growth. Mork's (1989) study provides empirical support to this theory, with the coefficients on all four lags of the price increase variable in the GDP equation statistically significant at the 5 percent level whereas none of the coefficients on the four lags of the price decrease variable are significantly different from zero. On the other hand, investment and consumption uncertainty that may arise in a climate of volatile oil prices have been suggested by Bernanke (1983) and Pindyck (1991), among others, to be the important means by which oil prices can affect economic growth. This idea motivates several non-linear price measures first developed by Hamilton (1996) and Lee *et al.*, (1995).

Hamilton (1996) considers the rate of price increase in the current period relative to price movements over the past year, rather than over the previous quarter only. Defining o_t as the rate of change of oil price in period t, this 'net oil price increase' (NOPI) measure is given as:

$$NOPI = \max\left\{0, o_t - \max\{o_{t-1}, o_{t-2}, o_{t-3}, o_{t-4}\}\right\} \quad (5.3)$$

Transforming the price variable in this manner focuses on those price increases that occur after a period of relative stability, placing less emphasis on price changes that occur during periods of existing price volatility. Similarly, the scaled oil price measure developed by Lee *et al.*, (1995) models the conditional volatility of oil prices with an AR(4)-GARCH(1,1) process.[80] This study will not consider the scaled price measure as the use of GARCH is not suitable with small samples (Levy, 2001). Furthermore, Jimenez-Rodriguez and Sanchez (2005, p. 214) report that the scaled measure performs similarly to the net price measure, while Jimenez-Rodriguez (2002) shows that the GARCH specification is inferior to a non-linear function estimated by kernel methods. The application of kernel semi parametric methods is also beyond the scope of the present study given the size of the time series data available.

As there is little theoretical basis *a priori* to distinguish the most-appropriate measure among the previously-discussed linear and non-linear alternatives for the case of New Zealand, and no precedent from the existing literature, the present study will consider the linear, asymmetric, and net specifications separately to address the short run impact

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[80] See Engle (2001), Wooldridge (2002) and Quantitative Micro Software (2004, Ch. 20) for discussion of the Generalized Autoregressive Conditional Heteroscedasticity (GARCH) modelling framework.

of oil price shocks. The next section lays out the methodology employed in the analysis, outlining the important steps to be followed.

5.3.3 Methodological Structure

The methodology employed in the subsequent analyses is based on the VAR model given in equation (5.1), where the vector y includes the following variables: real GDP, real oil price, real wage, real effective exchange rate, and consumer price level. The New Zealand macroeconomic variables are transformed into real series using the GDP deflator described above, whereas the real oil price series is deflated with the US PPI. Most of the variables (real GDP, real oil price, real wage, and real effective exchange rate) are expressed in log form, whereas the inflation variable is derived from the level of the Consumer Price Index (CPI). The remainder of this section develops the various tests and methodology to be utilised in this approach. The methodology adopted in this chapter follows the general structure of the majority of empirical studies, and the approach outlined in Jiménez-Rodríguez and Sánchez (2004; 2005) in particular.

Testing for Stationarity

The first stage of the estimation and modelling procedure is to identify the order of integration of the data series. This avoids the problem of spurious regression (Granger and Newbold, 1974). Once the order of integration, I(d), of each time series is known, the series must be differenced d times to induce stationarity, before it can enter the regression framework.[81] This study will utilise two tests for establishing the order of integration of the various time series, which take opposite approaches to this issue. As in chapter 4, the Augmented Dickey-Fuller (ADF) test and the alternative Kwiatkowski-Phillips-Schmidt-Shin (KPSS) test will be utilised as the methodologies underlying each test are well known and widely reported in the time series literature. Both the ADF and KPSS tests will be carried out using the software package EViews 5.0.

Having ascertained the order of integration of each series, the next stage involves the short run assessment of oil price shocks on economic growth. This includes performing

[81] A time series with the mean and variance that are not time-dependent is said to be 'stationary'.

Granger causality-type tests, followed by an analysis of the impulse response functions and error variance decompositions of the VAR models. Because the VAR dynamics are complicated, the impulse response functions and error variance decompositions are more informative statistics than the estimated variable coefficients and R^2 statistics that are usually reported for regression models (Stock and Watson, 2001). Consequently, the latter statistics will not be considered here.

Granger Causality Analysis

In order to ascertain whether there is a statistically significant relationship between oil prices and the important macroeconomic variables, pairwise Granger causality-type tests will be performed on the system of variables noted above using the standard Wald test, discussed in Griffiths *et al.*, (1993) for example.[82] The test is based on an unrestricted VAR(p), given as:

$$y_t = c + \sum_{i=1}^{p} \phi_i y_{t-i} + \varepsilon_t \qquad (5.4)$$

where y_t is a (n x 1) vector of endogenous first-differences, c = (c1, ..., cn)' is the (n x 1) intercept vector of the VAR, ϕ_i is the ith (n x n) matrix of autoregressive coefficients for i = 1, 2, ..., p, and $\varepsilon_t = (\varepsilon_{1t},...,\varepsilon_{nt})'$ is the (n x 1) vector of innovations. A crucial step involves the selection of the appropriate order of the VAR, p. This choice, which governs the number of lags to be included as explanatory variables in each equation within the system, is based on various selection criteria such as the Akaike Information Criterion and Schwarz Information Criteria (AIC and SBC, respectively), which are automatically provided by most software packages. Should these criteria disagree over the optimal lag length, the parsimonious lag structure will be chosen such that all equations are free from serial correlation in the residuals (see Pesaran and Pesaran, 1997; Quantitative Micro Software, 2004).

[82] It is important to stress that this test is only valid for VARs containing differenced data. Where levels data are used, the modified Wald (MWald) test can be used; see Toda and Yamamoto (1995) and Dolado and Lutkepohl (1996) for a discussion of the underlying theory.

Once the order of the VAR has been determined, the Wald test of Granger non-causality will be performed on the various pairs of variables within the system. This is primarily to determine whether the different representations of oil price change *directly* Granger cause economic growth in New Zealand. Such a relationship would be implied by the rejection of the null hypothesis that all p lags of the oil price coefficient are jointly equal to zero in the GDP growth equation of the VAR. However, a central theme in this study has been that indirect linkages may be the important transmission mechanisms for oil price shocks, as has been hypothesised in the recent literature (see discussion in section 5.2 and chapter 2). Therefore further tests can be utilised to deduce whether or not a relationship between oil price changes and the rest of the system exists. The present study will therefore consider the Likelihood Ratio test to address this issue if necessary.

The Likelihood Ratio test addresses the significance of a given variable with respect to the system as a whole, rather than in the context of a single equation. Specifically, it tests whether the coefficients on all oil price variables are jointly equal to zero in *all* of the equations in the system. This provides a means to test for the indirect transmission channels that are not addressed with the Wald test (Jiménez-Rodríguez and Sánchez, 2005).[83] In conjunction with the pairwise tests, these tests' statistical values should provide the important insights into whether or not oil price shocks have an impact on the system of key macroeconomic variables for New Zealand. Under such circumstances, the magnitude of this impact can be quantified using the impulse response function and forecast error variance decomposition mechanisms. These two procedures are discussed next.

Impulse Response Function and Variance Decomposition Analysis

To pursue the central issue of economic growth impact of oil price changes, it is useful to consider the magnitude of a price shock on the different variables over time. Impulse response functions can be used to estimate the dynamic impact of a one-standard-deviation shock to the error term in one equation on the other variables in the VAR.

[83] Alternatively one could employ the Granger test of block exogeneity, which considers whether the coefficients on all of the lags of *all* variables other than the dependent variable are jointly different from zero. In the present case however, the LR test seems more appropriate.

This assumes the error returns to zero in the following periods and that all other errors are equal to zero (Stock and Watson, 2001).

There are two established impulse response methodologies, the orthagonalised impulse response function (see Sims, 1980) and the generalised impulse response function (see Koop *et al.*, 1996; Pesaran and Shin, 1998a). Whereas results obtained via the orthagonalised methodology are highly sensitive to the ordering of variables within the VAR, the generalised methodology produces estimates that are invariant to the variable order of the VAR.[84] Given this desirable property, this study will employ generalised impulse response functions to consider the estimated magnitude of an oil price shock on GDP growth, directly and through the previously-noted indirect channels. In order to further determine how much of the unanticipated changes in each series are explained by shocks to the other variables, the study will also utilise the forecast error variance decomposition methodology.

Whereas the impulse response function considers the effect of a shock to one endogenous variable on the other variables in the VAR, the variance decomposition distinguishes the variation in one endogenous variable that is attributable to the shock components of the various random errors. This statistic is useful for estimating the degree to which oil price shocks, relative to shocks to the other variables, act as a source of volatility for the important dependent variables. In the next section, the issues of Granger causality, impulse response, and variance decomposition are investigated empirically. The results are discussed for New Zealand, with reference to other country case-studies.

5.4 Empirical Results

In this section the results of the various tests described above are discussed for the linear and nonlinear models of changes in oil prices on growth. Section 5.4.1 reports the results of the preliminary tests of stationarity, followed by the selection of the optimal VAR length in 5.4.2. Section 5.4.3 presents the results of the Wald tests of Granger non-causality and the Likelihood Ratio tests, which are followed by the impulse

[84] See Pesaran and Shin (1998a, pp. 18-20) for the detailed econometric specification of the generalised impulse response function.

response functions and variance decompositions in section 5.4.4. The models are estimated over the period 1989 to 2006, utilising quarterly data in constant 2000 prices for the relevant variables.

5.4.1 ADF and KPSS Unit Root Tests

The estimated statistics of the ADF and KPSS stationarity tests are presented in Table 5.2 for each variable in both the level and first difference form. Critical values for the ADF test are from Mackinnon (1996), while the asymptotic critical values from Kwiatkowski *et al.*, (1992) are utilised for the KPSS test. The results presented in Table 5.2 imply that each series is I(1), applying the first difference to attain stationarity. Recall that the null hypothesis of the ADF test is of non-stationarity for the series in question, thus, it is clear from Table 5.2 that this hypothesis cannot be rejected at the 5 percent level for the level form of any of the variables in the model. On the other hand, the null of the ADF is rejected in every instance at the 1 percent level for the first-differences of all variables. These results imply that the level form of each series is integrated of order one. To corroborate this interpretation however, it is useful to consider the results of the alternative KPSS test.

The KPSS test is opposite to the null hypothesis of the ADF test; it is a test of the null hypothesis that a given series is stationary, and hence does not need to be differenced. The results in Table 5.2 do not reject the hypotheses that the log of the real GDP, real wage and real effective exchange rate variables are stationary in levels, however the results for the first-difference form imply that the null hypothesis cannot be rejected for the first difference of any of the series. These results provide further evidence to the ADF test conclusions that the levels of all of the variables are I(1). The results are supported by various time series studies. Regarding New Zealand's GDP time series, Giles (1999) concludes that quarterly GDP is a nonstationary I(1) process over the time frame 1968 to 1994. Hendry and Juselius (2000, p. 39) argue generally that "it is sensible empirical practice to assume unit roots in (log) levels until that is rejected by well-based evidence…Monte Carlo studies have demonstrated that treating near-unit roots as unit roots makes statistical inference more reliable than otherwise." In addition, the studies reported in Table 5.1 also align with the unit root test results reported by Lee et al., (1995) for oil price shock models of the US economy, Cuñado and Perez de Gracia (2003) for 16 developed European countries, and Jimenez-Rodriguez and Sanchez (2005) for a group of 9 Organisation for Economic Cooperation and Development (OECD) countries.

Table 5.2 Results of the ADF and KPSS Unit Root Tests

Variable	ADF t-statistic	KPSS LM-statistic	Conclusion
LRGDP	-3.475*	0.108	Not I(0)
LROP	-1.998	0.217***	Not I(0)
LRWAGE	-2.517	0.079	Not I(0)
LREER	-3.443*	0.107	Not I(0)
CPI	-2.544	0.119*	Not I(0)
ΔLRGDP	-8.234***	0.285	I(0)
ΔLROP	-4.144***	0.132	I(0)
ΔLRWAGE	-8.988***	0.062	I(0)
ΔLREER	-5.706***	0.089	I(0)
ΔCPI	-5.396***	0.146	I(0)

Notes: LRGDP is log of real GDP, LROP is log of real oil price, LRWAGE is log of real wage, LREER is log of real effective exchange rate and CPI is Consumers' Price Index. Δ is difference operator. 5 percent critical values for ADF test are -3.515 (levels) and -2.931 (first-differences); 5 percent critical values for the KPSS test are 0.146 (levels) and 0.463 (first differences). *,**,*** indicate statistical significance at the 10, 5, and 1 percent levels, respectively.

In this study all of the variables are I(1) processes. The following short run analysis will therefore be conducted using the reduced-form VAR model where all of the variables enter in the first-difference form as follows:

Model I: [ΔLRGDP, ΔLROP, ΔLRWAGE, ΔLREER, ΔCPI]

Model II: [ΔLRGDP, ΔLROP+, ΔLROP-, ΔLRWAGE, ΔLREER, ΔCPI]

Model III: [ΔLRGDP, NOPI, ΔLRWAGE, ΔLREER, ΔCPI] where ΔLRGDP is the log difference of real GDP; ΔLROP is the log difference of real oil prices; ΔLRWAGE is the log difference of real wage rate; ΔLREER is the log difference of real effective exchange rate; ΔCPI is the first difference of Consumer Price Index; ΔLROP+ is the positive log difference of real oil price; ΔLROP- is the negative log difference of real oil price and NOPI is the net oil price increase. The next step involves determining the appropriate order of the VAR, *p*.

5.4.2 VAR Order Selection Tests

The process of determining the VAR order is usually based on one or more information criteria such as an AIC or SBC. The results of these two tests are presented in Table 5.3 for the various models, where in each case the maximum order considered was 6 lags.

It can clearly be seen from Table 5.3 that the two selection criteria disagree over the optimal lag length, with the AIC favouring a longer lag length than the SBC. Such a result is not uncommon (Pesaran and Pesaran, 1997).[85] In such situations, where the different selection criteria are not informative, the parsimonious VAR order should be chosen such that all of the individual equations are free from serial correlation. This condition is satisfied in the present application at 3 lags in each of the three separate models. Furthermore, the important diagnostic statistics suggest the models are not mis-specified at this lag length.[86] This $p = 3$ lag structure is also optimal for Jiménez-Rodríguez and Sánchez's (2005) linear and nonlinear price shock models for France, Italy, Norway and Canada. Other authors such as Mork *et al.*, (1994) and Lee *et al.*, (1995), as well as Jimenez-Rodriguez's (2005) models for the US, the UK, Germany and Japan, employ 4 lags in those VAR systems. This lag structure should be sufficient to capture the full dynamics of the oil price-economic growth relationship for New Zealand (see Jimenez-Rodriguez and Sanchez, 2005, p. 215). With this in mind, the results of the causality-type analyses are presented below.

[85] This is because the SBC tends to penalise the inclusion of more coefficients relatively more vigorously than the AIC (Pesaran and Pesaran, 1997).
[86] Standard F-tests of functional form, normality, and heteroscedasticity are not significant in the individual equations of the VAR(3).

Table 5.3 VAR Order Selection Criteria for Oil Price Models

Model	Lag Structure Maximum AIC	 Maximum SBC
Linear	4	0
Asymmetric	5	0
Net	5	0

5.4.3 Causality Analyses

In this section the results of the various causality tests are presented. Several alternative tests are reported, demonstrating the short run impact of oil price shocks in the macroeconomy. The pairwise Wald test is first considered, followed by the Likelihood Ratio test.

Results of the Wald Test of Granger Non-Causality

The earlier discussion suggests that economic theory is insufficient for determining which oil price representation is the most appropriate for the case of the economic growth impact in New Zealand. Below the results of the pairwise Granger non-causality are presented and discussed in Table 5.4, for each of the three price specifications.

From Table 5.4, it is clear that the null hypothesis cannot be rejected for any of the price change specifications. That is, neither the linear nor the asymmetric or net oil price variables Granger cause economic growth directly in New Zealand. This result is similar to those presented in several of the recent studies for other countries. Jimenez-Rodriguez and Sanchez (2005) perform standard Wald tests of Granger non-causality on the various price measures paired with economic growth.[87] They find that the linear price measure is not significant in any of the nine OECD countries studied, while the asymmetric price increase is only significantly different from zero for the case of France and Germany.[88] The asymmetric price decrease variable is not significant except for the full model of Europe and the case of Norway. The latter result may be explained by the

[87] They also consider the scaled oil price increase and decrease measures, which are not discussed here as they are not directly relevant to the present study.
[88] The 9 country groupings considered are: The US, the European Union (EU), Japan, Canada, France, Italy, Germany, Norway, and the UK.

unusually-high contribution of oil exports to GDP in that country. Lastly, the net oil price measure does not Granger cause economic growth for any countries except for Germany, where the net oil price is significantly different from zero at the 5 percent level. Cunado and Perez-de-Gracia (2003) also find that the linear, asymmetric and net oil price changes all do not Granger cause industrial production in the cases of Spain, Italy, and Finland. This cross-section of countries shares a number of economic attributes with that of New Zealand, i.e. for developed countries and net importers of oil products, except for Norway (International Energy Agency, 2006b). Hence, the finding that oil price changes do not directly affect economic growth in New Zealand is consistent with the evidence for similar countries.

Table 5.4 Results of the Wald Tests of Granger Non-Causality

Oil Price Model	Wald F-statistic	p-value
Linear	1.829	0.609
Asymmetric: Increase	1.505	0.681
Asymmetric: Decrease	1.617	0.656
Net	4.190	0.242

Notes: The above table reports p-values associated with the pairwise tests of Granger non-causality that all oil price coefficients are jointly zero in the GDP growth equation of the respective VAR models. The relevant 5 percent critical value for the Wald F-statistic with 3 degrees of freedom is 7.814 (Griffiths *et al.*, 1993).

As Jimenez-Rodriguez and Sanchez (2005, pp. 209-210) state, rather than all of these economies being unaffected by oil price shocks it may be that the Wald test is not able to account for the system-wide impact of oil price shocks. On the other hand the Likelihood Ratio test considers the null hypothesis that all of the oil price coefficients are jointly zero in all other VAR equations. This test can be utilised to consider the broader impact of oil price shocks, given the presence of labour market, foreign exchange market, and commodity market variables in the model. The results of the Likelihood Ratio test are presented in Table 5.5 for the different price shock models. These results will be used to conclude whether the interaction between oil prices and macroeconomic variables is generally significant for New Zealand.

It is clear from Table 5.5 that the linear price change, the asymmetric price increase and the net oil price variables are significant for the system as a whole, whereas the asymmetric price decrease is not. This is a similar result to that presented for most of the countries studied by Jimenez-Rodriguez and Sanchez (2005), except for the oil-producing countries of the US, the UK and Canada, where all of the price measures are significant. It suggests that the oil price increase transformations are important elements of the VAR models, whereas the interaction between the macroeconomic variables and negative price changes is not significant. This is a common theme throughout the literature, which is often assumed *a priori*; see discussion in Chapter 2 – section 2.4, especially Cunado and Perez-de-Gracia (2003) and Hamilton (1996), for example. Given that the negative variable is not significant with respect to the asymmetric VAR system, convention in the literature is followed and the asymmetric price decrease variable is removed from the subsequent empirical considerations.

Table 5.5 Results for Likelihood Ratio Tests: Oil Price Specifications

Oil Price Variable	Likelihood Ratio test statistic	p-value
Linear	137.759	0.000
Asymmetric: Increase	180.403	0.000
Asymmetric: Decrease	11.442	0.721
Net	231.816	0.000

Notes: The above table reports p-values associated with LR test of system significance for each oil price measure. Each cell contains the p-value associated with the null hypothesis that "all of the row oil price coefficients are jointly equal to zero in all equations of the VAR except its own". The 5 percent critical value for the LR test is 21.026 (Griffiths *et al.*, 1993).

The results of the Likelihood Ratio tests imply that oil prices *are* significant in the context of New Zealand's economic growth. Therefore, the effect of an oil price shock can be simulated using the impulse response and variance decomposition techniques noted above. In the next step it is important to determine the alternative specification that is the best representation of oil prices. Table 5.6 presents the results of the relative model performance by using the AIC and SBC test statistics, where the lowest value is preferred in this case (Quantitative Micro Software, 2004, p. 708).

Table 5.6 Relative Performance of Oil Price Shock Models

Oil Price Change Model	AIC test statistic	SBC test statistic
Linear	-25.483	-22.305
Asymmetric	-26.048	-22.870
Net	-26.838	-23.660

It can be concluded based on the estimated test statistics that the goodness-of-fit for the net oil price change model is superior to that of the linear and asymmetric models. Based on these results, the next section examines the macroeconomic impact of oil price shocks for New Zealand using the preferred net oil price specification.

5.4.4 Macroeconomic Impact of Oil Price Shocks: Impulse Response and Variance Decomposition Analysis

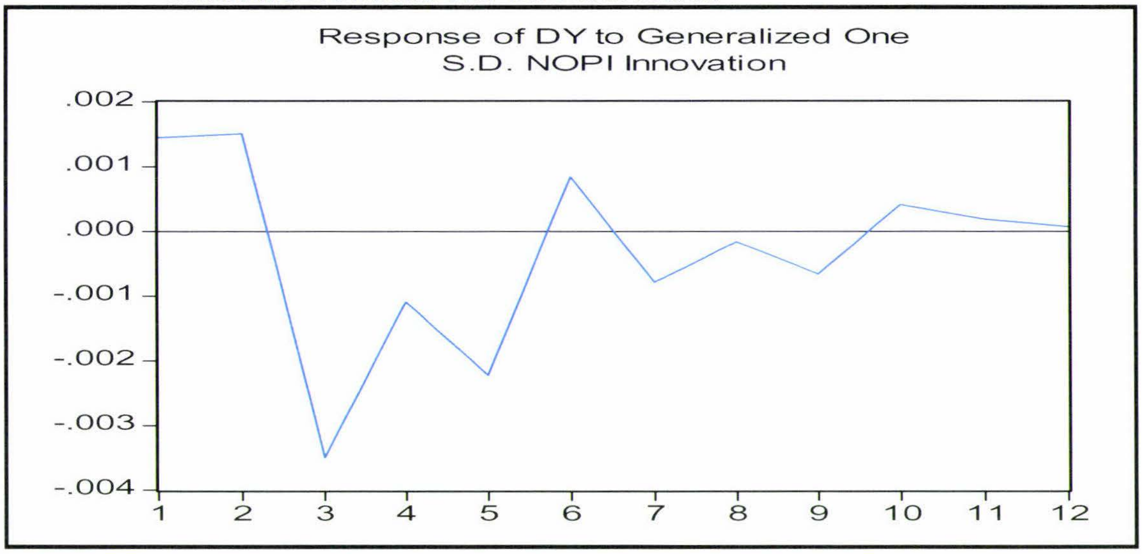
The generalised impulse response functions and the forecast error variance decomposition are examined focussing on the preferred net oil price shock model. Initially, the focus is on the direct impact of a simulated price shock on economic growth. In the next steps the potential indirect effects on economic growth and the relative contribution of oil price fluctuations to the volatility of the various endogenous series are considered.

Impulse Response Analysis

In examining the direct impact of a price shock, Figure 5.1 presents the impulse responses of the log-differences of the endogenous variables, i.e. real GDP (ΔLRGDP), inflation (ΔCPI), real effective exchange rate (ΔLREER), and real wage (ΔLRWAGE), to a generalised one-standard-deviation net oil price shock. The horizontal axis indicates the quarterly intervals over a three-year period. The 12-period length is chosen because most of the impulse responses appear to stabilise by that period.

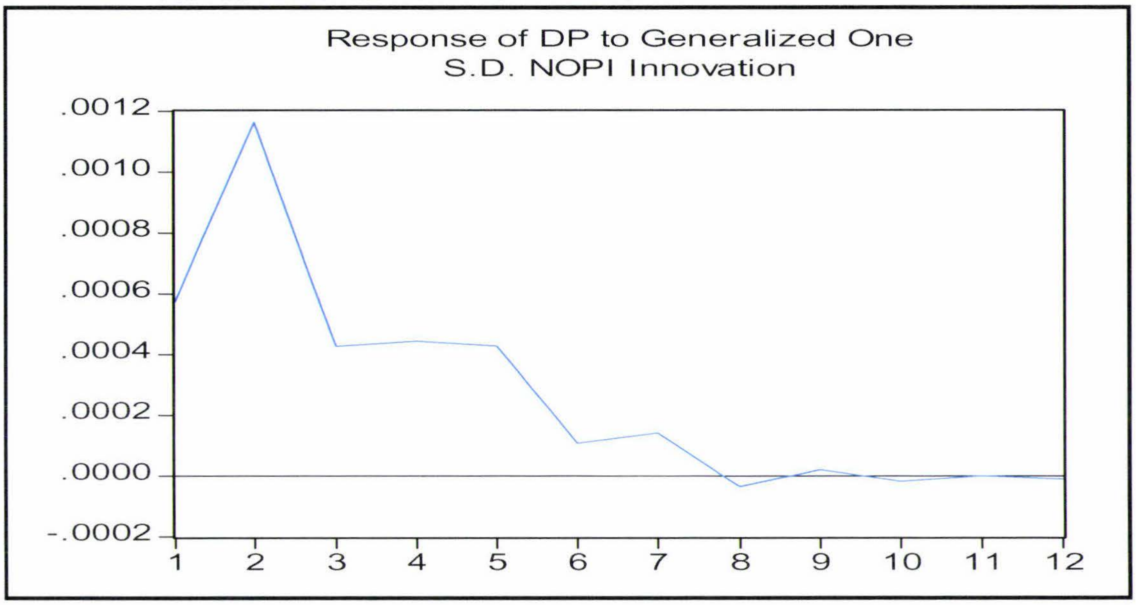
The impulse response function presented in Figure 5.1 traces the impact of a shock to the net oil price equation on real GDP growth over a 3-year period. It suggests the price shock affect in the second quarter that imposes a negative impact on economic growth; the largest negative impact occurs in the third quarter and remains negative over 2 years. This is consistent with the findings of Lee *et al.*, (1995) for GNP growth in the US, and Jimenez-Rodriguez and Sanchez (2005) for the cases of France, Italy, Norway and Canada. The y-axis indicates the rate of change of the given variable, and the impulse responses can be interpreted as percentage change values multiplied by the factor of 100. Accordingly, the third period negative impact is equal to nearly 0.4 percent of GDP growth. The cumulative effect is around 0.7 percent of GDP growth; however the impact asymptotes back to 0 after the tenth quarter. This suggests that the impact of the net oil price shock on the growth rate of GDP is relatively short-lived.

Figure 5.1 Generalised Impulse Response Function of GDP Growth to a One-Standard-Deviation Net Oil Price Shock



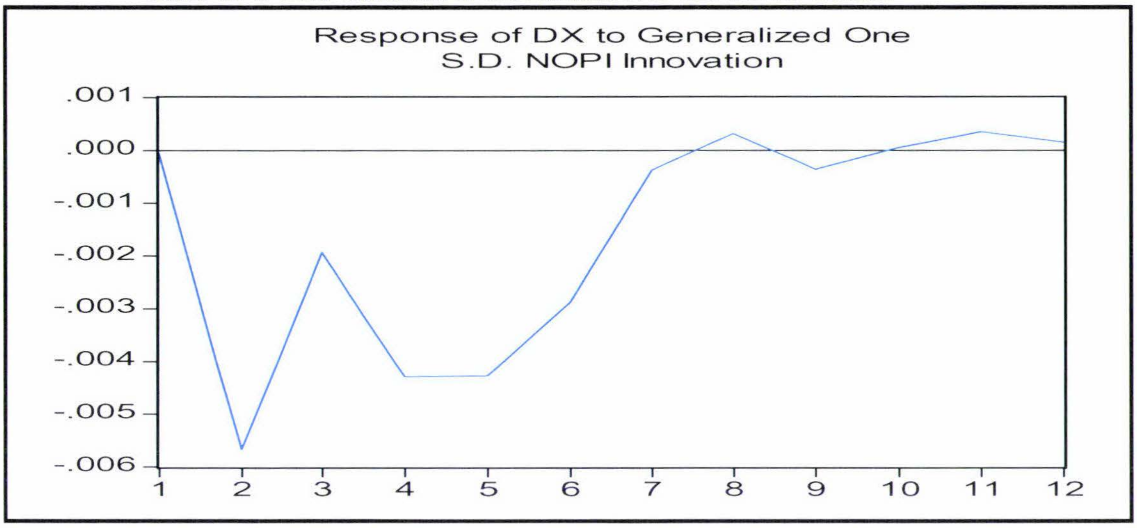
Next, the impact on inflation through an oil price change is examined. Figure 5.2 gives a clear indication that an oil price shock has an immediate and large effect on inflation. The dynamic profile of the impulse response suggests the shock to inflation is immediate, increasing in the order of 0.1 percent in the second quarter due to a one-standard-deviation price change innovation. This is followed by a gradual decrease over the next 6 quarters before the impact stabilises to 0 in around 2 years. This impact implies the effect on inflation is transitory, though the effect on the level of consumer prices is permanent. The impulse response suggests a cumulative impact in the region of 0.3 percent. Given the narrow band for inflation targeting in New Zealand, the implication of the impulse response function is that oil price shocks contribute to a difficult macroeconomic and monetary policy environment. The impacts of lower GDP growth and increased inflation due to oil price shocks, as shown in Figures 5.1 and 5.2 are similar to the findings in the context of the US economy (as noted in Chapter 2) found by Mork (1994) and Jones *et al.*, (2004). The impact of oil price shocks on the real effective exchange rate is considered next.

Figure 5.2 Generalised Impulse Response Function of Inflation to a One-Standard-Deviation Net Oil Price Shock



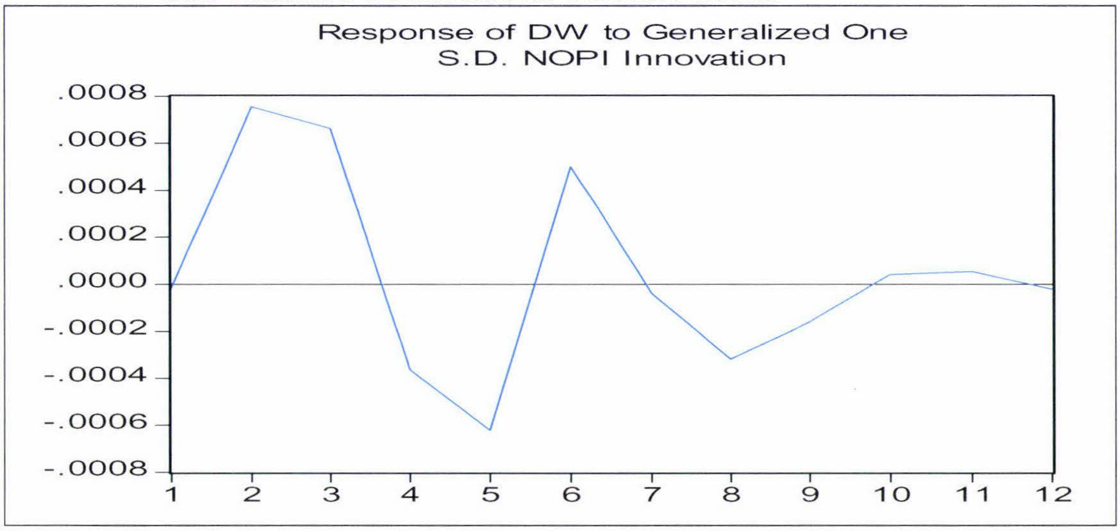
Before considering the implications of impulse response of oil price shock on real effective exchange rate, it is important to expand the definition given for the real exchange rate variable. In the present study this variable is defined where a decrease means a depreciation of the domestic currency in real terms. Such a movement would be expected to benefit exporters and harm importers. Accordingly, a sharp, negative response of the real exchange rate to the initial price shock suggests that domestic consumers would face higher prices for imported goods. On the other hand, export goods would be relatively more competitive on the world market, notwithstanding the oil price shock. The impulse response plotted for real exchange rate to a one-standard-deviation oil price shock in Figure 5.3 is persistent through to 10^{th} quarter (i.e. 2½ years). The magnitude of the sharpest fall occurs in the second quarter reaching nearly 0.6 percent, and the cumulative effect over time through 10 quarters is around 2 percent. Given that this movement occurs at the same time as its impact on GDP growth and inflation, the overall impact of the price shock is difficult to calculate. Based on the results presented so far it would appear not to be a trivial effect, as the cumulative effect is high so it will impact on several economic activities, adversely affecting overall growth. Below, the final impulse response for real wage growth is presented and discussed.

Figure 5.3 Generalised Impulse response Function of the Real Effective Exchange Rate to a One-Standard-Deviation Net Oil Price Shock



The impulse response function shown in Figure 5.4 indicates the impact on real wage growth due to net oil price shock. It can be seen that there is substantial volatility in the labour market in the year after the oil price shock. The time path of the impulse response indicates an initial appreciation in the real wage rate, before it decreases in the third to fifth quarters, and finally asymptotes to 0 in three years. This sequence can be rationalised as follows: the oil price shock initially induces substitution towards labour, as it is a relatively-cheaper factor input. After several periods however, it contributes to a reduced output growth (as seen in Figure 5.1) and lower exchange rate (as seen in Figure 5.3) that reduces demand, and also leads to a loosening of the labour market pressures. It is noted that the scale of effect is of smaller order of magnitude than those of previous factors shown in Figures 5.1 to 5.3. The maximum increase in the second quarter is around 0.07 due to one percentage change. Consequently, the smallest impact of real wage impulse response function suggests that the labour market is not as volatile as inflation or the exchange rate. In the next section the issue of macroeconomic importance of oil price event from the perspective that oil price shocks may contribute to the volatility in GDP growth and other series are examined. This is considered using the forecast error variance decomposition procedure noted in section 5.3.3.

Figure 5.4 Generalised Impulse response Function of Real Wage Growth to a One-Standard-Deviation Net Oil Price Shock



Variance Decomposition Analysis

The variance decomposition for each series (i.e. GDP growth, Net Oil Price, Real Wage Growth, Real Exchange Rate and Inflation) is further broken to indicate the attributes of innovations within the system of endogenous variables. This provides a gauge of how much of the unanticipated changes of the variables are explained by different shocks (Jiménez-Rodríguez and Sánchez, 2005, p. 222). The following Tables 5.7 to 5.10 report the variance decomposition estimated over the 8-period horizon (i.e. 2 years) for each of the endogenous variables based on the VAR model. The selection of the 8-period forecast horizon is based on the decomposition values converging to stable states.

The estimated variance decomposition of real GDP growth over the 2-year horizon is presented in Table 5.7. Here the variance in the GDP growth series is separated into various contributions of each factor. This is useful for assessing the *relative* importance of oil price shocks vis-à-vis shocks to the other sectoral variables, e.g. labour market (as represented by the real wage shock) and foreign exchange shocks (as represented by the real exchange rate shock). In estimating the impact on GDP growth, it can be seen that the oil price shock is a considerable source of volatility, i.e. it contributes substantially to around 9 percent of the volatility in output growth.

Real wages growth also contributes as much to the volatility of around 9 percent. Inflation contribution is lower than NOP and real wage growth, i.e. less-than 6 percent. This compares to the US, the UK and Italian economies, where Jimenez-Rodriguez and Sanchez (2005) find the scaled oil price variable to contribute 9.6 percent, 9.9 percent, and 8.8 percent of the volatility in the GDP growth series, respectively. On the other hand, the real effective exchange rate is estimated to have the largest source of volatility on GDP growth. This can be explained by the importance of international trade to New Zealand's economy. A very similar result was found for the case of Japan in the Jimenez-Rodriguez and Sanchez (2005) study, where international trade is a similarly dominant activity. In light of these results, the net oil price shock appears to be an important factor that contributes to the volatility of output growth over the two-year horizon in New Zealand. However, the indirect avenues need to be considered to gain a fuller understanding of the diverse impacts of oil price changes. The variance decomposition for the inflation variable over the comparable two-year horizon is presented in Table 5.8 below. The similar variance decompositions for real wage growth and the real exchange rate are considered thereafter.

Table 5.7 Estimated Variance Decomposition of Real GDP Growth over an 8 Quarter Horizon

Horizon	GDP Growth	Net Oil Price	Real Wage Growth	Real Exchange Rate	Inflation
0	1.000	0.014	0.041	0.022	0.001
1	0.930	0.230	0.035	0.017	0.038
2	0.841	0.079	0.053	0.048	0.035
3	0.702	0.069	0.087	0.146	0.058
4	0.685	0.083	0.083	0.144	0.056
5	0.677	0.085	0.086	0.149	0.057
6	0.671	0.086	0.087	0.148	0.056
7	0.670	0.085	0.087	0.148	0.056
8	0.668	0.087	0.088	0.148	0.058

Table 5.8 shows the estimated values of each variable due to innovation within the system via the effect of inflation. The net oil prices are the most crucial source of

volatility in inflation. While the GDP growth and exchange rate variables contribute 3.7 and 4.3 percent to the inflation variance at the 8-period stage, respectively, the net oil prices contribute almost 10 percent to inflation. This also exceeds the real wage impact of 8.5 percent of the total, in 2 years after the shock. These results are comparable to the results for France and Italy by Jimenez-Rodriguez and Sanchez (2005).

Table 5.8 Estimated Variance Decomposition of Inflation over an 8-Quarter Horizon

Horizon	GDP Growth	Net Oil Price	Real Wage Growth	Real Exchange Rate	Inflation
0	0.001	0.022	0.003	0.004	1.000
1	0.011	0.091	0.002	0.009	0.93
2	0.022	0.091	0.052	0.026	0.887
3	0.035	0.093	0.068	0.038	0.865
4	0.034	0.100	0.074	0.041	0.852
5	0.037	0.099	0.083	0.042	0.843
6	0.037	0.100	0.085	0.043	0.840
7	0.037	0.099	0.085	0.043	0.840
8	0.037	0.099	0.085	0.043	0.839

Table 5.9 presents the estimated variance decomposition values to real wage rate growth and other variables over 2 year time horizon. It is seen that domestic macroeconomic variables in New Zealand play a minor role in determining the key bilateral exchange rates and the trade-weighted index, vis-à-vis the prevailing macroeconomic conditions abroad. Thus, while domestically real wage growth adds to the volatility of real exchange rate, it is not surprising that most of the volatility in the real exchange rate series is impacted by oil price shock. The net oil price volatility contributes nearly 6 percent of the volatility over the 2 year period. This is more than the estimated rate of 4 percent contribution of GDP growth, and the 2 percent contribution of inflation. On the other hand, the incredible result for real wages of 31 percent suggests that real wage growth is internationally competitive and affects the exchange rate. This large volatility finding has not been reported for any of the country studies in the recent literature.

Table 5.9 Estimated Variance Decomposition of Real Effective Exchange Rate over 8-Quarter Horizon

Horizon	GDP Growth	Net Oil Price	Real Wage Growth	Real Exchange Rate	Inflation
0	0.022	0.000	0.214	1.000	0.004
1	0.030	0.028	0.227	0.951	0.012
2	0.030	0.031	0.226	0.948	0.012
3	0.041	0.041	0.307	0.874	0.013
4	0.040	0.053	0.307	0.862	0.013
5	0.042	0.058	0.309	0.847	0.018
6	0.043	0.057	0.312	0.837	0.018
7	0.043	0.057	0.312	0.837	0.018
8	0.043	0.057	0.311	0.837	0.020

As can be seen in Table 5.10, the estimated values of the variance decomposition shows the volatility for real wage growth is not caused by oil price shocks. The estimated values imply that the macroeconomic effects of oil price changes are not transmitted through the labour market. This result supports the estimated impulse response results, suggesting that the labour market is relatively unaffected and so is unimportant in terms of the macroeconomic consequences of exogenous shocks to the world price of oil. Overall, the findings that net oil price shocks add substantial volatility to GDP growth, real exchange rate and inflation reaffirm the results of previous variance decompositions and impulse responses noted above, that oil price shocks have important macroeconomic effects for New Zealand.

Table 5.10 Estimated Variance Decomposition of Real Wage Growth over 8-Quarter Horizon

Horizon	GDP Growth	Net Oil Price	Real Wage Growth	Real Exchange Rate	Inflation
0	0.041	0.000	1.000	0.214	0.003
1	0.053	0.006	0.967	0.204	0.007
2	0.066	0.010	0.891	0.186	0.066
3	0.062	0.010	0.799	0.240	0.063
4	0.073	0.013	0.783	0.238	0.062
5	0.072	0.014	0.781	0.234	0.074
6	0.073	0.015	0.777	0.241	0.077
7	0.073	0.015	0.777	0.243	0.077
8	0.073	0.015	0.777	0.244	0.077

5.5 Conclusion

This chapter has empirically considered the impact of oil price shocks on economic growth in New Zealand, over the quarterly period 1989-2006. This period coincides with deregulation of the oil markets in particular, and product and factor markets in general, in the wake of market reforms conducted after 1984. The short run impact of oil price shocks on economic growth has been considered in a multivariate framework including inflation, real wages, and exchange rate variables. This has allowed the models to analyse the direct economic impact of oil price shocks, as well as the indirect linkages involving the labour, currency, and commodity markets which are indicated in the economic theories as important. The models estimated employ the linear oil price and two leading nonlinear oil price transformations to examine the various short run impacts. Utilising the Wald test of Granger causality, the results indicate that although the linear oil prices and the two non-linear price measures do not Granger cause economic growth directly, there are important growth effects as assessed by examining the impulse response and variance decompositions of price shocks and economic growth factors.

Following the causality analysis of oil price-growth nexus, the generalised impulse responses and error variance decompositions reaffirm the direct link between the net oil price shock and growth, as well as the indirect linkages via inflation and the real exchange rate. These variables have important influences on the domestic economy. The results obtained for New Zealand are similar to various other developed country-studies and small, open European economies that are similarly reliant on imported oil resources. Another robust result shows that following an oil price shock, the labour market reacts with only minor consequences for economic growth. It does not appear to be an important transmission channel in the case of New Zealand. This result has been rationalised in terms of the economic theory, and supported by similar evidence from other country case-studies.

Overall, it can be said that there is an important relationship between exogenous oil price shocks and economic growth. This is reinforced by the finding that oil prices have substantial effects on inflation and the exchange rate in New Zealand, which are linked to the growth of GDP. Given that oil consumption continues to increase in New

Zealand, and economic policy-makers are focussed on attaining higher living standards over the medium term, the results obtained here may be of value to policy-makers given the lack of prior research in this area.

Appendix 5.1

DETAILS OF VARIABLES AND DATA SOURCES

Table A5.1 Oil Price Shock-Economic Growth Models: Variable Details and Data Sources

Variable	Description	Source
Output / Real Gross Domestic Product (GDP).	Nominal GDP deflated by GDP deflator. Constant 2000 prices.	Statistics New Zealand *PC INFOS* series SNCQ.S1NB15; IFS line 19699.BIRZF (GDP Deflator).
Oil Price	Dubai Spot Price (US$) deflated by US Producer Price Index (PPI). Constant 2000 prices.	IFS line 46676AAZZF (Nominal Oil Prices); IFS line 11136...ZF (US PPI).
Real Wages	Nominal NZ Hourly Earnings (averaged across all sectors and both sexes), deflated by Consumer Price Index (CPI). Constant 2000 prices.	Statistics New Zealand *PC INFOS* series EESQ.SASZ9Z (Nominal wage); Statistics New Zealand *PC INFOS* series CPIQ.SE9A (CPI).
Real Effective Exchange Rate	Trade Weighted Index (TWI) deflated by GDP deflator.	Reserve Bank of New Zealand www.rbnz.govt.nz (TWI); IFS line 19699.BIRZF (GDP Deflator).
Energy Prices	Energy component of Consumer Price Index.	OECD *Main Economic Indicators* series NZL.CPGREN01..4.

Notes: IFS is the International Monetary Fund's *'International Financial Statistics'* and OECD is the Organisation for Economic Cooperation and Development.

Chapter Six
CONCLUSION

6.1 Introduction

This study empirically examines several key elements of New Zealand's energy-growth nexus. The methodology used to estimate time series models applied the Autoregressive Distributed Lag (ARDL) approach to cointegration, and causality based on the Vector Autoregression (VAR) model representations. Based on theoretical and practical concerns, the energy consumption effects were analysed over the period 1960-2004, while the price shock-growth models were estimated for the quarterly period 1989-2006 that represents the period of deregulation of the domestic oil markets.

A number of different models were estimated for each of the consumption-growth and price-growth relationships. For the consumption models, trivariate demand, trivariate supply and multivariate supply models were estimated based on the ecological economic and neoclassical theories of economic growth. These three models included energy price, labour, and labour and capital variables, respectively. The various oil price variables utilised for the oil price shock models in chapter 5 reflected the investment uncertainty, asymmetric effects and sectoral reallocation arguments to examine the impact of oil price shocks on the exchange rate, macroeconomic and employment variables. The estimated models provided important empirical evidence on the relationships of energy consumption and oil prices with economic growth that are robust to model specification and pass various diagnostic tests. Implications for energy and economic policies were then presented that suggest economic growth strategies can be pursued despite energy consumption constraints, such as Kyoto Protocol obligations. Suggestions for mitigating the impact of oil price shocks on economic growth that focussed on relevant policy factors were also noted.

The rest of this chapter is arranged as follows. Section 6.2 briefly summarises the contributions and key findings of each of the preceding chapters. Section 6.3 discusses the crucial economic and energy policy implications and section 6.4 suggests areas of further research pertaining to energy-economic growth issues for New Zealand.

6.2 Chapter Summary

The main focus of this study is on the issues of energy consumption and energy price shocks as they relate to economic growth in New Zealand. Chapter 1 presents the key issues surrounding the energy-economic growth nexus and the various theoretical perspectives of the neoclassical and ecological economics schools of thought, as well as briefly outlining the empirical evaluation in the subsequent chapters.

Chapter 2 provides a broad review of the theoretical and empirical energy consumption-economic growth and energy price-economic growth literature, and notes the ambiguity in the results that justify country-specific studies. It also emphasises the theoretical rationale for including various variables within the modelling framework, and outlines the crucial variables to be considered in the empirical analysis of energy price and consumption issues in the economic growth framework.

Chapter 3 entails a descriptive analysis of New Zealand's macroeconomic development that focuses on the period since 1960. This includes a discussion of the package of economic reforms delivered between 1984 and 1991 that created a more-free and liberal New Zealand economy moving into the last decade of the 21st century, as well as noting the subsequent path of economic growth. This is complemented by a detailed discussion of the physical and economic characteristics of the New Zealand energy sector (including oil, electricity, gas, coal, geothermal and other renewables) and the changes that have occurred during the period under consideration (i.e. 1960-2004). The final section of chapter 3 deals with the broader political aspects of the energy sector, including the key elements of legislation that pertain to the main energy resources, both directly and indirectly.

Chapter 4 addresses the issue of energy consumption-economic growth nexus empirically using the cointegration and causality techniques. The three models estimated are trivariate demand model that includes a composite energy price variable; trivariate supply model that includes a labour force variable, and multivariate supply model that incorporates labour and capital variables in a production function framework. These models overcome the problems of omitting variables that may indicate the contribution and causality of those variables in the consumption-growth nexus. The ARDL approach to cointegration is utilised to estimate the three long run models based on the sample size of 45 observations, i.e. 1960-2004. The results indicate the existence of a single long run relationship in each model. In the trivariate demand and trivariate supply models, energy consumption is the dependent variable in the long run relationship whereas capital is the dependent variable in the expanded production function approach. Moreover, this study finds that real GDP growth Granger causes energy consumption over the period 1960-2004 without feedback. These results are robust across the model specifications.

Interesting results are also found concerning the causality between the various factors of production in the supply-side models, i.e. labour, capital, and energy. These relationships are further explored by means of the long run ARDL coefficients, which indicate that capital and labour are both significant substitutes for energy in the long run. These results are predicted by the theory of production, and suggest that policies involving labour and capital may be elements of an economic response to managing and conserving energy consumption. The results in chapter 4 provide empirical support to the neoclassical theory that energy use is a function of economic growth and not vice versa, which strengthens the argument that energy conservation measures may be enacted in New Zealand without necessarily impacting negatively on the process of economic growth.

Chapter 5 empirically evaluates the macroeconomic significance of oil price shocks. Several arguments from the recent theoretical and empirical literature are noted in constructing a linear and two nonlinear transformations of oil price variables to test various hypotheses. These tests are conducted in the context of a VAR model where oil price and real economic growth variables as well as inflation, real wages and real exchange rates are included. Granger causality tests are employed on the oil price variables in relation to economic growth; however no significant direct causality is identified. The net oil price increase measure is selected as the best-fitting price measure and its significance in relation to the system as a whole is tested by means of a Likelihood Ratio test. The next step involves the impulse response and variance decomposition analysis. The results suggest that net oil price shocks have an important effect on real GDP growth, exchange rates and inflation that are all of the predicted sign, as well as serving as a crucial source of volatility to all three variables. On the other hand, the impact on the labour market (i.e. the wage rate variable) is very small and this does not appear to be an important transmission channel. Theoretical justification for the indirect oil price shock impacts is based on the terms of trade, investment uncertainty and inflation arguments that predict the sign and magnitude of the estimated exchange and inflation effects. On the other hand, the sectoral reallocation argument that predicts a significant and negative effect on employment is not supported by the data for the New Zealand economy. The estimated results are comparable to findings noted for several open European economies, such as Belgium and Italy, which are similarly reliant on imported oil and petroleum products.

Overall, both energy consumption and oil prices are identified as important variables for economic growth in New Zealand. The estimated models based on the alternative theoretical concerns allow for several policy implications that New Zealand can be utilised to enhance growth and at the same time follow the global environment and energy-use protocols. These are elucidated in the next section.

6.3 Policy Implications

This study has determined that the dominant direction of causality between the aggregate energy consumption and economic growth in New Zealand is from economic growth to energy consumption, without feedback. Furthermore, these results have been shown to be robust to the choice of model, across two supply-side consumption models and a trivariate demand-side model. The impact of oil price shocks on critical macroeconomic variables has also been examined, with the finding that real GDP is affected directly by net oil price shocks as well as indirectly through the channels of inflation and the effective exchange rate. Only in the case of the labour market, as reflected by the real wage rate, is the hypothesised indirect effect seemingly small for New Zealand. These findings have several implications for economic policies and for the use of energy resources, as well as the wider issues surrounding energy prices.

The results presented in chapter 4 show that energy resources do not Granger cause economic growth in New Zealand, whereas economic growth is a causal determinant of energy consumption. These results confirm the earlier finding of Fatai *et al.*, (2004) and suggest that energy conservation strategies may be enacted without necessarily reducing the economic growth. In the face of binding Kyoto Protocol emissions reduction obligations, the results suggest it may be feasible for the trade-off between economic growth and environmental objectives to be avoided or offset. The findings of this study are very crucial, given the political difficulties that surround the implementation of costly environmental and conservation measures. This is because conservation measures that do not entail economic costs are more acceptable politically, and hence can be implemented more easily and with more chance of success (as noted in chapter 3 – section 3.4). Furthermore, these results suggest that existing policies aimed at the development of sustainable energy resource systems should be encouraged. The reported direction of causality suggests that increasing the role of sustainable resources in total consumer energy may be able to deliver the expected environmental benefits without curtailing economic growth. This result, however, is partially dependent on the nature of the substitution possibilities between fossil fuel and renewable resources. Clearly this excludes some of the important roles of energy in economic systems at present, such as transport fuels and in steel production.

The other important results noted in chapter 4 concern the causality between energy and economic growth and the peripheral linkages of the energy price, capital and labour variables. In particular, the results of the long-run ARDL coefficients suggest that capital and energy are substitutes. This implies that well-formulated investment policies may be useful elements of the response to energy conservation issues such that economic growth impacts of reducing energy consumption are minimised.

The results of chapter 5 point out that oil price effects are not limited to the direct GDP effects as have been assumed in a number of studies. On the contrary, the indirect channels of inflation and exchange rates are simulated to react to oil price shocks with further negative consequences for economic growth. In respect of the inflation channel, this suggests that the Reserve Bank of New Zealand's policy of targeting inflation may need to accommodate the impact of exogenous oil price movements. This is particularly important as the substantial impact of monetary policy on a large number of economic variables is a well known fact of the growth literature. It thus implies the possibility of oil price shocks affecting other vital variables, which in turn suggests a potential cumulative effect that may belie the small contribution of oil to GDP. Similarly the impact on exchange rates has important implications for both importers and exporters, with the projected movement following a price shock harming importers (and benefiting exporters) in the short run. Such movements are likely to impact on GDP through changing the composition of aggregate demand. Given these impacts, policies that seek to provide transparent information on forecasted oil price movements, as well as government responses that are appropriate given the identified cause of the price shock (i.e. transitive or permanent) can guide monetary policy and the behaviour of economic agents in the foreign sector. The impact of such measures may be to reduce the direct impacts of oil price shocks as well as the implied flow-on effects concerning the inflation and exchange rate variables. Last, it should be made clear that the problems deriving from the exogenous nature of oil prices are jointly faced with many of out key trading partners. Therefore, the economic conditions in New Zealand are likely to respond to the changing conditions abroad.

6.4 Further Research

There are further lines of analysis that can be undertaken in the future for energy-growth nexus. While the analysis in chapter 4 indicates a statistically significant causal relationship between total energy consumption and economic growth that is robust to trivariate demand-side and two supply-side model specifications, an area in which further investigation may provide useful insights concerns the disaggregation of total energy consumption data by relevant sectors. In doing so, it would allow the investigation of energy consumption-economic growth causality to proceed to the resolution of individual sector and industry impacts. This is an empirically-challenging process that requires the use of appropriate and comparable measures of economic activity and related variables; however it is crucial to evaluate the specific relationships between disaggregated sectors and energy resources that can inform policy-makers of the magnitude of impacts and the contributions to economic growth. This is vital given that various sectors consume varied compositions of energy resources. Understanding the nature of the individual energy consumption-growth relationships would thus allow for well-informed policies that could target the relatively inefficient use of energy resources. It will be a challenge to comprise the data sets of sufficient length to provide robust results for the information on employment, GDP and trade contributions by the various sectors and industries.

Concerning the issue of oil price variables and their relationship with economic growth, an interesting avenue for further research would consider the use of the Scaled Oil Price Increase (SOPI) and Decrease (SOPD) variables that were noted briefly in chapters 2 and 5. These instruments have appeared in several research studies in the last decade and have provided robust results. Furthermore, the economic theory underlying model development and estimation is sound. The Generalised Autoregressive Conditional Heteroscedasticity (GARCH) methodology could be used to estimate the SOPI or SOPD coefficients, however it would require a longer time series than is available currently. On the other hand, as the model utilises quarterly data, this avenue of further enquiry could be realised in the next few years.

The results presented in this study highlight some of the relationships between energy consumption and economic growth, and oil prices and economic growth, in the context of models constructed using relevant variables that were selected based on the theory. On the basis of the various models determined in chapters 4 and 5, the relationships of energy consumption and oil prices with economic growth appear to be substantial for New Zealand. Accordingly, the relevant policy implications have been noted above. On the other hand, however, some of the relevant extensions to the study presented here imply that further analysis remains to draw firm conclusions on the disaggregated aspects of the energy-growth nexus. Noting the disparity in the existing energy-growth literature highlighted in chapter 2, the results provide the relationship of the energy sector to New Zealand's economic growth and draw policy implications based on these results that policy-makers could find important to develop future policies.

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