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Population Changes and Implications for Economic Growth and the Environment in Australia

A Dissertation submitted
for the award of Doctor of Philosophy

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CERTIFICATION OF DISSERTATION

I hereby certify that the ideas, results, analyses, and conclusions presented in this dissertation, submitted in fulfilment for the award of Doctorate of Philosophy and entitled ‘Population changes and implications for economic growth and the environment in Australia’ are entirely my own effort, except where otherwise acknowledged. I also certify that the document has not been previously submitted, either in whole or in part, for any other award, except where due reference is made.

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To

The departed soul of my beloved father, Gazi Abdul Halim and my elder brother, Gazi Zakir Hossain, who wanted me to do this highest level of learning.

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ABSTRACT

In recent decades, Australia has experienced rapid population growth and changes. These changes in population have varied significantly in a spatial sense and in age structure. However, while the size of the population has been gradually increasing, the proportion of people in the older age groups has increased more than the younger age groups. This transition has resulted in noticeable changes in demography through the ageing of the profile of the Australian population. It is hypothesised that this variation of the age structure has had a significant impact on both the economy and environment. The purpose of the thesis is to examine the impact of population changes on economic growth and the environment over the past 40 years in Australia.

The conceptual framework of this study links the issue of the population–economy–environment relationship with various theoretical and methodological forms. Firstly, population driven economic growth is analysed based on neoclassical and Malthusian theories. Neoclassical theory holds that capital, labour and technology influence the growth of an economy, while Malthusian theory suggests that population can outgrow their resources, if left unchecked. Secondly, a population-led environmental impact assessment is framed by neo-Malthusian theory whereby over-population is treated as a major source of environmental degradation. This also explores the effects of social systems on the environment, and vice versa, with the use of structural human ecology (SHE) theory. Lastly, the economy–environment relationship is analysed on the basis of ecological modernisation theory (EMT), which posits that economic growth benefits the environment, leading to the Environmental Kuznets Curve (EKC) hypothesis.

Utilising the concept of neoclassical growth theory, this study initially examines the impact of changes in the age structure of the population on economic growth. Estimates are obtained from the dynamic ordinary least squares (DOLS), fully modified ordinary least squares (FMOLS) and auto-regressive distributed lag (ARDL) models simultaneously. The overall result implies a significant negative impact of an increased dependency ratio on real gross domestic product (GDP) per capita in Australia. A lower dependency ratio indicates a higher ratio of workers per capita and thereby a greater supply of labour to the economy.

Secondly, the population-based stochastic impacts on population, affluence, and technology (STIRPAT) models are estimated using ridge regression, in the context of neo-Malthusian theory. In the analysis, the ecological footprint (EF) per capita is applied as the dependent variable, which measures the degree of environmental impact caused by human activities. The result shows that population size has the most significant effect, followed by GDP per capita, on EF.

Thirdly, the relationship between economic growth and environmental quality is examined using both panel and time series data, based on the theoretical perspective of EMT. Carbon dioxide (CO_2) emissions are used as the explanatory variable for estimation purposes. The EKC hypothesis is tested using a Cobb–Douglas production function formulation, with ARDL bound and Johansen–Juselius co-integration tests for confirmation. Both tests confirm the long-run dynamic relationship amongst the variables. The study also found that both economic growth and energy consumption are emissions-intensive and that the EKC hypothesis is valid for Australia.

Finally, the dynamics of population changes and their implications for regional economies and the environment are discussed, based on a comprehensive review of the literature. The review findings illustrate that the dynamics of population changes enhance economic opportunities and simultaneously put pressure on the regional environment.

Overall, the study finds evidence of the impact of population size and age structure on the environment, which is consistent with neo-Malthusian and structural human ecological theories. On the other hand, the impact of real GDP per capita increases has a negative impact on environmental quality, which does not meet the expectations of neo–classical theories and refutes the EKC hypothesis. Considering the findings, Australia should work towards sustainable population management that can be accommodated without damaging the environment. It also needs population policies that target increases in skilled working age groups in order to counteract the problems associated with an aging population, especially in regional Australia.

An efficient trade-off between environmental protection and economic benefits could be established. To this end, both CO_2 and EF should be reduced through changing consumption patterns, improving the efficiency of resource use, and cleaner technology choices. In addition, more emphasis needs to be placed on utilising renewable resources, such as biomass, biogas, biofuels, hydro, solar, and wind power, which would be more environmentally and economically sustainable options for Australia.

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Abbreviations

ABARE	Australian Bureau of Agricultural and Resource Economics
ABARES	Australian Bureau of Agricultural and Resource Economics and Sciences
ABS	Australian Bureau of Statistics
ACT	Australian Capital Territory
ADF	Augmented Dickey–Fuller
ADF-GLS	Augmented Dickey–Fuller Generalised Least Square
AIC	Akaike Information Criterion
ARDL	Auto–regressive Distributed Lag
ARIMA	Auto–regressive Integrated Moving Average
ASGS	Australian Statistical Geography Standard
BC	Bio capacity
BRIC	Brazil Russia India and China
CCCU	Carbon Capture Utilisation and Storage
CIS	Commonwealth of Independent States
CO_2	Carbon Dioxide
CO_{2-e}	CO_2 equivalent
CSIRO	Commonwealth Scientific and Industrial Research Organisation
CUSUM	Cumulative Sum of Recursive residuals
CUSUMsq	Cumulative Sum of Square of Recursive residuals
CSF	Carbon Sequestration Factor
DOLS	Dynamic Ordinary Least Squares
DR	Dependency Ratio
ECM	Error-Correction Model
EF	Ecological Footprint
EMT	Ecological Modernisation Theory
EQF	Equivalence Factor
EKC	Environmental Kuznets Curve
FMOLS	Fully Modified Ordinary Least Squares
GCC	Gulf Co-operation Council
GCF	Gross Capital Formation

GDP	Gross Domestic Product
GNP	Gross National Product
GFN	Global Footprint Network
GHGs	Greenhouse Gases
GRDC	Grain Research and Development Corporation
HQIC	Hannan–Quinn Information Criterion
IPAT	Impact of Population, Affluence and Technology
IPACT	Impact of Population, Affluence, Consumption and Technology
IPCC	Inter-governmental Panel on Climate Change
IPS	Im Pesaran and Shin
IRFs	Impulse Response Functions
IYF$_S$	Inter-temporal Yield Factors
KPSS	Kwiatkowski Phillips Schmidt and Shin
LGA	Local Government Area
LLC	Levin Lin and Chu
LM	Lagrange Multiplier
LR	Likelihood Ratio
MENA	Middle East and North Africa
NO_2	Nitrogen Dioxide
NSC	National Sustainability Council
NSW	New South Wales
OECD	Organization for Economic Co-operation and Development
OLS	Ordinary Least Squares
PhD	Doctor of Philosophy
PPP	Purchasing Power Parity
RA	Remoteness Area
RAI	Regional Australia Institute
RR	Ridge Regression
SA2	Statistical Area Level 2
SBIC	Schwartz–Bayesian Information Criteria
SHE	Structural Human Ecology
SO_2	Sulphur Dioxide
SR	Savings Rate

STIRPAT	Stochastic Impacts by Regression on Population Affluence and Technology
UK	United Kingdom
US	United States
VAR	Vector Autoregressive
VEC	Vector Error Correction
VIF	Variance Inflation Factor
WB	World Bank
WWF	World Wildlife Fund
WWII	World War II
YDR	Yangtze Delta Region
YF_S	Yield Factors

CHAPTER 1

INTRODUCTION

1.1 Background

Environmental changes, resulting from human and economic activities over the past two centuries, have emerged as a global concern. The world has been confronting the challenge of unprecedented growth of the economy on the one hand, while simultaneously attempting to maintain environmental quality on the other. Environmental quality has come to the forefront of contemporary issues for both developed and developing countries, primarily as a result of global climate change. In the light of the importance of addressing climate change issues, an enormous volume of research has investigated the major determining factors of environmental impacts. Given their mixed and inconclusive findings, this study investigates the impact of population changes on the economy and the environment in Australia and offers a diverse set of policy recommendations.

In general, population changes are assumed to have a powerful impact on economic growth and the environment. A growing population may lead to higher gross national product (GNP) based on the argument that more workers lead to increased production, and this increase in production leads to more output and consumption, and, in turn, increased incomes. Inversely, population changes can impede economic growth because a larger population reduces the available resources to satisfy the demands of the larger population. A number of environmental difficulties arise throughout the development process due to excessive use of natural resources. Sometimes, economic growth fuels technological innovations and changes in lifestyle that improve environmental quality (Simon 1981; Beckerman 1992). Thus, there is significant interaction among population changes, economic growth, and environmental quality, as larger populations facilitate economic growth, but also place pressure on the environment.

The relationship between population changes, economic growth, and environmental quality is not simply a matter of the number of people in a country, but also involves the per capita resources they use, the technology advancement level, the age structure of the population, the level of the development process and the magnitude of emissions (Hugo 2013). In recent decades, the dynamic changes of fertility, mortality, and immigration intakes in Australia have produced a fundamental change in the population age structure. The uneven distribution and the changing age structure of the population are now major concerns for economic growth and for ensuring environmental quality in Australia (Race et al. 2011).

The Australian population has been experiencing a demographic transition since the 1960s, whereby the proportion of people in the older age groups has increased and the proportion in younger age groups has decreased. The most noteworthy recent change in the population age structure in Australia is the increasing proportion of elderly people. According to Australian Bureau of Statistics (ABS), Australia's population was a little under 4.5 million in 1911, and by 2015 it was 23.92 million (ABS, 2015). The size and structure of its population over the past 100 years has been influenced by World Wars, the Great Depression, the post-WWII baby and immigration booms, and contemporary social and economic changes (ABS 2012). These changes in population have impacted on both the economy and the environment.

In Australia, for instance, many human activities, including the use of natural resources, have a direct impact on the environment. Australia ranks in the top 10 countries globally in respect to GHG emissions per capita (National Sustainability Council (NSC 2013). Raupach (2007) estimates that CO_2 emissions from fossil fuels are the principal driver of climate change, and he also adds that Australia, with only 0.32% of the global population, accounts for 1.43% of the world's CO_2 emissions. Australia is producing more CO_2 emissions to achieve its economic growth than almost any other major economy. Its high greenhouse gas emissions intensity per unit of gross domestic product (GDP) is fuelled by the country's heavy reliance on coal-fired energy. These high emissions are mainly the result of the high emissions intensity of energy use. Understanding the impacts of energy use and economic growth on CO_2 emissions is therefore a useful initiative in formulating effective policies for emissions reduction while maintaining positive and sustainable economic growth. The role of energy use and economic growth on CO_2 emissions is not well understood in the literature as yet, both in terms of theory and empirical data.

With the rapid growth in industrialisation over the past 200 years, the world has witnessed a significant rise in energy demand that has made the trade-off between economic growth and environmental quality increasingly difficult, as this massive demand is met with energy production dominated by the extraction of non-renewable fossil fuels, which produce GHG emissions (Ahuja & Tatsutani 2009). Despite significant efforts by countries to reduce emissions through various measures, over 80% of global energy is still produced from fossil fuels, reported by World Economic Outlook (WEO 2014). As a consequence, environmental quality has deteriorated significantly in many countries, including Australia.

The ecological footprint (EF) is a more comprehensive measure of pollution and represents a powerful indicator of anthropogenic pressure on the environment (Vackar 2012). It measures the biological productive land and sea area needed to meet consumption needs, and also includes all of the waste of a given population (Wackernagel & Rees 1996). Australia has the seventh biggest EF per capita in the world revealed by World Wildlife Fund (WWF 2012). The per capita EF and biocapacity (BC) are gradually decreasing in Australia; however, the rate of decrease of EF is lower than biocapacity, indicating the gradual degradation of the environmental quality in Australia (Uddin et al. 2015). However, no study to date has used this indicator to analyse the economy–environment relationship in Australia.

Recognising the comprehensiveness of EF as a measure of pollution, many recent studies (Al-Mulali et al. 2015c; Wang et al. 2011b; Galli et al. 2012a; Mostafa 2010; Caviglia-Harris et al. 2009; Bagliani et al., 2008b) have used EF as an indicator for environmental quality. Therefore, in order to provide a better and fine-grained understanding of the relationship between environmental quality and economic growth, this thesis has considered both CO_2 emissions and EF per capita as environmental quality variables in the analysis.

The impacts of human activities on the economy and the environment are not new phenomena. In the early 1970s, Ehrlich and Holdren (1971) employed the IPAT (Impact of Population, Affluence and Technology) identity to assess the magnitude of human impacts on the environment. The IPAT model defines the environmental impact as the product of population (P), affluence (A) and technology (T). This model was further modified by York et al. (2003b) into STIRPAT (Stochastic Impacts by

Regression on Population, Affluence and Technology). A number of methodologies have been used to measure the degree of environmental impacts. However, there is no literature that has attempted to reveal the major driving factors of these environmental impacts by using a STIRPAT model in the context of Australia.

1.2 The Case of Australia

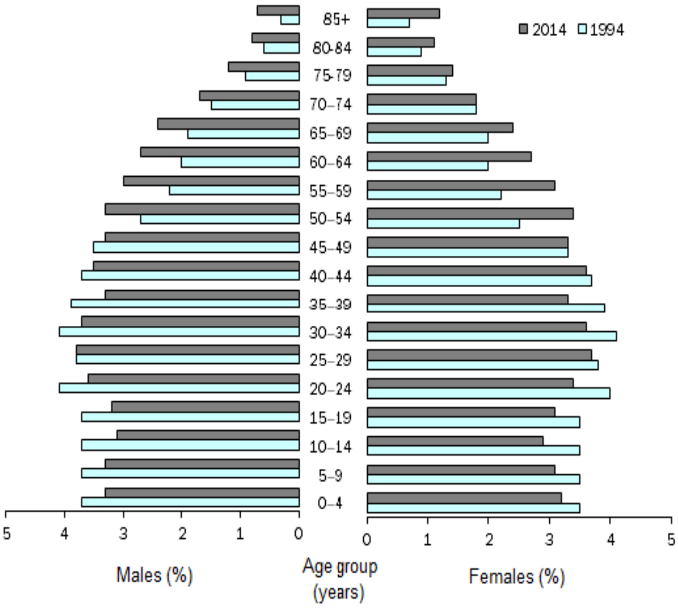
The global population grew very slowly until the mid-19th century because of its slightly higher birth rates than death rates (World Bank 2009). Then the industrial revolution influenced the factors that affected birth and death rates and changed this trend into a dramatic expansion of the world's population. However, during this time, economic growth was experienced in all its magnitude and varied nature. Population and economic growth in the world simulteneously increased significantly in the period of 1800 to 1950, contrasting with the period of previous slow growth rates. Then, during the 50-year period from 1950 to 2000, the global population doubled, agricultural production tripled, and GDP and energy use quadrupled (World Bank 2015). Population Reference Bureau (PRB) estimated that the world population growth rate slowed from 2.1% in the late 1960s to 1.2% today, but the size of the world's population has continued to increase from 3 billion in 1960 to 7 billion in 2011 (PRB 2011).

Australia has also experienced population growth during this time. The current population growth rate is 1.4%, reported in March 2015. Although this rate has slowed from its peak in 2008-09, and just below the 20-year average growth rate, it is still higher than the global rate. This rate is also faster than that of other developed countries (UK 0.8%, USA 0.7%) and even higher than high birth rate countries such as Bangladesh (1.2%), India (1.3%) and Vietnam (1.1%) (World Bank 2015).

The Australian population has been experiencing a demographic transition since the 1960s, where the proportion of people in the older age groups has increased and the proportion in younger age groups has decreased (ABS 2015). The most noteworthy recent change in the population age structure in Australia is the increasing proportion of elderly people. Due to the increase in life expectancy from 70.82 years in 1960 to 82.24 years in 2014, along with a decreasing fertility rate, the proportion of elderly people has increased (ABS 2014). Such a transition has resulted in noticeable changes in demography in the form of an ageing of the Australian population.

Population ageing is an obvious demographic characteristic of most developed countries. It is related to both sustained low fertility, which results in proportionately fewer children, and increasing life expectancy, which results in proportionately more elderly people. In Japan, Italy, Greece, Sweden and Hong Kong, the number of people aged 65 years and over already exceeds the number of children aged 0–14 years (ABS 2014). In Australia, based on the latest population statistics, the number of people aged 65 years and over is projected to exceed the number of children aged 0–14 years around the year 2030 (ABS 2014).

Figure 1.1: Population Pyramid 1994-2014



Source: ABS, 2015

The population pyramid (Fig. 1.1) depicts the sex and age structure of Australia's population during the period from 1994 to 2014. It channels the population on the horizontal axis, with females shown on the right and males on the left. The female and male populations are divided into 5-year age groups, sketched on the horizontal axis along the vertical bars. The oldest age groups appear at the top and the youngest at the bottom. The changes of fertility, mortality, and net migration make the pyramid gradually evolve over time.

The young age dependency ratio (ratio of people aged 14 years or less to people aged 15–64) has gradually decreased from 49.31% in 1960 to 28.86% in 2014, due to a decrease in the number of young people along with an increase in the working age population. Although the working age population has increased, the elderly dependency ratio (ratio of people aged 65 years and over to people aged 15–64) has also gradually increased from 14.05% in 1960 to 24.14% in 2014. This is because the number of elderly people has increased more rapidly than the number of young people. The age dependency ratio (the sum of the young and elderly dependency ratios) has gradually decreased from 63.35% in 1960 to 47.71% in 2009, and then increased to 50.99% in 2014 (Feenstra et al. 2015).

The dependency ratio of old to young has changed in the opposite direction. A lower dependency ratio indicates a higher ratio of workers per capita and thereby a greater supply of labour to the economy. It also implies fewer people to feed and potentially more savings being accumulated for productive investment in the economy. Population changes are not simply a function of economic change. It is often regarded as the static backdrop against which economic, social, political and environmental forces are played out. Regional Australia Institute (RAI) explained that the dependency ratio plays an important and complex relationship with economic growth in both cause and effect directions (RAI 2015b). Economic growth is also often associated with the use of natural resources. Jones (1997) recognised that each increase in population places additional strain on natural resources. Along with the population changes, there are numerous socio-economic variables that impact the lifestyles of the population.

Australia’s GDP has grown by more than 3% per annum in each of the last three decades. It is therefore assumed that this rate of growth will continue into the future. The high correlation between energy consumption and real GDP contributes to high per capita GHG emissions.

Australians are consuming more than three times their fair share of the planet’s natural resources. If they continue these consumption patterns, they will face an ecological overshoot that will have far-reaching future consequences for people and the environment. In 2014, Australians had one of the largest environmental footprints per capita in the world, requiring 6.25 global hectares (gha) per person, which is the 13th largest EF per capita in the world. According to the Living Planet Report (LPR), this is 2.4 times the average global footprint (2.6 gha) and well beyond the level at which the planet can regenerate on an annual basis; which is an equivalent of about 2.1 global hectares per person per year (LPR 2014).

While this is a slight improvement on where it was in 2012, when the report had Australia ranked 7th, it still means Australians are using more natural resources than most other countries (LPR 2014). CO_2 emissions have been the dominant component of humanity's EF for more than half a century. In 1961, CO_2 was 36% cent of the total footprint but by 2010 it comprised 53% (LPR 2014). The most significant factor contributing to the Australian EF is CO_2 emissions from fossil fuels, followed by industrial and residential energy use (Wiedmann 2008).

1.3 Purpose and Objectives

This research firstly aims to examine the relationship between population changes and economic growth. Secondly, it investigates the impact of humans on the environment. Finally, it examines the interaction between the economy and the environment. Dependency ratio is used as a proxy for the changes of population age structure and EF and CO_2 emissions as a proxy for environmental quality. The overall objective of this study is to examine the interaction among population changes, economic growth and environmental quality, using both time series and panel data in Australia through an examination of the following research questions:

1. What is the impact of population changes on economic growth in Australia?
2. What is the nature of the relationship between dependency ratio, savings rate, trade openness and capital formation?
3. How can the impact of population on the environment be assessed?
4. Are there any other factors associated with the population–environment relationship?
5. What is the relationship between EF and economic growth?
6. What are the directions of causality among EF, economic growth, financial development and trade openness?

7. What is the dynamic relationship among CO_2 emissions, energy consumption and economic growth in Australia?

8. Does variation of population changes have an impact on regional economies and the environment in Australia?

1.4 Justification for the Research

Australia has been experiencing demographic changes in recent decades as a result of declining fertility, changing migration patterns, mobility and ageing of the population. The age structure of Australia's population has been changing dynamically — the total dependency ratio has gradually decreased, despite an increase in the elderly dependency ratio, due to a rise in net migration and working-age population. The hypothesis is that the population changes have a flow-on effect on both the economy and the environment, and vice versa. However, research to date has not established a link among population changes, the economy and the environment in Australia.

There is a scarcity of empirical work on the various measures of impact of population changes on the economy and the environment. Earlier studies in Australia are included with other nations' measures. These are outdated in the present context of measuring human impacts on the economy and the environment. Most of the previous empirical studies have used cross-country panel data to estimate the relationship between population, income and environmental quality. Time series studies are fewer in number and their findings have different implications. In support of this view, Dinda (2004) declared that time series data analysis provides a more complete picture, Lieb (2003) mentioned that time series analyses are more appropriate than cross-country studies, and Lindmark (2002) argued that cross-country studies provide only a general understanding of how the variables are related to each other, and this offers little guidance for policymakers. This research fills the gap by incorporating recent data and enhanced econometric techniques.

The dependency ratio which represents the age structure of the population can capture the overall impact of demographic changes in a more appropriate way. In spite of many cross-country and also country specific studies, the importance of dependency variables in economic growth has not been highlighted in the literature. It is also evident that age structure, rather than population size, has a significant impact on economic growth, but studies showing this impact in Australia are limited. Relatively few researchers have considered the dependency ratio as a key variable in their studies on economic growth (Wei & Hao 2010; Fang & Wang 2005; Kelley & Schmidt 1995). Most studies have been cross-country comparisons.

Additionally, most studies have been conducted to measure population and economic growth impact on environmental problems using only a single indicator, such as CO_2 emissions (Madu 2009), energy consumption (Romero et al. 2009), or transport energy (Liddle 2013). Although the EF has proved to be a useful measure to describe the environmental impacts caused by human activities, there are no studies using this indicator in Australia. The few who have used EF as a proxy for environmental impact used cross-country data (Bagliani et al. 2008b; Caviglia-Harris et al 2009; York et al. 2004, 2009; Hervieux & Darne 2014; Marquart-Pyatt 2015; Jorgenson & Burns 2007; Jorgenson & Rice 2005; Jorgenson 2003; Niccolucci 2012; Vackar 2012). Very few studies (Bagliani et al. 2008a; Lenzen & Murray 2001; Mingquan et al. 2010) have measured environmental impact using single-country data with EF as a dependent variable.

Furthermore, the hypothesis that economic growth could be a remedy to environmental problems at a stage of economic development when people become wealthier, is known as the Environmental Kuznets Curve (EKC) hypothesis and was postulated by Kuznets (1955). Nonetheless, the empirical evidence on the inverted U-shape relationship between EF and income is still inconclusive in the literature, and there is a scarcity of research in the Australian context.

Finally, an integrated study provides useful information to assist in the assessment of the interaction among population changes, economic growth and the environment. There is no empirical research that examines the interaction among population changes, economic growth and environmental impacts in Australia using the STIRPAT method, which is popular in the population economics literature. Ultimately, this study overcomes the gaps in the literature by employing alternative modelling frameworks, longer samples than earlier studies and using recent advances in econometric techniques providing an extension of the analysis. This analysis will help explain how population changes impact both on economic growth and the environment, and to examine whether economic growth could be detrimental to environmental quality. Related policy implications are also discussed.

1.5 Scope of the Research

The study focuses on the impacts of population changes on economic growth and environmental quality in Australia. The study is interested in how the impact of population changes on both the economy and the environment can be assessed. It aims to recognise the EKC hypothesis based on the link to the economy and the environment. The study would also like to discover the impact of population changes on regional economies and the environment in Australia. The thesis addresses the research questions empirically, in the context of the Australian economy. Age structure or dependency ratio is used for population changes, real GDP per capita is used for economic growth, and EF and CO2 emissions per capita are used for environmental quality indicators in the respective models. Both theoretical and empirical viewpoints have been applied with time series and panel data in the thesis, which seems to have enlarged the scope of the thesis, even though the boundary of the thesis is considered to be tightly defined. The research study is limited as it focuses only on the Australian economy from 1971 to 2014. This study has found a regional level data limitation in using the STIRPAT analysis in the study.

1.6 Conceptual Framework

In the literature, the relationship between population changes and economic growth revolves around a number of distinct views. One view is that population changes, in and of themselves, are a driver of economic growth. The argument in favour of this view is that the larger population stimulates innovation, which in turn expands the size and scale of economy. In addition, it can facilitate economic growth by providing skilled labour needed for economic activity in a country. The eminent scholars who share this view include Boserup (1965), Kremer (1993), Simon (1976), Kuznets (1960), and Grossman and Helpman (1991).

In contrast, population changes may impede economic growth if one takes the view that a larger population reduces available resources. For example, Daley and Lancy (2011) demonstrate that population growth is not a substitute for economic potential and does not create growth, in and of itself. Rather, population is a key element and facilitator of development but not a simplistic cause of the development. A number of contemporary researchers also demonstrate that the population as a whole is not an important determinant of economic growth, but that instead the dependency ratio, which represents the age structure of the whole population, plays the critical role instead. Proponents of this view include Guest (2011), Mason (2003), Kelley and Schmidt (2005) and Prskawetz et al. (2004). The conceptual framework, which is outlined in Figure 1.2, depicts the complex relationships between the triangle of population changes, economic growth and environmental quality.

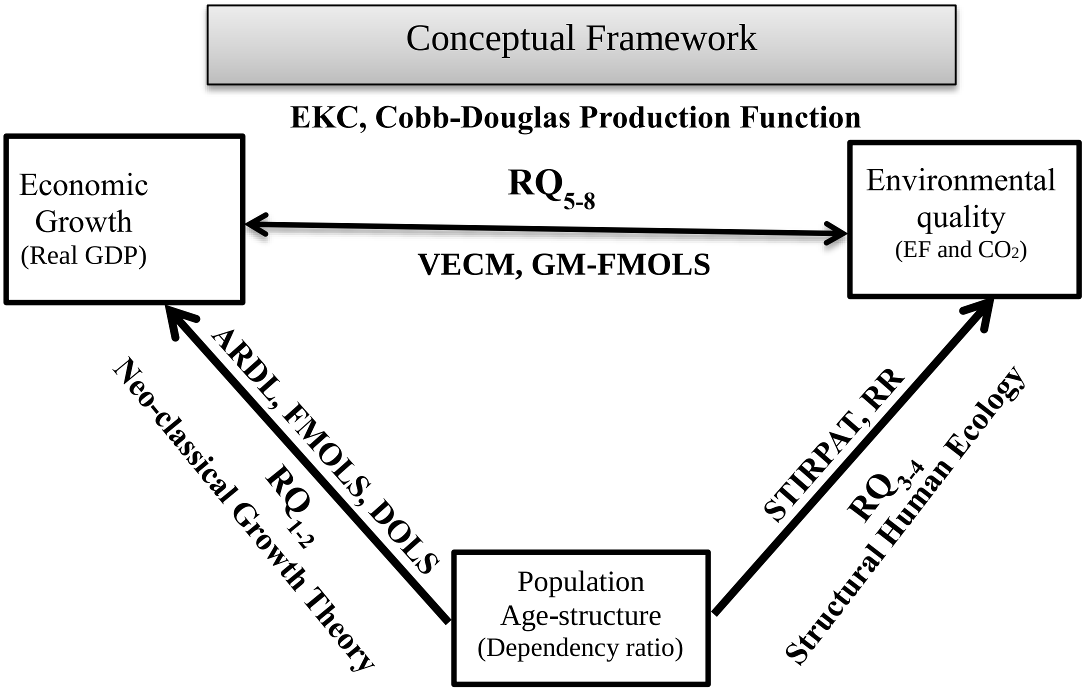


Figure: 1.2 The Conceptual Framework of the Thesis: The interaction among Population changes, Economic growth and Environmental quality.

Environmental quality is also often seen simply as a function of population growth. Population growth puts pressure on the environment through excessive exploitation. Moreover, population growth enhances innovation, which potentially lessens the negative impacts on the environment. Likewise, economic growth has both negative and positive impacts on the environment. The limit of impact of economic growth on the environment depends on the degree of natural resources use, technological advancement, and the level of emissions.

Finally, the framework underlines the relationship between population changes and the economic growth of Australia. To identify this relationship, this study employs the auto-regressive distributed lag (ARDL), fully modified ordinary least squares (FMOLS) and dynamic ordinary least squares (DOLS) methods in line with neo-classical growth theory. To examine the impact of population changes on environmental quality, this study uses the EF as a dependent variable, which represents the environmental quality indicator. The STIRPAT model is estimated with a simple OLS and then a ridge regression (RR) to determine the other factors responsible for environmental quality according to structural human ecology theory. The interaction between the economy and the environment is tested using the EKC and Cobb–Douglas production function approaches by using panel vector error correction (VEC) model, group mean fully modified ordinary least squares (GM–FMOLS) estimation techniques under both time series and panel data referencing ecological modernisation theory (EMT).

1.7 Methodological Approaches and Organisation of the Thesis

This thesis incorporates a series of papers that have been published, manuscripts that have already been accepted for publication, and manuscripts that have been under review during the period of candidature. In addition to this introductory chapter, this thesis consists of six analytical chapters. All the chapters are strongly linked to each other, in a logical order, under the three keywords of population, economy and environment and each chapter is also separated in the context of reviewing literature, incorporating methodologies and addressing specific research problems(s). The dependency ratio, which represents the population age structure, has been used as a key determinant of population changes in Australia. On the other hand, real GDP per capita has been used as a proxy of the economy of Australia, and finally, EF and CO_2 emissions have been used as indicators of the environmental quality of Australia.

Time-series econometric techniques are applied in Chapters 2 to 4, as well as in Chapter 6, and a panel data technique is applied in Chapter 5.

Chapter 2 outlines the impact of population changes on the economy, while accommodating other variables, such as savings rate, capital formation and trade openness. The major econometric approaches, the augmented Dickey–Fuller

Generalised Least Square (DF–GLS) test (Elliot et al. 1996) and the Kwiatkowski, Phillips, Schmidt and Shin (KPSS) test (Kwiatkowski et al. 1992) are used for assessing stationarity of the series; Johansen's (1988) co-integration test, and Pesaran and Shin's (1998) and Pesaran et al.'s (2001) ARDL bounds tests are used for assessing co-integrating relationships; FMOLS (Phillips and Hansen 1990) and DOLS (Stock and Watson 1993) are used for analysis of the co-integrating vector of the variables, based on the framework of neoclassical growth theory (Barro and Sala-i-Martin 1992). The possibility of structural breaks in the time series data, and their probable impacts is also tested by sequential Bi–Perron test. In addition, the stability of the model is verified by cumulative sum of recursive residual (CUSUM) and sum of squares of recursive residual (CUSUM of squares) tests.

Chapter 3 describes the impact of human activities on environmental quality by estimating the STIRPAT model (York et al. 2003b) based on the framework of structural human ecology theory (Duncan 1961; Catton 1987). The analysis starts with a simple OLS regression; then ridge regression (RR) (Hoerl & Kennard 1970) was used to accommodate the multicollinearity problem among the data. A combination of theory, model and estimation strategies are applied in this chapter, which is the first integrated approach of this kind in an Australian study and includes EF as a dependent variable in the model. The other variables used are population size, urban population concentration, non-dependent population ratio, affluence or GDP per capita, industry share of GDP, and CO_2 emissions per capita.

Chapter 4 examines the relationship between real income and environmental quality using the EKC hypothesis. The Johansen (1988) co-integration techniques and VEC model are simultaneously employed to examine both the long-run and short-run relationship between real income and environmental quality variables. The degree of environmental impacts of economic activity is measured by EF per capita as the explanatory variable, while real GDP per capita, and its quadratic and cubic forms, are used as predictor variables in the OLS regression model.

Chapter 5 is the continuation of chapter 4 but is unique in the ways that it incorporates panel data analysis to confirm the outcomes of Chapter 4. The chapter conducts Levin, Lin and Chu (LLC), Im, Pesaran and Shin (IPS), and Fisher–ADF tests for unit root analysis and Pedroni (four within-group; panel-υ, panel-ρ, panel-ρρ and panel-ADF and three between-group; group-ρ, group-ρρ and group-ADF) tests to check whether the panel data are co-integrated. Then this chapter incorporates GM–FMOLS method to reveal the co-integrating vector of regression.

Chapter 6 is the extension of Chapter 5, where an alternative dependent variable, CO_2 emissions, was used as indicator of environmental impact, instead of EF, in the framework of the Cobb-Douglas production function (Cobb-Douglas, 1928), where population and energy consumption are used as explanatory variables. Johansen–Juselius co-integration and ARDL bounds tests have been used to confirm the long-run dynamic relationship among the variables. DOLS and FMOLS methods also were used to check the robustness of the results. In addition, it incorporates impulse response functions (IRFs) and variance decomposition analysis for assessing the impacts of shocks from one variable to another variable.

In regional Australia, there is an enormous spatial variation and there are significant changes in age structure of the population. Has this variation and these changes in age-structure had significant impacts on the regional economy and environment in Australia? To answer this question, Chapter 7 of the thesis offers a critical review of the literature. The aim of this review is to provide an overview of population dynamics and their impacts on regional economies and the environment, which need to be compared to the empirical results obtained in the previous chapters of the thesis.

Each analytical chapter accommodates a relevant economic theory, estimation model, sources of data, and estimation techniques in detail. The econometric software STATA 12 and EViews 8 are used to produce the output of these estimators of the thesis.

Finally, chapter 8 provides an overview of the results, policy recommendations, key contributions to the literature and future research directions.

CHAPTER 2

POPULATION CHANGES AND ECONOMIC GROWTH

Summary: This chapter examines the relationship between age structure and economic growth, incorporating savings rate, capital formation and trade openness for Australia. Using data for the period 1961–2014, the dynamic ordinary least squares and fully modified ordinary least squares methods are applied to investigate the long-run relationship, and the auto-regressive distributed lag model is used to investigate both the short-run and long-run relationship amongst the variables. Each of the three models confirms, to varying degrees, the long-run relationship between the dependency ratio, savings rate, trade openness, capital formation and real gross domestic product (GDP); however, no significant short-run relationship is found. The recently developed bounds testing approach and the Johansen–Juselius maximum likelihood approach are used to reveal that a co-integration relationship exists among the variables. The overall result implies that changes in population age structure had a significant impact on real GDP per capita in Australia over the study period. The impact is also influenced by savings rate, trade openness, and capital formation (in order of magnitude). However, advantages of the age structure may disappear in the near future due to the rapid increase in the elderly dependency ratio. This may lead to a slowdown in GDP growth in the economy. In light of the demographic challenges facing Australia, policy makers need to formulate demographic and economic policies encouraging a lower dependency rate and higher savings rate, and a higher degree of capital formation and trade openness to enhance economic growth rates in the future. Australia needs a demographic policy that targets increases in the skilled working age population in order to counteract the problems associated with an ageing population.

2.1 Introduction

In general, population changes are assumed to have a powerful impact on economic growth. In the literature the relationship between population changes and economic growth has been widely investigated by economists, demographers and social scientists. However, there is continuing debate about the effects of demographic changes on economic growth. The debate revolves around two distinct views: those who believe population changes restrict economic growth (Barro 1991; Mankiw et al.

1992; Solow 1956; Mason 1988; Smith 1776) and those who believe they promote economic growth (Boserup, 1965; Kremer 1993; Simon 1976; Kuznets 1960, 1967; Grossman & Helpman 1991).

Some researchers (Solow 1956; Malthus 1826; Smith 1776) view that population changes impede economic growth as the larger population reduces available resources. The pioneer of population theory, Malthus (1826), stated that population changes keep pace with per capita output growth. In line with the Malthusian point of view, Solow (1956) implied that higher population growth per se would be detrimental to economic development. Smith's (1776) view was similar, arguing that population growth is clearly a consequence and not a cause of economic growth.

In contrast, some researchers (Kuznet 1960; Kremer 1993) believe that population changes intensify economic growth as the larger population stimulates innovation, which in turn expands the size of the economy. Kuznets (1960) highlighted the positive effects of population changes on economic growth through increased production, consumption and savings. Kremer (1993) found a positive relationship between larger populations and faster improvements in living standards.

The third group of researchers view that demographic changes have few economic consequences. Ehrlich and Lui (1997), Feyrery (2002), and Landreth and David (2002), in their cross-country studies, provide evidence to support this contention.

The many demographic variables that can potentially affect an economy — such as fertility rate, life expectancy, population size, population growth and population density – have been fully investigated in the literature. Each of these variables alone cannot capture the full effect, since each captures only one part of the demography of a population. However, it is contended that the dependency ratio, which represents the age structure of a population, can capture the overall impact of demographic changes in a more appropriate way. To explore the effects of changing demographics on economic performance, the dependency ratio may be considered as a well-defined index of population age structure.

Relatively few researchers have considered the dependency ratio as a key variable in their studies on economic growth (Wei & Hao 2010; Fang & Wang 2005; Kelley & Schmidt 1995). The implication is that a higher working age population leads to a lower dependency ratio — with a lower dependency ratio indicating a higher ratio of workers per capita and thereby a greater supply of labour in the economy. It also implies that there are fewer dependants (i.e. fewer people to feed), as the working age group bears the responsibility of supporting dependants, which enables potentially more savings being accumulated for productive investment in an economy. A lower dependency ratio raises savings, and the mobilisation of savings into investment forms capital, and capital formation then leads to further economic growth.

Inspired by the research findings of Prskawetz et al. (2004), the motivation for including the dependency ratio instead of the growth rate of a population is that the growth of the working-age population is affected by the level of savings. Inversely, Bloom et al. (2003) empirically confirmed that the level of savings is affected by the age structure of a population. This study uses the dependency ratio as a proxy for demographic changes and savings rate changes in order to study their effect on economic performance in Australia over the past 45 years.

Coale and Hoover (1958) were reluctant to assume that the savings rate was influenced by the impact of demographic changes on economic growth. However, evidence presented more recently suggests that this assumption has some support (Song 2013). Researchers now claim that a high dependency ratio in many countries restricts the ability of the economy to generate the savings needed to sustain economic growth (Mason 1988, 2003).

With changes to the dependency ratio, the impacts of population aging on economic growth become more significant in Australia. Hence, it is a suitable time to examine the interdependency among the changes in age structure, as a result of population aging and savings, and other related variables, such as trade openness and capital formation. A primary objective of this chapter is to determine the long-run relationship between the population age structure and economic growth. The study assumes the age dependency ratio is a proxy for demographic changes.

Furthermore, previous empirical research on the influence of demographics on economic performance has paid little attention to time series co-integrated data for a single country. The age structure of Australia’s population has been changing dynamically — the total dependency ratio has gradually been decreasing despite an increase in the elderly dependency ratio, due to a rise in net migration and working-age population. This study uses non-stationary time series data for Australia, for the period 1971–2014, to reveal the effects of population age structure and savings rate on economic growth.

The remainder of this chapter is organised as follows. Section 2.2 presents a review of the relevant literature; Section 2.3 explains changes in the age structure of Australia's population over the study time period; Section 2.4 introduces the models and estimation strategies, as well as the data and its sources; Section 2.5 outlines and discusses the results of the study; and Section 2.6 concludes the study.

2.2 Review of Literature

The study of population age structure and its impact on the economy has drawn much attention from researchers and policymakers from a number of disciplines. Changes in the population age structure affect economic growth in different ways and inversely, economic growth itself has an impact on population changes. The size of a population is not as important for economic growth as either the age distribution or dependency ratio of the population (Guest 2011). Mason (2003) found a negative correlation between the size of a population and economic growth. Kuznets (1960) observed that per capita output increased with increases in population. Kelley and Schmidt (2001) found both positive and negative effects of population changes on economic growth.

Kaspura (2011) found that population growth impacted the economy as a whole and not just per capita income. Similarly, Stilwell (1997) suggested that a growing population leads to higher gross national product; he argued that more workers leads to increased consumption, and this increase in consumption leads to more output, and in turn, increased income. Conversely, Feyrery (2002) did not find any significant influence of population growth.

Kelley and Schmidt (2005) stated that total population has no impact on the economy as a whole, whereas changes in the age structure of a population have a significant impact, because the increase in total population does not necessarily indicate an increase in the labour force. Prskawetz et al. (2007) and An and Jeon (2006) reached similar conclusions about the positive effect of population age structure on economic growth, but their findings were not supported by de la Croix et al. (2009). Bloom et al.

(2001) showed that working age population has a positive and significant effect on GDP per capita.

Bloom and Williamson (1998) investigated the nature and magnitude of the contribution of age structure to economic growth for East Asia. They found that a decrease in the dependency ratio contributed to economic growth in East Asia; on the other hand, they showed that countries in South Asia are projected to gain from their age structure changes in the future. Demographic change also accounted for a large portion of Ireland’s economic performance in the 1990s (Bloom & Canning 2003). In contrast, Bloom et al. (2004) explained that Africa’s increasing fertility rate explained its poor macro-economic performance.

Using panel data, Kelley and Schmidt (1995) found that the dependency ratio had a significant effect on the growth rate of per capita output during the 1970s and 1980s in Europe. Similarly, Becker et al. (1999) revealed that the working age population had a greater positive impact on per capita output than the total population. In Barro’s (1991) model, the growth rate of per capita output is positively related to a lower fertility rate, which reduces the adverse savings rate impact that results from a high young dependency ratio. Mason (1988) showed that countries with a low dependency ratio have a higher savings rate, which is considered a driving force of per capita income. Similarly, Bloom et al. (2004) explained that the increased longevity could lead to increased savings. Inspired by the research findings of Mason (1988) and Prskawetz et al. (2004), the motivation for including the dependency ratio instead of the growth rate of the population in this study is the established relationship that shows that growth of the working age population is affected by its level of savings.

The literature also makes clear that there is nothing automatic about the effects of demographic changes on economic growth. Changes in age structure simply affect the supply side of economic growth. Economic growth also depends on numerous other macr-oeconomic factors, namely, financial developments, inflation rate, trade openness and investment (Kar et al. 2014).

Using data from a panel of 57 countries over the period 1970–1989, Wacziarg (2001) concluded that trade openness has a positive and significant impact on economic growth. After controlling for endogeneity in their study, Irwin and Tervio (2002) achieved similar results. Using a dynamic panel data model, Brunner (2003) found that trade openness had a positive and significant impact on the level of income and a non-robust impact on income growth.

Higgins (1998) mentioned that the effects of demographic changes on savings and net capital flows depend on the economy's degree of openness. Nations with a low dependency ratio devote more resources to investment, while those with a higher dependency ratio spend a large share of their resources taking care of dependants. Jappelli and Modigliani (2003) noted that households save money during their working life, but no so during their retirement. According to the dependency rate hypothesis proposed by Leff (1971), as the dependency rate increases, the working age population bears a heavier family consumption burden, which then decreases savings rates.

There is an impressive body of empirical literature based on econometric estimation that documents how population age structure affects economic growth in an economy. Most of the studies have been cross-country comparisons. Single country studies are limited to three: Lewis (1983), Lee et al. (2000), and Athukorala and Tsay (2003). However, these studies emphasised age structure and savings interdependency instead of the economic growth relationship. No study to date in Australia has used the dependency ratio as a proxy for the age structure of population.

The Commonwealth Treasury of Australia (2000) noted that the number of working age people is associated with the GDP growth of Australia. These findings indicate that Australia's economic growth might, to some extent, be correlated with demographic variables. The number of people producing goods and services has been decreasing relative to the number of people in retirement. For instance, in 1970, the ratio of the working age population to aged persons was 5:1, and this ratio is expected to decrease to 2.7:1 by 2050, which implies that about one-quarter of the population will be aged 65 years or older (May & Saunders 2013). Hassan et al. (2011) noted that the aging population has serious policy implications in developed economies like Australia and Japan. Hence, this is a crucial time to examine the relationship between population age structure and economic growth in Australia.

2.3 Methodology and Data

Several methods have been used in the empirical literature to reveal the impact of population changes on the economy. Neoclassical growth theory (Barro & Sala-i-Martin 1992) explores the relationships between economic growth and the level of economic development. Mason (1987, 88) and Kelley and Schmidt (1995) identified that neoclassical growth theory is more efficient than simple correlation or production function theory. The model takes the following form:

$$Y/N_{g_{(t,\ t+n)}} = y(Y/N_t\,, X; Z_{(t,\ t+n)}) \tag{1}$$

where Y/N_g represents the GDP per capita growth rate over the interval period (t, t+n) and it varies with the initial level of per capita income(Y/N_t). X variables refer to educational attainment and population density, and Z variables represent factors influencing the economic environment, as well as changes in savings, political stability, investment returns, and the like. Levine and Renelt (1992) found that investment rates constitute the most robust variable in such studies. Barro and Lee (1993) experimented with alternative demographic specifications, including total population growth and the youth-dependency ratio.

Using the theoretical framework of the neoclassical growth model (Barro & Sala-i-Martin, 1992), this study assumes that there is a cumulative influence of the dependency ratio, savings rate, trade openness, and capital formation on economic growth. In light of this assumption, this study incorporates the dependency ratio with other variables into the equation in the following way:

$$Y_t = \beta + \beta_1 DR_t + \beta_2 SR_t + \beta_3 GCF_t + \beta_4 OPN_t + \varepsilon_t \tag{2}$$

where the coefficients of the dependency ratio (DR), savings rate (SR), gross capital formation (GCF) and trade openness (OPN) with real GDP per capita (Y) are β_1, β_2 β_3 and β_4, respectively with error term, ε_t. These coefficients present the long-run elasticity estimates of GDP per capita with respect to the other variables.

Real GDP per capita is gross domestic product converted to international dollars, using purchasing power parity rates and adjusting for inflation. The savings rate is considered as a percentage of GDP and calculated as gross national income less total consumption, plus net transfers. The age dependency ratio is the ratio of dependants (people 14 years or younger, or 65 and older) to the working age population (those aged 15–64 years). Gross capital formation (GCF) consists of outlays on additions to the fixed assets of the economy plus net changes in the level of inventories, and it also refers to the percentage of GDP, while the variable trade openness is measured as the sum of imports and exports divided by total GDP. Data for these variables are annual and were obtained from three different sources: (i) World Bank (2015), (ii) Penn World version 8.1 (Feenstra et al., 2015), and (iii) US Census Bureau (2015), and covers the period 1961–2014 for Australia.

2.4 Estimation Strategies

A multi-stage procedure was adopted to test the interdependency among the variables. In the first stage, the order of integration and co-integration of the variables was tested by implementing the augmented Dickey–Fuller (ADF) generalised least squares method (Elliott et al. 1996), the Kwiatkowski, Phillips, Schmidt and Shin (KPSS) (Kwiatkowski et al., 1992) Unit Root test, and the Johansen co-integration (Johansen, 1988) test, respectively. The second stage involved comparative analysis of the existence of long-run relationships among the variables using the DOLS and FMOLS methods. In the third stage of estimation, bounds testing, using the ARDL methodology of Pesaran and Shin (1998) and Pesaran et al. (2001) was employed to estimate both the short-run and long-run relationships among the variables. Pesaran and Shin (1998) showed that with the ARDL framework, the OLS estimators of the short-run parameters are consistent and the ARDL-based estimators of the long-run coefficients are consistent, even in small sample sizes. The ARDL approach to establish the co-integration relationship among the variables was estimated using the following unrestricted error correction regression:

$$\Delta Y_t = \delta_1 + \sum_{k=1}^{n} \beta_{1,k}\,\Delta Y_{t-k} + \sum_{k=1}^{n} \beta_{2,k}\,\Delta DR_{t-k} + \sum_{k=1}^{n} \beta_{3,k}\,\Delta SR_{t-k} + \sum_{k=1}^{n} \beta_{4,k}\,\Delta OPN_{t-k} + \sum_{k=1}^{n} \beta_{5,k}\,\Delta GCF_{t-k} + \lambda_1 Y_{t-1} + \lambda_2 DR_{t-1} + \lambda_3 SR_{t-1} + \lambda_4 OPN_{t-1} + \lambda_5 GCF_{t-1} + \nu_{1,t} \qquad (3)$$

It could be that some of the variables in question may be stationary, some may be integrated to order 1, i.e. $I(1)$ or even fractionally integrated, and there is also the possibility of co-integration among some of the $I(1)$ variables, but not integrated to order 2. Prior to implementing the bounds testing of ARDL, the statistical and stability tests of the model were examined. Checking the dynamic stability of the ARDL model involves verifying that all of the inverse roots of the characteristic equations associated with the model lie strictly inside the unit circle. This study used the Breusch Godfrey Lagrange Multiplier (LM) (Breisch, 1978; Godfrey, 1980) test for autocorrelation. The presence of structural breaks throughout the period was traced by the Sequential Bai–Perron test. Once the stability test was satisfied, the study performed the 'F-test' for approaching bounds test to reveal the long-run relationship among the variables.

The null hypothesis of the F-test $H_0: \lambda_1 = \lambda_2 = \lambda_3 = \lambda_4 = \lambda_5 = 0$ implies that there is no cointegration among the variables. A rejection of H_0 implies that the variables have a long-run relationship. The acceptance or rejection of the hypothesis depends on the computed F-statistic and the critical value provided by Pesaran et al. (2001).

Exact critical values for the F-test are not available for an arbitrary mix of $I(0)$ and $I(1)$ variables. However, Pesaran et al. (2001) supplied bounds on the critical values for the asymptotic distribution of the F-statistic. For various situations (e.g. different numbers of variables [k+1]), they give lower and upper bounds of the critical values. In each case, the lower bound is based on the assumption that all of the variables are $I(0)$, and the upper bound is based on the assumption that all of the variables are $I(1)$. If the computed F-statistic falls below the lower bound, the study would conclude the absence of co-integration, by definition. If the F-statistic exceeds the upper bound, the study would conclude that they have co-integration. Finally, if the F-statistic falls between the bounds, the test would be inconclusive.

The Johansen (1988) and Johansen and Juselius (1990) co-integration tests were also carried out to reinforce the conclusions of the estimation that there is co-integration among the variables. At this stage of the estimation process, the co-integration is normally carried out on variables entered into the model. The lag orders of the variables were then selected using Schwartz–Bayesian Criteria (SBC) and Akaike's Information Criteria (AIC). The long-run relationship among the variables was estimated after the selection of the ARDL model by AIC or SBC. Once the integration and co-integration were established, this study estimated an OLS regression model using the level data. This provides the long-run equilibrating relationship among the variables as:

$$Y_t = \delta_2 + \sum_{k=1}^{n} \alpha_{1,k}\, Y_{t-k} + \sum_{k=1}^{n} \alpha_{2,k}\, DR_{t-k} + \sum_{k=1}^{n} \alpha_{3,k}\, SR_{t-k} + \sum_{k=1}^{n} \alpha_{4,k}\, OPN_{t-k} + \sum_{k=1}^{n} \alpha_{5,k}\, GCF_{t-k} + \nu_{1,t} \tag{4}$$

Finally, the study estimated an OLS within an error-correction model (ECM) framework to represent the short-run dynamics of the relationship or speed of adjustment among the variables. It shows how quickly the variables return to the long-run equilibrium, and takes the form of:

$$\Delta Y_t = \delta_1 + \sum_{k=1}^{n} \vartheta_{1,k}\, \Delta Y_{t-k} + \sum_{k=1}^{n} \vartheta_{2,k}\, \Delta DR_{t-k} + \sum_{k=1}^{n} \vartheta_{3,k}\, \Delta SR_{t-k} + \sum_{k=1}^{n} \vartheta_{4,k}\, \Delta OPN_{t-k} + \sum_{k=1}^{n} \vartheta_{5,k}\, \Delta GCF_{t-k} + \zeta ECT_{t-1} + \nu_{1,t} \tag{5}$$

where ζ represents the adjustment coefficient and ECT is the error correction term. The ARDL method tests the existence or absence of a co-integrating relationship among the variables.

2.5 Empirical Results

Since the Pesaran et al. (2001) bounds testing approach is applicable for the variables that are $I(0)$ or $I(1)$, in the first stage, the order of integration of the variables was tested using the augmented Dickey–Fuller generalised least squares (DF–GLS) (Elliot et al., 1996) and the KPSS) (Kwiatkowski et al., 1992) tests to avoid any spurious relationship.

Table 2.1: DF–GLS Unit Root Test Results

Variables	Levels			1st Differences		
	Test Statistic	Critical Value	Remarks	Test Statistic	Critical Value	Remarks
Intercept						
Y	-0.194	-1.947	I(1)	-3.447	-1.947	I(0)
DR	-3.278	-1.947	I(0)	-2.598	-2.611	I(1)
SR	-2.424	-2.609	I(1)	-9.882	-1.947	I(0)
OPN	-0.308	-1.947	I(1)	-7.765	-1.947	I(0)
GCF	-1.511	-1.947	I(1)	-6.201	-1.947	I(0)
Intercept and Trend						
Y	0.996	-3.183	I(1)	-4.315	-3.183	I(0)
DR	-1.905	-3.184	I(0)	-3.223	-3.766	I(1)
SR	-3.117	-3.759	I(1)	-10.092	-3.185	I(0)
OPN	-3.013	-3.758	I(1)	-8.171	-3.184	I(0)
GCF	-2.022	-3.180	I(1)	-6.524	-3.184	I(0)

Note: The DF–GLS unit root test for all the variables is carried out at 5% level of significance. I(0) means integrated order zero and I(1) means integrated order one.

All of the DF–GLS test statistics for all the series (except the dependency ratio, DR), are below the critical values in absolute terms (Table 2.1). So this test implies that all the variables, except the DR, are non-stationary in nature; but when the variables were converted into first differences, the value of the DF–GLS test for all the series were above the critical values. So, overall results indicate that the regressors integrated both the order $I(0)$ and $I(1)$, which are called mutually or fractionally integrated series.

The KPSS test outcomes in Table 2.2 are the opposite in terms of outcomes of the DF-GLS tests, which prove the presence of integration in the series. As the DF–GLS test fails to reject its null hypothesis, but the KPSS test rejects it, these two unit root tests clearly revealed that both time series variables are non-stationary, except the DR. Therefore, this result is absolutely identical to the DF–GLS test results, which implies that the series are mutually integrated of order $I(0)$ and $I(1)$.

Table 2.2: KPSS Unit Root Test Results

Variables	Levels			1st Differences		
	Test Statistic	Critical Value	Remarks	Test Statistic	Critical Value	Remarks
Intercept						
Y	2.644	0.463	I(0)	0.727	0.739	I(1)
DR	0.693	0.739	I(I)	1.509	0.463	I(0)
SR	0.548	0.463	I(0)	0.295	0.463	I(1)
OPN	0.826	0.463	I(0)	0.129	0.463	I(1)
GCF	0.491	0.463	I(0)	0.105	0.463	I(1)
Intercept and Trend						
Y	0.631	0.146	I(0)	0.105	0.146	I(1)
DR	0.205	0.216	I(1)	0.188	0.146	I(0)
SR	0.232	0.146	I(0)	0.173	0.216	I(1)
OPN	0.152	0.146	I(0)	0.059	0.146	I(1)
GCF	0.167	0.146	I(0)	0.069	0.146	I(1)

Note: The KPSS unit root test for all the variables is carried out at 5% level of significance. I(1) and I(0) means integrated order zero and one respectively.

After identifying the degree of integration, it was necessary to undertake the test for co-integration. The estimation process started with the ARDL method (Eq. 3), which requires selection of optimal lags for the auto-regressive part of the model at the initial stage. Usually, these maximum lags are determined by using one or more of the information criteria, i.e. AIC, SBC. These criteria are based on a high log-likelihood value, with a ‘penalty’ for including more lags to achieve this. The form of the penalty varies from one criterion to another — the smaller the value of an information criterion, the better the result.

Table 2.3: Test Statistics

Lag	LR	FPE	AIC	SC	HQ
0	NA	92.25627	18.71393	18.90513	18.78674
1	493.7457	0.003376	8.492435	9.639649	8.929300
2	109.9333	0.000565	6.673632	8.776857*	7.474552*
3	42.29170*	0.000479*	6.429758*	9.488995	7.594733
4	28.34983	0.000575	6.452177	10.46743	7.981207

**denotes lag order selected by each criterion.*

The study used the general-to-specific modelling approach, guided by SBC criteria, to select the optimal lag length in the model. Given the VAR-based lag order selection presented in Table 2.3, a maximum lag of 2 was chosen for each variable according to the results of the SBC, as it is a consistent selector.

Table 2.4: Johansen–Juselius Test Results

Trace Statistic				
H_0	Eigenvalue	Statistic	5% Critical value	Prob*
r = 0 τ	0.52	86.75	69.82	0.00
r ≤ 1	0.45	48.28	47.86	0.04
r ≤ 2	0.18	17.37	29.80	0.61
Max–Eigen Statistic				
H_0	Eigenvalue	Statistic	5% Critical value	Prob*
r = 0	0.52	38.48	33.87	0.01
r ≤ 1	0.45	30.90	27.58	0.01
r ≤ 2	0.18	10.14	21.13	0.73

*Note: * denotes MacKinnon et al. (1999) p-values. τ refers to the rejection of the hypothesis at the 1% level.*

The results of the Johansen–Juselius co-integration test for three variables are summarised in Table 2.4. As shown, both the value of the trace statistic and max statistic are statistically significant, indicating the presence of one co-integrating equation at the 1% level of significance. Therefore, only one co-integration equation among real GDP per capita and its determinants is evident. On the basis of the results, the long-run relationship among the variables is established.

Two additional econometric estimation approaches were also utilised — DOLS and FMOLS — to reinforce the results of the co-integration test. The comparative estimation results are summarised in Table 2.5.

The FMOLS test (Phillips & Hansen, 1990) is conducted over the DOLS (Stock & Watson, 1993), subject to eliminating endogeneity in the regressors and serial correlation in the errors. The negative and significant sign of the dependency ratio implies that changes in population age structure have an inverse relationship with economic growth. On the other hand, the positive and significant sign of savings rate implies that changes in the savings rate has a positive relationship with economic growth. The FMOLS test displays the Durban–Watson statistic of 1.78, which differs qualitatively from the DOLS results. The comparative test statistics indicate that a more significant result is achieved when using the FMOLS rather than the DOLS, to establish the long-run relationships among the variables.

Table 2.5: DOLS and FMOLS Model Results

Variables	Coefficients		t-Statistic		Prob.	
	DOLS	FMOLS	DOLS	FMOLS	DOLS	FMOLS
DR	-0.145	-0.172	-4.012	-3.071	0.00	0.00
SR	0.060	0.042	2.324	3.745	0.02	0.00
OPN	0.058	0.042	4.513	4.914	0.00	0.00
GCF	0.072	0.024	2.644	1.368	0.03	0.01

	DOLS	FMOLS
Adjusted R-squared	97.17%	99.69%
Durban-Watson statistic	0.937	1.78

The study carried out the bounds test, using equation 3, by imposing the optimum lags on each side of the first differenced variables. The calculated joint F-statistic is 4.376. The lower and upper bounds for the F-test statistic at the 10%, 5%, and 1% significance levels are (2.26, 3.35), (2.62, 3.79), and (2.96, 4.18), respectively (Pesaran et al., 2001). As the value of the F-statistic exceeds the upper bound at the 5% significance level, it can be concluded that there is evidence of a long-run relationship among the variables. Once the co-integration relationship among the variables is established, equation 4 can be estimated to identify the long-run elasticity coefficients. The elasticity coefficients and test statistics are provided in Table 2.6.

Table 2.6: ARDL Model: Long-run Relationship Results

ARDL(Eq. 3): Based on AIC: Dependent variable, Y				
Regressors	Coefficients	Std. Error	t-Statistic	Prob.
ΔY	0.544	0.181	3.005	0.006
ΔDR	-0.073	0.027	-2.704	0.009
ΔSR	0.014	0.012	1.667	0.025
ΔOPN	0.025	0.011	2.272	0.021
ΔGCF	0.016	0.009	1.778	0.019

Diagnostic test statistics	Test-stats	p-value
Serial correlation	0.844	0.126
Adj. R-squared	0.642	
Durban–Watson statistic	2.078	

The coefficients of Y, DR, SR, OPN and GCF are significant in terms of both 5% significance level and expected signs. The ARDL analysis shows that the largest impact on economic growth is caused by the age dependency ratio. The long-run multiplier between the age dependency ratio and economic growth is (-0.073/0.544) =

-0.134, and savings rate to economic growth is (0.014/0.544) = 0.026, respectively. In other words, in the long run, a 1% increase in the age dependency ratio and savings rate will lead to a 0.13% decrease and a 0.03% increase in economic growth, respectively. The results of long-run relationships among the variables by ARDL are identical to DOLS and FMOLS.

To investigate the short-run dynamics, the error correction term in equation (5) was estimated, and the results are presented in Table 2.7. The short-run dynamic behaviour of the variables is not consistent with the long-run relationship found earlier. The coefficients are not significant except for Y in terms of both a 5% confidence level and signs, but the coefficient of the error-correction term, ECT (-1), is negative and significant, which confirms the existence of a long-run relationship as revealed by both the Johansen–Juselius test and ARDL bounds testing approach of co-integration. The magnitude of the coefficient of ECT (-1) implies that nearly 0.54% of any disequilibrium among the variables is corrected within one year.

Table 2.7: ARDL Model: ECT Estimates

ARDL(Eq. 3): Based on AIC: Dependent variable, Y				
Regressors	Coefficients	Std. Error	t-Statistic	Prob.
ΔY	0.603	0.305	1.977	0.050
ΔDR	-0.063	0.381	-0.165	0.863
ΔSR	0.004	0.003	1.333	0.230
ΔOPN	0.013	0.006	2.167	0.038
ΔGCF	0.014	0.008	1.750	0.098
ECT (-1)	-0.54	0.39	-1.385	0.018
Diagnostic test statistics	Test-stats	p-value		
Serial correlation	0.714	0.106		
Adj. R-squared	0.506			
Durban–Watson statistic	2.044			

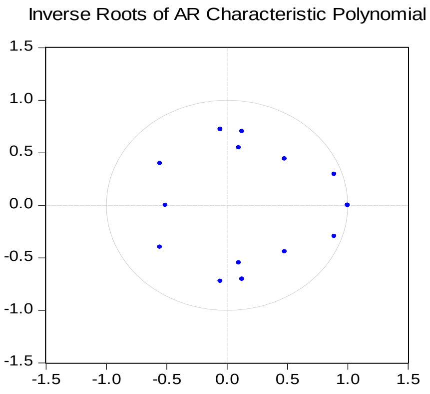
The sequential Bai–Perron (2003) test was then conducted to check whether there were any structural breaks in the time series data and their impact on estimated parameters. This test allows for a maximum number of 5 breaks, employing a trimming percentage of 15, and uses the 5% significance level. The test selects the error distributions to differ across breaks to allow for error heterogeneity. The sequential test results in Table 2.8 reject the nulls of 0, 1 and 2 breakpoints in favour of the alternatives of 1, 2 and 3 breakpoints, but the test of 4 versus 3 breakpoints does not reject the null. The problem of the presence of structural breaks is solved through first differencing the data.

Table 2.8: Sequential Bai–Perron Test Results

Break Test	F-statistic	Scaled F-statistic	Critical Value**
0 vs. 1 *	93.91639	187.8328	11.47
1 vs. 2 *	14.73919	29.47839	12.95
2 vs. 3 *	29.55371	59.10742	14.03
3 vs. 4	5.910031	11.82006	14.85
* Significant at the 0.05 level. ** Bai–Perron (2003) critical values.			
Sequential F-statistic determined breaks: 3			
		Sequential	Repartition
1		1985	1979
2		2002	1985
3		1979	2002

The dynamic stability of the estimated ARDL model is shown by whether or not the inverted roots of the characteristic polynomial lie within the unit root circle. As can be seen in Figure 2.1, all reported inverse roots of the AR polynomial have roots with modulus less than one and lie inside the unit circle, indicating that the estimated VEC is stable. This is a very favourable result because if the VEC were not stable, certain results, such as impulse response standard errors, would not be valid, making the model results and conclusions suspect.

Figure. 2.1: Inverse Roots of AR Characteristic Polynomial



To check the stability of the coefficients, the cumulative sum of recursive residual (CUSUM) (Figure 2.2) and the sum of squares of recursive residual (CUSUM of squares) (Figure 2.3) were tested. Graphically, these statistics are plotted within two straight lines bounded by the 5% significance level. If any point lies beyond the 5% level, the null hypothesis of stable parameters is rejected. The plots of both statistics are well within the critical bounds, implying that the ARDL model is stable.

Figure. 2.2: Cumulative Sum of Recursive Residual

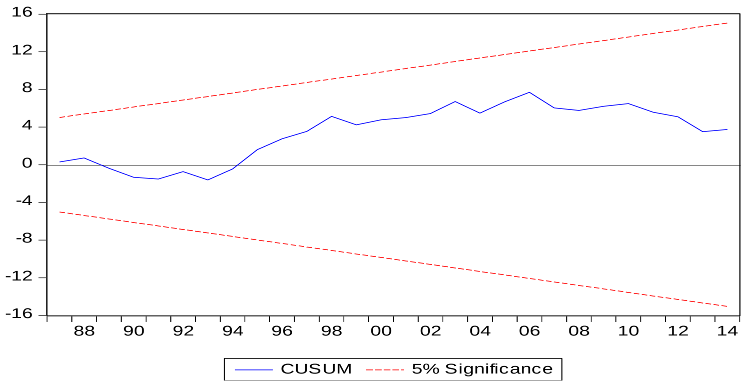
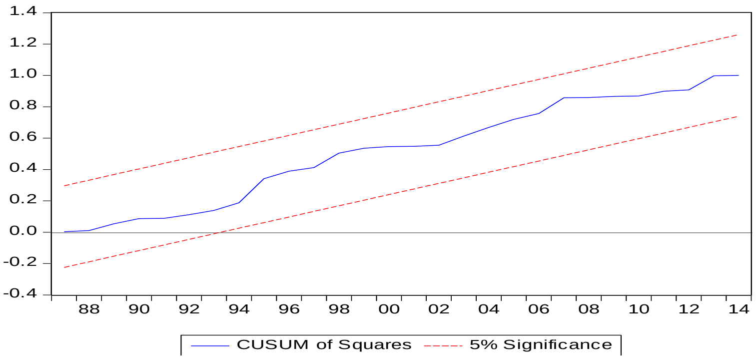


Figure. 2.3: Sum of Squares of Recursive Residual



2.6 Discussion and Conclusion

This chapter has investigated how the age structure of a population, savings, capital formation, and trade openness affect economic growth in Australia. There is a continuing debate about the relationship between these macro-economic variables and the difficulty of specifying and estimating the relationships for an economy which has experienced profound demographic changes over the past few decades. To assess the relationship among the variables, this study has developed a model in which the variables of savings rate, capital formation, trade openness, and real GDP per capita interact endogenously. The main proposition is that changes in the age dependency ratio influence GDP per capita inversely through these channels of savings rate, capital formation, and trade openness.

This study adopted the bounds testing approach with the ARDL model framework to establish the long-run relationship among the variables using time series data for Australia for the period 1961–2014. All three models, DOLS, FMOLS, and ARDL, confirmed that the dependency ratio is estimated to have a negative and fairly large effect on GDP per capita. This is in line with the implications of growth theory. The estimated coefficient of dependency ratio does imply that a higher dependency ratio depresses real GDP per capita. The coefficients for the rest of the variables (saving rate, trade openness, and capital formation) are positive and statistically significant, but small.

The results imply that the effects of population age structure, savings rate, trade openness, and capital formation on economic growth are statistically significant. The larger, and more important, question is whether they are important in economic terms. Because there are huge controversies around dependency effects on economic growth, the formulation of the theoretical model and the formulation of the econometric estimation was critical (Higgins, 1998; Ram, 1982). Hence, the issue of robustness is particularly pressing, because of the extension of the dependency hypothesis to include savings, trade, and capital formation.

Now turning to the estimation techniques, firstly, the robustness of ARDL bounds testing was verified by the DOLS and FMOLS estimators. These estimators address the econometric issues related to non-stationarities, endogeneity, and correlation in the errors. Secondly, the study examined the sensitivity of structural breaks in the time series data, relying on the sequential structural breaks test employed by Bai–Perron (2003). Finally, the dynamic stability of the estimated ARDL model and its coefficient were checked by the CUSUM and CUSUM of squares.

The negative and significant sign of the error correction term confirms the existence of a long-run relationship, as revealed by both the Johansen-Juselius test and ARDL bounds testing. However, the short-run dynamic behaviour of the variables is not consistent. The results indicate the inverse effect of the age dependency ratio on GDP per capita, and the positive effect of the rest of the variables on GDP per capita. The findings support the population-driven economic growth hypothesis, which states that population changes in a country promote economic development.

The results imply that the economic performance of Australia during the period 1961–2014 can be explained by the influence of demographic changes and the savings rate. This finding is partially supported by Kidman (2012). However, the advantages of age structure may disappear in the near future due to an imbalance between the young and the elderly age dependency ratios. This may ultimately lead to a slowdown in the growth of the economy. Australia needs demographic and economic policies that target increasing the working age population to counteract the issues caused by an increasingly ageing population.

In addition, the results suggest that the effect of demographic structure, savings rate, and trade openness on GDP growth appears to be more pronounced in the long run than in the short run. It is essential for government to undertake initiatives that target market reforms in order to greatly improve the efficiencies of labour; this will ensure that accumulated savings are channelled into productive investment.

Australia is now confronted with a rapidly ageing population. Japan has already suffered a long-term economic recession due to its fast ageing rate (An & Jeon, 2006). Recent examples of this phenomenon also exist in the economic performance of Italy and Greece in recent times. Hence, as demographic changes occur more rapidly, it can be expected that these changes might have a bigger impact on Australia's economic performance in the future. Therefore, the reality is that without population increases, Australia's economic growth will stall due to demographic change. Skilled immigration intake can be increased progressively year to year, and as migrants are predominantly of working age, this will assist in maintaining workforce growth rates. Moreover, as many migrants are skilled, this will also raise general skill levels and productivity. In contrast, there are strong arguments against population growth, mostly concerning issues such as negative social change, environmental pressures, and a lack of infrastructure (Jones, 1997). Eventually, government policy must accommodate all of these concerns.

Governments should also put measures in place to ensure that the economy grows at a higher rate than that of the population. This will ensure that the increasing demand for services arising from population growth is met. Having a larger, healthier and better educated workforce will only bear economic fruit if the extra workers can find jobs. Australia, characterised by an ageing population, requires policies that are capable of adapting to these demographic dynamics. It cannot afford to risk a future in which its population age structure hinders productivity and stability.

The high ratio of working age people to dependants can quickly build up capital and increase national per capita income. When relatively large generations reach prime age for working and saving, a country will experience a demographically induced economic boost, because a higher participation rate increases the dynamism of the labour market, and high levels of skilled labour make an economy more adaptable and better able to respond to changing economic trends. However, these types of demographic changes do not pay dividends automatically. To materialise these benefits, countries must invest in education to train the next generation of young workers, and then manage their economies so that conditions are stable and workers can find their desired jobs.

Much of the thinking among economists and demographers in past decades has been that population growth, in itself, has mixed effects on economic growth. The issue of the links between demographic change and economic growth have been explored in this chapter. However, what is important is not the population growth per se, but the changing age structure of the population. Changes in age structure merely create the potential for economic growth. Whether or not this potential is captured depends on the policy environment of an individual country. To take full advantage of demographic changes, favourable labour legislation, efficient macr-economic management practices, openness to trade, and an enhancing immigration policy are just some government actions needed to facilitate economic growth.

As Australia's savings grow and demographic changes continue, it is important to ensure that the transformation of savings into investment in productive capital is as efficient as possible. In light of the demographic challenges facing Australia and the rest of the world, the government needs to formulate demographic policies that promote a lower dependency ratio and higher savings rate, and a higher degree of capital formation to enhance economic growth.

CHAPTER 3

POPULATION CHANGES AND THE ENVIRONMENT

Summary: *Population changes have flow-on implications for society, the economy and the environment. Hence, it is hypothesised that the driving forces of environmental impacts are population size, urban population concentration, non-dependent population ratio, affluence or gross domestic product (GDP) per capita, industry share of GDP, and* CO_2 *emissions per capita. There are many theoretical and methodological forms that have been used to analyse the population–environment relationship. This chapter uses a consistent, well-known population-based framework, the refined STIRPAT model, to assess the sources of environmental impacts. The specific drivers of those impacts are not fully revealed; however, the STIRPAT model depicts a simple outline of non-proportionate impacts of human activities on the environment. This model is not confined to analyses of any specific environmental threat such as* CO_2 *emissions, sulfer dioxide emissions, biodiversity, loss of natural vegetation etc., but can accommodate any impact variable. Environmental impacts data was analysed using the STIRPAT model combined with the Ridge Regression (RR) method. This was because multicollinearity among the data sources could be a substantial problem, and the application of RR to the STIRPAT model enabled collinearity to be avoided. In this study, the ecological footprint (EF) per capita is considered the dependent variable as it measures the degree of environmental impact caused by human activities. The results clearly show that population size has the most significant effect on EF per capita, followed by GDP per capita and urbanisation. Thus, the impact of key driving forces on the environment, revealed in this study, should be taken into account in future planning and long-term strategies for environmental impact abatement of population changes.*

3.1 Introduction

Human activities create a demand for resources to fulfil basic needs, such as food, water, clothing, and shelter, among others. With a larger population, more resources are demanded. A number of theories state that the size of the population is one of the key variables that affect the environment (de Sherbinin et al. 2007). This statement is traced back to the work of Malthus, whose theory still causes strong reactions more than 200 years after it was first published (Malthus 1967). The Malthusian idea is that environmental degradation occurs because of the pressure the population places on resources.

Another view on the population–environment nexus, provided by Boserup (1981), is that population growth enhances technological innovation, which lessens the negative impact on the environment. Turner and Ali (1996) have made a comparison between the theories of Malthus and Boserup. Boserup considered technology as endogenous to the population and resources interaction, while Malthus saw it as exogenous. On the other hand, the followers of Malthus maintain the view that increased population naturally surpasses Earth's resources and capacity to cope, therefore eventually leading to ecological failure (de Sherbinin et al. 2007).

Supporters of Malthus have been criticised for overlooking cultural adaptation, technological developments, trade, and institutional arrangements (de Sherbinin et al. 2007). The widely cited IPAT formulation, introduced by Ehrlich and Holdren (1971), is framed in neo-Malthusian terms. It explains the magnitude of the human-imposed impacts on the environment. However, the IPAT formula itself has been criticised due to there being no linear relationship among the variables (de Sherbinin et al. 2007). Thus, York et al. (2003b) reshuffled the IPAT identity into the STIRPAT model, which harmonises non-proportionate impacts of the population on the environment.

In Australia, for instance, many human activities, including the use of natural resources, have a direct impact on the environment. Australia ranks within the top 10 countries globally in respect to GHG emissions per capita (NSC 2013). The per capita CO_2 emissions is comparatively higher than the rest of the countries which is considered as the principal driver of climate change.

Australia is reported to be one of the countries most at risk from the effects of climate change (Stern 2006). The destruction of habitat by human activities — including land clearing, clearance of native vegetation, expansion of dryland salinity, and intensification of resources in various sectors — is widely reported to be contributing to severe environmental impacts in Australia (Glanznig 1995). Literature suggests that human wellbeing can be improved without, or with minor, impact on the environment. Dietz et al. (2007) found that although urbanisation, economic structure, age distribution and life expectancy are among the drivers of environmental impacts, they have little or no effect on the environment. GDP per capita, or affluence, does drive these environmental impacts, but at the same time it improves other aspects of human wellbeing without costing the environment (Madu 2009).

Although the EF method has proved to be a useful tool to describe the environmental impacts caused by human activities, the specific forces driving those impacts are not yet fully understood (Wei et al. 2011). Despite there being a scientific consensus on the primary drivers of environmental impacts, little progress has been made in determining the precise relationship between drivers and impacts (Dietz et al. 2007). Researchers have traced the environmental impacts using different dependent variables. For example, Madu (2009) measured environmental impact as a proxy for CO_2 emissions and rate of vegetation losses, whereas total energy consumption was used as the dependent variable in a study by Romero et al. (2009). A study by Liddle (2013) used private transport energy consumption as the dependent variable for measuring environmental impact.

A number of studies also utilised EF as a proxy for environmental impact, but most of them have used cross-country data. Very few studies have measured environmental impact using single-country data with EF as a dependent variable. In Australia, no studies have been identified which trace the driving forces of environmental impacts using EF as a proxy for the dependent variable. Thus, the purpose of this chapter is to find the key factors responsible for environmental impacts in Australia, using EF as the dependent variable through the refined STIRPAT model along with RR.

This chapter is organised as follows: Section 3.2 presents a brief overview of the literature on factors affecting environmental impacts; Section 3.3 describes the model, model specification, estimation of OLS coefficients with ridge regression, data, and description of variables; the major findings are described in Section 3.4; and finally, conclusions are outlined in Section 3.5.

3.2 Review of Literature

Two of the most compelling issues that the world has been facing are rapid population growth and economic development, both of which have sharply increased global resource demand and exacerbated environmental deterioration (Mingquan et al. 2010).

The WWF (2012) reports that the spiralling global population and over-consumption are threatening the health of the planet. Ying et al. (2009) similarly mention that the ecosystem faces the twofold impact of population growth and an increasing per capita resource consumption. Population, along with economic activities and technology, have also been theorised to be the key driving forces of environmental deterioration (Dietz & Rosa 1994). Other studies reveal that population and affluence are critical indicators of a broad range of environmental impacts (Dietz et al. 2007).

Taking the Henan province of China as an example, Jia et al. (2009) computed and analysed the province's EF from 1983 to 2006. The results showed that the major drivers of Henan's EF are population size and GDP per capita. Employing the partial least square method for this study, the authors showed that the curvilinear relationship between economic development and ecological impact, i.e. the classical EKC hypothesis, did not exist in Henan province. However, the EKC literature has shown mixed results in terms of empirical evidence (Tallarico & Johnson 2010). Lin et al. (2009) showed that population size has the largest potential effect on environmental impacts, followed by urbanisation, industrialisation, GDP per capita, and energy intensity. Similarly, Hobday and McDonald (2014) concluded that population growth is one of the contemporary drivers of environmental impact in Australia. The changes in the EF depend both on changes in per-capita consumption, and the rate of growth of the population (Hanley et al. 1999).

Refining the methodology and updating the earlier EF estimates, and using recent data for NSW, Lenzen and Murray (2001) showed that the NSW community increased its total EF by 23% in the five years between 1993–94 and 1998–99. During this period, the population grew by 7%, implying that changes in EF are associated with population changes and increasing resource use. Analysing a sub-national area of Siena province in Italy, Bagliani et al. (2008a) showed that urbanisation has an impact on EF. Using the lifecycle approach, Wood and Garnett (2010) showed that the environmental impact of urban populations is generally higher than that of remote populations in northern Australia. The most fundamental assumption governing the demographic–environmental relationship is that an economically active population exerts a disproportionate pressure on environmental impacts (Roberts 2012).

Madu (2009) showed that population size and affluence are the most important anthropogenic drivers of environmental impacts in Nigeria, while urbanisation, or modernisation, brings about a reduction in environmental impacts. Roberts (2012) used the STIRPAT framework to assess the strength of age structure in driving US county-level CO_2 emissions. These estimates paint a complex picture of age-structure in respect to CO_2 emissions: counties with older working-age populations have higher emissions than their younger counterparts, while the size of the total dependent population illustrates no significant relationship. Knight and Rosa (2012) established a link between household dynamics and fuel wood consumption using STIRPAT analysis, which has been implicated in an increased anthropogenic threat to the environment.

Wang et al. (2011b) employed the STIRPAT model to reveal the factors that contribute to CO_2 emissions in the Minhang District, Shanghai, China. They found that population size, affluence and urbanisation level increase CO_2 emissions, while energy intensity decreases CO_2 emissions. Shi (2003) found that global population change over the last two decades is more than proportionally associated with growth in CO_2 emissions, and the impact of population change on emissions is much more pronounced in developing countries than it is in developed countries. Fan et al. (2006) revealed that the impact of population size, affluence and technology on the environment varies at different levels of development. Inversely, Toth and Szigeti (2016) have argued that population has become the least important driver of growth and environmental degradation, especially in the last two decades. Using a data series from 1961 of population, GDP, bio-capacity and EF, they concluded that the main driver of growth and environmental degradation is not population per se, but consumption patterns and levels, multiplied by the number of consumers, especially in developed countries' situations.

Cole and Neumayer (2004) have shown that population increases are matched by proportional increases in CO_2 emissions, and a higher urbanisation rate and lower average household size also increase emissions. Madu (2009) measured environmental impact as a dependent variable by the rate of vegetation loss. She showed that this measurement assesses the cumulative effects of vegetation loss on soil, the water cycle, and wildlife. Ping and Xinjun (2011) applied the EF and STIRPAT methods within the Yangtze Delta Region (YDR) and its 16 cities to assess their sustainability status, and they analysed the relevant driving factors. Their research showed that the distribution pattern of the EF and the degree of sustainability development varied distinctly from city to city in the YDR. The driving factor that made the greatest change in EF was GDP per capita.

Fan et al. (2006) revealed both the positive and negative impacts of a working-age dominated population on the environment, while Cole and Neumayer (2004) showed significant and positive impacts, but in both studies, the effects became non-significant when urbanisation was included in the model. Shi (2003) showed that economies whose GDP outputs are heavily derived from manufacturing are energy-intensive and will produce higher CO_2 emissions, whereas economies whose GDP is largely derived from services are less energy-intensive and will produce lower emissions.

The WWF (2012) estimates that Australia has the seventh biggest EF per capita in the world, and the ecological deficit is increasing daily. Both per capita ecological footprint and bio-capacity are gradually decreasing in Australia; however, the rate of decrease of EF is lower than bio-capacity, indicating the gradual degradation of the environment in Australia. The report also revealed that the average household emits 14 tonnes of greenhouse gases each year, and 3.5 tonnes of that will still be trapping heat in the Earth’s atmosphere in 500 years. Globally, a number of methodologies and indicators have been used for measuring the degree of environmental impacts. However, there is no literature which has attempted to reveal the major driving forces of these environmental impacts as a proxy for EF in Australia. Even the measurement of EF using the STIRPAT model and Ridge Regression, following structural human ecology theory, has never been used in the context of Australia.

3.3 Methodology

3.3.1 Models

It is generally assumed that every person and each populated area (e.g. a region, city, or country) has an impact on the environment (van den Bergh & Verbruggen 1999). Based on this generalisation, a lot of studies have been conducted to examine the consequences of the population on the environment. The model applied in this part of the thesis has primarily been retrieved from Dietz and Rosa’s STIRPAT model. The acronym STIRPAT stands for Stochastic Impacts by Regression on Population, Affluence, and Technology. This model is guided by the theoretical framework of structural human ecology (SHE) to conceptualise the relationship between society (human ecosystem) and the environment. The human ecosystem comprises four interacting determinants: population, social organisation, environment, and technology (Duncan 1961; Catton 1987). This theoretical approach emphasises the bidirectional interplay between the social system and the natural environment (Knight 2008).

However, the application of this model to determine the effects of socioeconomic factors on the environment is not a recent endeavour. Originally, this model emerged from the ecological model IPAT in the early 1970s. The IPAT model was employed to assess the magnitude of human impacts on the environment, and was introduced by Ehrlich and Holdren (1971). The principal idea of an IPAT model is that environmental impact (I) is the product of three key driving forces: population size (P); affluence (A), and technology (T), which is expressed by the following simple mathematical accounting equation:

$$I = P^{*}A^{*}T \tag{1}$$

Until 2005, a series of reformations of the IPAT model had been conducted in the ecological literature. Waggoner and Ausubel (2002) added a consumption variable into the IPAT model (C), which represents consumption per unit of GDP, thus resulting in IPACT. Subsequently, Schulze (2002) added another variable, behavioural decisions, into the IPACT formula and argued that human behaviour is a key driving force of environmental impact. Xu et al. (2005) mentioned two additional variables, social development (S) and management (M), explaining social development and society's capability to decrease environmental impacts. Eventually, this explanation was considered difficult to quantify the degree of environmental impact by these two variables.

The IPAT identity, relabelled the 'Kaya' equation, lies at the heart of the efforts to project greenhouse gas (GHG) emissions by the Intergovernmental Panel on Climate Change (Uddin et al. 2013). However, none of the above models allow testing of the non-monotonic relationship of human-induced factors and environmental changes. In addition, Alcott (2010) has argued that the success in lowering any of the right side factors of IPAT identity does not necessarily lower impact. To address these problems, York et al. (2003b) reshuffled the IPAT identity into the STIRPAT model. Mostly, the STIRPAT model uses different forms of dependent variables with cross-country data, but in this chapter single-country EF data has been used as a proxy for environmental impact. This harmonises non-proportionate impacts of population size on the environment in the form of $I_i = aP_i^b A_i^c T_i^d e_i$ or in logarithmic form as:

$$\ln(I) = \mathrm{a} + \mathrm{b}\ln(P) + \mathrm{c}\ln(A) + \mathrm{d}\ln(T) + e \tag{2}$$

where, in Eq. 2, I is environmental impact, expressed by EF as the dependent variable. The subscript ‘i’ denotes the number of observations in the study. The constant ‘a’ scales the model, and the residual or error term ‘e’ possesses the effects of all other variables of I that are uncorrelated with P, A and T, while b, c and d are the exponents or coefficients of these independent variables that must be estimated from the regression. The coefficients are used here to represent the net effects of the variables and are referred to as the Ecological Elasticity (EE). Affluence is generally measured as per capita gross domestic product.

EE is defined as the proportionate change in environmental impacts due to a change in any driving force (York et al. 2003a). The coefficients b and c represent population (P) and affluence (A) elasticity of impacts respectively. The coefficients b and c represent population and affluence elasticity of impacts respectively. The technology elasticity of impact is denoted by d, which has much controversy (Fan et al. 2006) in the literature in respect of single operational measure for environmental quality.

T is considered the most significant contributor to environmental impact (Commoner 1972), but the impact values are determined by using the estimated value of I, P, and A, and they equate the environmental impact per unit of economic activity (York et al. 2003b). Whether T needs to be included in, or excluded from, the error term in the STIRPAT model is an important issue in assessing the driving forces of environmental quality. Madu (2009) included T in the error term in his study because of inappropriate measures of technology (T) in the regression. In a typical application of the basic STIRPAT model, T is included in the error term, rather than estimated separately. Many studies simply drop T altogether, performing to estimate P, A, and A^2 without the difficulty of pinning *T* down to a single metric (York et al. 2003b). Regardless of the specific approach, *T* remains difficult to translate into a single variable.

Sometimes, researchers disaggregate technology (*T*) by adding other variables into the equation. In the logarithm format, it becomes a natural additive (Cole & Neumayer 2004). Using the natural logarithm, the coefficients of the independent variables can be estimated as elasticities, where changes in any explanatory variable cause percentage changes in the dependent variable. York et al. (2003b) have suggested that other explanatory variables can be added to the basic STIRPAT model if they are conceptually consistent with the specification of the model. Thus, most STIRPAT research uses an econometric framework as a starting point, and then specifies models on different scales by simply adding or dropping variables. In most of the cases, population size (*P*) and affluence (*A*), described as GDP per capita, are used as explanatory variables, while the EF, energy consumption, CO_2 emissions, and GHG emissions are the most common derivatives of environmental impact (*I*), treated as the dependent variable.

Shi (2003) disaggregated *T* into two parts. The first was manufacturing output as a percentage of GDP (denoted by M), and second was services output as a percentage of GDP (denoted by S). The author used the percentage of manufacturing and services to capture the difference in *T*. It was expected that economies whose GDP outputs are heavily derived from manufacturing will be energy-intensive and will produce higher environmental impacts, whereas economies whose GDPs are largely derived from services will be less energy-intensive and will produce lower environmental impacts.

3.3.2 Model Specification

The basic STIRPAT model consists of three driving forces: population (P), affluence (A), and technology (T). In addition to these basic factors of the STIRPAT model, any other variables that are conceptually compatible can be added into the model (York et al. 2003b). In this study, all the models use EF as the dependent variable, which incorporates an index of the environmental impact. The specific and measurable driving forces which have influenced the environment (EF) include: total population; affluence measured by GDP per capita and the quadratic term of GDP per capita; percentage of people living in urban areas; percentage of GDP from the industrial sector; energy use per capita; percentage of non-dependent population; energy intensity; and CO_2 emissions per capita. Six specifications of the STIRPAT model are estimated using ordinary least squares (OLS) regression and then Ridge Regression (RR) is used to correct for multicollinearity. These models are:

$$\text{Model 1}: \ln(I) = \mathrm{a} + \mathrm{b}\ln(P) + \mathrm{c}\ln(A) + e$$

$$\text{Model 2}: \ln(I) = \mathrm{a} + \mathrm{b}\ln(P) + \mathrm{c}\ln(A) + \mathrm{d}\ln(A^2) + e$$

$$\text{Model 3}: \ln(I) = \mathrm{a} + \mathrm{b}\ln(P) + \mathrm{c}\ln(A) + \mathrm{d}\ln(\mathrm{T}) + e$$

$$\text{Model 4}: \ln(I) = \mathrm{a} + \mathrm{b}\ln(P) + \mathrm{c}\ln(A) + \mathrm{d}\ln(\mathrm{T}_1) + \mathrm{d}\ln(\mathrm{T}_2) + e$$

$$\text{Model 5}: \ln(I) = \mathrm{a} + \mathrm{b}\ln(P) + \mathrm{c}\ln(A) + \mathrm{d}\ln(A^2) + e\ln(\mathrm{T}_1) + f\ln(\mathrm{T}_2) + e$$

$$\text{Model 6}: \ln(I) = \mathrm{a} + \mathrm{b}\ln(P) + \mathrm{c}\ln(A) + \mathrm{d}\ln(A^2) + e\ln(\mathrm{T}_1) + \mathrm{f}\ln(\mathrm{T}_2) + g\ln(C) + e$$

Model 1 is known as the two factors (population and affluence) STIRPAT model, where T is included into the error term. In Model 2, an additional explanatory variable, affluence squared (A^2), is added for the assessment of the non-monotonic relationship between affluence and environmental impact. The basic STIRPAT model, framed in Model 3, consists of three common variables — population (P), affluence (A), and technology (T) — where T is viewed as the rate of urbanisation. In Model 4, T is decomposed into two components: the percentage of people living in urban areas (T_1) and the percentage of GDP from the industrial sector (T_2). Taking the percentage of GDP from industry as the T_2 variable, Model 5 was developed, and finally, Model 6 is called the saturated model, comprising all previous independent variables, including CO_2 emissions per capita (C).

3.3.3 Estimation Strategies

In this stage of estimation strategies, the multicollinearity problem is assessed through the correlation coefficient matrix. The high values of the correlation coefficients among explanatory variables suggest the existence of multicollinearity amongst the independent variables. The effects of multicollinearity in the regression equation create inaccurate estimates of the regression coefficients (Marquardt 1970). The variance inflation factor (VIF) is also incorporated to identify the multicollinearity among the variables in the estimation process. It measures multicollinearity by regressing one independent variable on all of the remaining independent variables (Halcoussis 2005). The rule of thumb cut-off value for VIF (VIF $= (1 - \mathrm{R}^2)^{-1}$) is 10.

The complete elimination of multicollinearity is not possible but the degree of multicollinearity can be reduced by adopting ridge regression (Montgomery 2001). The benefits of ridge regression (RR) are most striking in the presence of multicollinearity, as illustrated by Hoerl and Kennard (1970). Following the usual notation, suppose the study's use of the regression equation is written in matrix form as:

$$Y = X\beta + \varepsilon \tag{3}$$

where Y represents the dependent variable, X refers to independent variables, and β is the regression coefficients to be estimated, while ε represents the errors from residuals. In ordinary least squares, Hoerl and Kennard (1970) proposed that the regression coefficients can be estimated using the following formula:

$$\hat{\beta}_{ls} = \left(X'X\right)^{-1}X'Y \tag{4}$$

The ridge regression equation proceeds by adding a small constant value k to the diagonal entries of the correlation matrix, $X'X$, before taking its inverse. The value of k reduces the standard errors and improves the stability of the least squares estimator. The result of the ridge regression estimator is:

$$\hat{\beta}_{ridge} = \left(X'X + kI_p\right)^{-1}X'Y \tag{5}$$

In equation (5), $\hat{\beta}_{ridge}$is a biased estimator of β, whereas in equation (4) $\hat{\beta}_{ls}$ is the unbiased estimator. The relation between $\hat{\beta}_{ls}$ and $\hat{\beta}_{ridge}$ is equal to:

$$\hat{\beta}_{ridge} = \frac{n}{n+k}\hat{\beta}_{ls} \tag{6}$$

Thus, the ridge estimator always produces shrinkage towards zero, while k controls the amount of shrinkage. The effective degrees of freedom associated with a set of parameters determine the degrees of shrinkage. In a ridge regression setting, if k=0, with p parameters, they are initially not penalised, whereas if k is large, the parameters are heavily constrained and the degrees of freedom will effectively be lower, tending to 0, as $k \longrightarrow \infty$. There are several procedures to select the exact value of k for ridge regression estimation. The appropriate selection of k is $= \frac{p}{\widehat{\beta}'} \frac{\widehat{\sigma}^2}{\widehat{\beta}}$, where $\widehat{\beta}$ and $\widehat{\sigma}^2$ are found by ordinary least squares estimation.

3.3.4 Data

Total population, GDP per capita, working-age population, industry share of GDP, and urban population density are the most common metrics of control variables. EF per capita (Dietz et al. 2007; Mingquan et al. 2010; Ping & Xinjun 2011; Wei et al. 2011; Zhao 2010), fuel consumption per capita (Knight & Rosa 2012; Madu 2009), and rate of vegetation loss (Madu 2009) are the most common units of environmental impacts of the dependent variable. Table 3.1 lists the definitions of variables used in the analysis. Data from 1960 to 2014 for the study were collected from various sources. The data on EF, in terms of global hectares, were obtained from the Global Footprint Network (GFN 2015).

Table 3.1: Description of the Variables

Variable	Description	Unit of measurement
Dependent Variable		
Ecological footprint	Land area required to support consumption of a nation	Hectare
Independent Variable		
Population	Population size	Number
Non-dependent population	Percentage of population aged 15–65	%
GDP per capita	Per capita gross domestic product	USD per capita in current prices
Quadratic of GDP per capita	[log (GDP per capita)-Mean]^2	USD per capita in current prices
Percentage of non-service GDP	Percentage of GDP not in service sector	%
Urbanisation	Percentage of population living in urban areas	%
CO_2 emissions per capita	Emissions from industrial processing stemming from the burning of fossil fuels	Metric tonnes of CO_2 per year
Energy intensity	Energy consumed in the production of each unit of economic output	Ratio of GDP

GDP per capita in current US dollars were obtained from the World Development Indicators (World Bank 2014). The demographic data such as population size, the percentage of non-dependent population, and percentage of urban population were obtained from the ABS (2014) and the World Bank (2014). The industry value added data (percentage of GDP) was sourced from the open data catalogue at the World Bank National Accounts (World Bank, 2014). The industry value added comprises value added in mining, manufacturing, construction, electricity, and water and gas. The CO_2 emissions per capita data in terms of metric tonnes came from the World Bank (2014) and the United States Energy Information Administration (2014). CO_2 and energy intensity was measured as the amount of CO_2 or energy consumed in the production of each unit of economic output.

The dependent variable is ‘ecological footprint’ in terms of hectares as an indicator of the environmental impacts. This measure allows comparison across types of impacts by estimating the quantity of land that would be required to support the material consumption of a nation. The logarithm of these data is taken to minimise excessive positive skewness. EF has also been extensively accepted as an environmental quality indicator for a given population (Lenzen & Murray 2003; Wackernagel et al. 2004). It measures the amount of natural resources needed to satisfy the consumption requirements and waste assimilation needs of an individual, a city, a nation, a country, or the entire human world in a given year (Wackernagel et al. 2002; Wood & Garnett 2009). GDP per capita is used as a measure of a nation’s level of economic development, and the quadratic of GDP per capita is used to allow for a non-monotonic relationship between development and environmental impacts.

Typically, GDP per capita has a positive effect on environmental impacts (Dietz et al. 2007; Roza et al, 2004). Similarly, it is predicted that GDP per capita will have a positive effect on the EF. The percentage of the population living in urban areas is used as a general indicator of economic development and modernisation. It may improve environmental efficiencies and it may change the lifestyles and consumption patterns. Based on this assumption for Australia, urbanization is expected to have a positive effect on the EF. As an indicator of economic structure, the percentage of GDP not in the service sector is included to test that the environmental impacts of a shift to a service economy are positive.

3.4 Results and Discussions

Firstly, the correlation coefficient among all the variables was tested before estimating, using ordinary least squares. Table 3.2 shows the OLS regression estimates for STIRPAT Models 1 to 6, and it analyses the effects of hypothesised drivers.

Table 3.2: OLS Regression Results

Variable	Symbol	UC	Standard error	t-test	Sig.	Collinearity Statistics	
						Tolerance	VIF
Model 1							
Population	lnP	2.159	0.299	7.22	0.000	0.028	34.63
GDP per capita	lnA	-0.307	0.068	-4.52	0.000	0.028	34.63
Model 2							
Population	lnP	2.276	0.464	4.91	0.000	0.008	120.50
GDP per capita	lnA	-0.344	0.129	-2.67	0.010	0.012	81.84
(GDP per capita)^2	lnA^2	-0.007	0.022	-0.32	0.741	0.116	8.59
Model 3							
Population	lnP	2.564	0.329	7.79	0.000	0.010	99.35
GDP per capita	lnA	-0.530	0.110	-4.82	0.000	0.021	45.87
% Urban	lnT$_1$	2.191	0.882	2.48	0.016	0.042	23.81
Model 4							
Population	lnP	2.794	0.365	7.65	0.000	0.017	57.42
GDP per capita	lnA	-0.485	0.114	-4.25	0.000	0.009	107.58
% Urban	lnT$_1$	1.271	1.091	1.16	0.249	0.026	37.10
% Industry GDP	lnT$_2$	0.256	0.182	1.41	0.165	0.103	9.72
Model 5							
Population	lnP	1.816	0.462	3.93	0.000	0.009	107.82
GDP per capita	lnA	-0.338	0.116	-2.91	0.005	0.007	129.51
(GDP per capita)^2	lnA^2	0.099	0.032	3.09	0.003	0.012	25.05
% Urban	lnT$_1$	4.736	1.505	3.15	0.003	0.039	82.81
% Industry GDP	lnT$_2$	0.255	0.167	1.53	0.135	0.102	9.72
Model 6							
Population	lnP	2.151	0.497	4.33	0.000	0.007	129.53
GDP per capita	lnA	-0.354	0.114	-3.11	0.003	0.007	130.59
(GDP per capita)^2	lnA^2	0.056	0.041	1.37	0.178	0.023	42.48
% Urban	lnT$_1$	4.314	1.501	2.87	0.006	0.011	85.30
% Industry GDP	lnT$_2$	0.188	0.169	1.11	0.273	0.024	41.19
CO_2 emissions	lnC	0.486	0.295	1.65	0.106	0.096	10.31

The collinearity results show that the VIF ranges between 8.59 and 129.53 among the models. This is an indication that there is collinearity, given the VIF is more than 10 (Wei et al. 2011), which exceeds the acceptable standard. The RR model was then applied to analyse the major drivers of the EF to mitigate the collinearity problem within the independent variables.

The accuracy of the RR results relies on the correct selection of the ridge parameter k. According to Hoerl and Kennard (1970), regression coefficients are to be obtained when the ridge parameter ranges from 0 to 1. Assuming the ridge parameter's step-length is 0.05, the model was analysed using STATA 2012 version. The value of the ridge parameter k was 0.05 in this study. Table 3.3 shows the RR results.

Table 3.3: Ridge Regression Results

Variable	Symbol	Model 1	Model 2	Model 3	Model 4	Model 5	Model 6
Population	lnP	2.147 (0.219)	2.213 (0.434)	2.437 (0.297)	2.367 (0.304)	1.699 (0.401)	2.109 (0.437)
GDP per capita	lnA	-0.295 (0.053)	-0.324 (0.107)	-0.487 (0.093)	-0.436 (0.097)	-0.309 (0.099)	-0.323 (0.102)
(GDP per capita)^2	$\ln A^2$	---	-0.005 (0.013)	---	---	0.087 (0.028)	0.055 (0.037)
% Urban	$\ln T_1$	---	---	2.017 (0.582)	1.213 (1.023)	4.509 (1.305)	4.204 (1.301)
% GDP from Industry	$\ln T_2$	---	---	---	0.214 (0.181)	0.206 (0.107)	0.171 (0.167)
CO_2 emissions per capita	lnC	---	---	---	---	---	0.449 (0.234)
Constant	a	-14.173 (4.342)	15.487 (6.504)	-28.076 (7.099)	-29.156 (7.072)	-29.904 (6.535)	-31.79 (6.531)
R^2	--	0.842	0.839	0.856	0.859	0.879	0.883
Root MSE	Sigma	0.088	0.089	0.084	0.084	0.077	0.076
N	---	55	55	55	55	55	55

Note: GDP per capita was centred by subtracting their respective means in logarithmic form. Standard errors are in parentheses.

Population and GDP per capita were used in Model 1 to analyse the human impacts on the environment in Australia. Results indicated that a positive 1% change in the population, with other factors remaining constant, would lead to a 2.15% increase in environmental pressure. A 1% increase in per capita GDP would lead to a 0.30% decrease in environmental pressure. The results of Model 1 show that the net environmental impacts in Australia increase by 1.85% with both population and GDP per capita growth of 1%. The goodness of fit of Model 1 was 0.842, which was high, showing that the population and affluence factors explain almost 84.20% of all environmental pressures as measured in Australia.

By taking the quadratic term of GDP per capita (A^2), Model 2 tests the non-monotonic relationship between affluence and environmental impacts. The goodness of fit was 0.839, which is slightly lower than that for Model 1. It shows that the three factors — population, per capita GDP and its square term — explain 83.90% of all the environmental pressures measured in Australia. The coefficients of population and per capita GDP were 2.213 and -0.324 respectively, indicating that a 1% increase in population would lead to an increase of 2.21% in environmental pressure, and a 1% increase in GDP per capita would lead to a 0.32% decrease in environmental pressure. The p-value of the quadratic term of affluence is not significant, so this specified model is not well fitted with the hypothesised independent variables.

Table 3.4: Ridge Regression vs. Ordinary Least Squares Results Comparison

Model	Independent variables	Coefficients		Standard Error		t-Statistic	
		Ridge	Least Squares	Ridge	Least Squares	Ridge	Least Squares
1	Population	2.147	2.159	0.219	0.299	9.804	7.221
	GDP per capita	-0.295	-0.307	0.053	0.068	-5.566	-4.515
2	Population	2.213	2.276	0.434	0.464	5.099	4.905
	GDP per capita	-0.324	-0.344	0.107	0.129	-3.028	-2.667
	(GDP per capita)^2	-0.005	-0.007	0.013	0.022	-0.385	-0.318
3	Population	2.437	2.564	0.297	0.329	8.205	7.793
	GDP per capita	-0.487	-0.530	0.093	0.110	-5.236	-4.818
	% Urban	2.017	2.191	0.582	0.882	3.465	2.484
4	Population	2.367	2.794	0.304	0.365	7.862	7.655
	GDP per capita	-0.436	-0.485	0.097	0.114	-4.495	-4.254
	% Urban	1.213	1.271	1.023	0.091	1.186	13.967
	% Industry GDP	0.214	0.256	0.181	0.182	1.182	1.406
5	Population	1.699	1.816	0.401	0.462	4.237	3.931
	GDP per capita	-0.309	-0.328	0.099	0.116	-3.121	-2.914
	(GDP per capita)^2	0.087	0.099	0.028	0.032	3.107	3.094
	% Urban	4.509	4.736	1.305	1.505	3.455	3.147
	% Industry GDP	0.206	0.255	0.107	0.167	1.925	1.527
6	Population	2.109	2.151	0.437	0.497	4.826	4.328
	GDP per capita	-0.323	-0.354	0.102	0.114	-3.166	-3.050
	(GDP per capita)^2	0.055	0.056	0.037	0.041	1.486	1.366
	% Urban	4.204	4.314	1.301	1.501	3.231	2.874
	% Industry GDP	0.191	0.188	0.167	0.169	1.144	1.112
	CO_2 emissions per capita	0.449	0.486	0.234	0.295	1.919	1.647

Population, affluence, and urbanisation were selected in Model 3. The goodness of fit is 0.856, indicating that these three factors are able to explain 85.60% of the impact on EF. All coefficients were significant at 0.05 ($p<0.05$) levels, which indicates the model is perfectly fitted.

The coefficients of population size and GDP per capita were 2.367 and -0.436 respectively in Model 4. These suggest that population and affluence represent elasticity of 2.317 and -0.436, which means a 1% change in population and affluence variables may lead to 2.32% and 0.44% changes in EF respectively.

In Model 5, the coefficient of population size was 1.699, suggesting that a 1% change in population size will lead to a 1.70% change in the EF. Similarly, A, A^2, T_1 and T_2 had elasticities of -0.309, 0.087, 4.509 and 0.206 respectively, indicating that a 1% change in each type of variable would induce 0.31%, 0.09%, 4.51% and 0.21% changes in environmental impacts respectively. In this model, only the industry share of GDP (T_2) was not significant.

In Model 6, the rate of impact of population (2.109) and urbanisation (4.204) were almost similar to the other models. The variable with the highest impact was urbanisation (4.204), followed by population (2.109) and industry share of GDP (0.171). Therefore, population and urbanisation were the most important coefficients of environmental impacts in this model. On the other hand, the coefficient values of GDP squared, industry share of GDP, and CO_2 emissions per capita were not significant at the 95% confidence interval level. Therefore, this model is not well fitted to explain the relationship between environmental impacts and the independent variables.

Table 3.4 provides a detailed comparison between the ridge regression and the ordinary least squares results. The outcome of the ridge regression confirms the efficient estimation of regression coefficients using OLS.

3.5 Conclusions

This chapter utilised EF as the index of environmental impacts and revealed the major driving forces of EF in Australia. So the results imply that the STIRPAT model is able to provide an appropriate analytical framework for decomposing the impact of human activities on the environment, quantitatively, for a single country. The OLS and RR results fully illustrate that the impact of population, economy, and technology on EF is different in different forms of models.

This chapter has firmly established that population, affluence and urbanisation are the main influencing drivers of environmental impacts in Australia. The findings presented in this chapter also clearly provide new evidence that population has the most significant effect on EF. However, the impact of population on the environment is more than proportional, i.e. a 1% increase in population size is associated with a 2.15% change in environmental impacts. This finding supports Rosa et al. (2003) in that population has long been hypothesised to be the primary driver of environmental stressors. There is growing evidence to support this hypothesis as presented in this chapter.

The regression coefficient value in each model generally supports the Malthusian view that population size has had a severely adverse impact on the environment (Shi 2003). It has also shown that affluence influences environmental change in Australia, although its effect is negative. At the initial stage of development, environmental degradation increases with increases in GDP or affluence, especially in developing countries. But in most developed countries higher standards of living and associated lifestyles lead to reductions in environmental degradation (Dietz et al. 2007). Urbanisation also adversely affects environmental quality in Australia where rapid urbanisation is currently being experienced, supporting this contention.

CHAPTER 4

ECONOMIC GROWTH AND THE ENVIRONMENT: AN APPLICATION OF A TIME-SERIES MODEL

Summary: This chapter examines the relationship between income and environmental quality using the Environmental Kuznets Curve (EKC) hypothesis. The hypothesised link is tested using time-series analysis of 27 countries, including Australia, over the period 1961–2014. The degree of environmental impacts of economic activity is measured using Ecological Footprint (EF) per capita as the explanatory variable, while real Gross Domestic Product (GDP) per capita and its quadratic and cubic forms are used as predictor variables in the regression model. First, the EKC hypothesis is tested through examining the relationship between EF and GDP. Further, the long-run relationship between EF and GDP is investigated using a Vector Error Correction (VEC) model. It was found that there is a co-integrated relationship between the variables in almost all countries, which were statistically significant. The EKC hypothesis was supported for Australia along with nine other countries. Additionally, almost all error correction terms were correct in sign and are significant, which implies that some percentage of disequilibria in EF in the previous year adjusts back to the long-run equilibrium in the current year. Therefore, an efficient trade-off between environmental protection and economic benefits exists and EF should be reduced through changing consumption patterns, improving the efficiency of use of resources and cleaner technology choices to reduce GHG emissions.

4.1 Introduction

In economic history, the environment–economic relationship has become gradually more prominent. During the Great Depression of the 1930s, soil degradation emerged as a major environmental problem and in the 1950s and 1960s, concerns about pesticide use and air pollution were raised which drew attention to environmental issues (Meadows et al. 2004). In the last decades of twentieth century, the sustainability of environmental exploitation through the utilisation of natural resources has gained acceptance as a core challenge to the whole economic growth process. Thus, for the global economy in the future, environmental considerations are expected to be a determining factor in shaping economic development.

The relationship between the environment and economic growth is complex, especially concerning the magnitudes, causes and impacts of each on the other. The literature has demonstrated that economic development has both negative and positive influences on the environment. The limit of impacts of economic growth on the environment depends on the degree of use of natural resources in production and consumption and the level of emissions of various pollutants that result.

The income–inequality relationship, first theorised by Kuznets (1955), has been reinterpreted in the environmental economics literature through the EKC hypothesis. In the EKC, the economy–environment relationship produces an inverted U-shaped curve, where environmental degradation first rises, and then falls, with increasing economic development. Furthermore, List and Gallet (1999) tested for the presence of an N-shaped curve in this relationship by using a cubic functional form examining the relationship between pollution and income. The N-shaped curve also occurs when environmental quality firstly shows a positive relationship with economic growth, then a negative relationship, and then moves back to a positive relationship with a higher level of economic development.

Most of the previous empirical studies on the EKC hypothesis have used econometrics techniques with either cross-section or panel data approaches. Compared to cross-country (section) studies, time-series studies are fewer in number and their findings have different implications. In support of this view, Dinda (2004) declared that time-series data analysis provides a more complete picture of the relationship between pollution and particular phases of economic development in individual countries. Critically analysing the two estimation techniques, Lieb (2003) declared that time-series analyses are more appropriate than cross-country studies in explaining the EKC hypothesis. However, Stern (1998) concluded that there has not been enough explicit empirical testing of the theoretical models, and that there is insufficient rigorous and systematic analysis of the economy–environment relationship.

A wide variety of national-level environmental indicators has been used in the literature to examine the EKC hypothesis, but there is no consensus regarding which indicators are the most theoretically appropriate for estimation purposes. The majority of studies have used particular pollution measurements (e.g. Sulphur Dioxide (SO_2), Nitrogen Dioxide (NO_2), or CO_2 as dependent variables), while others have used environmental pressure indicators (e.g. municipal waste, deforestation, biodiversity, water quality); and yet other studies employ composite indexes of environmental degradation.

Consequently, the analysis performed in this chapter tests the validity of the EKC using a much more comprehensive measurement of environmental degradation— Ecological Footprint (EF). It has been widely utilised in the fields of ecology and environmental social sciences, and is regarded as a reliable indicator of anthropogenic pressure on the environment. The most common independent variable is income per capita, but some studies have used income data, converted into purchasing power parity (PPP), while others have used incomes at current market exchange rates. Other explanatory variables have also been included in these models, but income has regularly been found to have the most significant effect on indicators of environmental quality.

The main aim of this chapter is to investigate the relationship between the economy and environment, using proxies of real GDP for the economy and EF for the environment. These will be examined in 27 different countries, including Australia, for the period from 1961 to 2014. These countries vary in population size, stage of economic development, degree of emissions, and uses of natural resources. The study tests the EKC hypothesis for these economies to find out the relationship between the two variables, EF and GDP per capita. It initially uses OLS regression, then the Johansen (1988) co-integration techniques and error-correction term (ECT) are employed to examine the long-run relationship between these variables.

The remainder of this chapter is organised as follows: Section 4.2 outlines the relationship between EF and economic growth; Section 4.3 presents a review of the relevant EKC literature; Section 4.4 explains the method used and the data to conduct the analysis; Section 4.5 presents the estimation strategy; Section 4.6 addresses the empirical results of the study; and Section 4.7 concludes the study.

4.2 Ecological Footprint and Economic Growth Relationship

In the fifty year period between 1950 and 2000, the global population more than doubled; global agricultural production tripled; and global GDP and energy use quadrupled (World Bank, 1992). This, of course, raised demands on resources and the environment to unprecedented levels. Eventually, the concern arises as to whether the world has enough energy, resources and environmental capacity to sustain this level of output.

With the progress of economic growth and industrialisation, people have been, both, utilising natural resources and emitting industrial pollutants at record levels. The increasing rate of resources consumption eventually increases the rate of resources extraction, pollution emissions, land erosion, and biodiversity destruction (Meadows et al., 2004). When humans use more natural resources or emit more pollutants into the atmosphere, than are replaced, the EF increases. So it is evident that there is a direct link between the level of economic activity, natural resources consumption and EF. Just like GDP per capita is frequently used as a measure of economic welfare, it is also possible to measure human welfare by measuring EF.

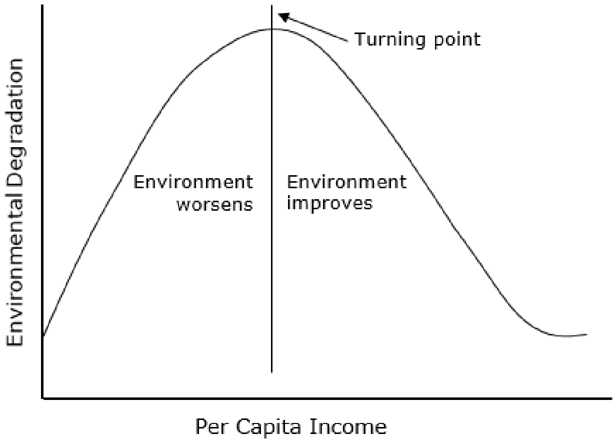
In most of the countries to be examined, the average per capita resource demand, which is commonly referred to as the ecological footprint, has increased gradually. At the same time, the average per capita resource supply, which is commonly referred to as bio-capacity, has been gradually decreasing. Therefore, the gap between per capita ecological resource demand and supply of these economies has inflated considerably over the 54 year study period.

The GFN (2015) estimates that China`s share of global EF, which is a measure of humanity`s demand on the planet, is a massive 19%, followed by the USA 13.7%, India 7.1%, Brazil 3.7% and Russia 3.7%. Australia’s EF in 2014 was 6.3 global hectares (gha) per person. This is 2.4 times the average global footprint (2.6 gha) and well beyond the level at which the planet can regenerate on an annual basis — the equivalent of about 2.1 global hectares per person per year (Living Planet Report, 2014). Australia on average has the 13th largest EF per capita in the world. While this is a slight improvement on where it was in 2012, when the report ranked it 7th, it still means Australia is using more natural resources than most other countries. The most significant factor contributing to the Australian EF is CO_2 emissions from burning fossil fuels, followed by industrial and residential energy use and urbanisation. In the study countries, the average per capita EF varies between 0.67 gha (in India) and 7.60 gha (in Pakistan). Concurrently, the highest annual GDP was $60,143 for Singapore, and the lowest was $55 for Nepal. Descriptive statistics of the data of the two variables are shown in Appendix 4A.

4.3 Literature Review

The common theme of the majority of the pollution–income relationship studies is the assertion that environmental quality deteriorates in the early stages of economic development and improves later. The EKC is postulated as inverted U–shape and derives its name from the work of Kuznets (1955), who described the relationship between inequality and economic development, as shown in Figure 4.1. However, the idea of the EKC came into effect with Grossman and Kruger's (1991) study of the North American Free Trade Agreement. Dinda (2004) showed that pollution grows rapidly in the first stages of economic development, due to higher priority being given to increasing material output. This rapid growth inevitably results in greater use of natural resources and emissions of pollutants, which in turn puts more pressure on the environment. In later stages of development, as income rises, people value the environment more, regulatory institutions become more efficient and pollution levels decline.

Figure 4.1: The Environmental Kuznets Curve



Source: Panayotou (1993)

The environmental consequences of economic development have significant implications for a large number of policy questions confronting both the developed and developing world. Robust public debate has arisen amongst those who maintain that environmental degradation is a necessary outcome of economic growth and those who believe, conversely, that economic growth and environmental quality can co-exist. This debate was first highlighted internationally at the 1992 United Nations Conference on Environment and Development in Rio de Janeiro, Brazil.

Using time-series data from 21 countries from 1980 to 2006, Boulatoff and Jenkins (2010) revealed the existence of a long-run negative relationship between income and CO_2 emissions. Seldeon and Song (1994) found that increased economic growth triggers environmental degradation. Their conclusion was that an environmentally adjusted measure of national income could significantly change the shape of the development–environment relationship.

At the other extreme is the view that environmental improvement is not inconsistent with economic growth. Arrow et al. (1995) stated that people spend proportionately more on environmental quality as their income rises. Earlier studies by Bergstrom and Goodman (1973) found that income enhances environmental improvements; Andreoni and Levinson (2001) estimated that high-income countries can more easily achieve more consumption and less pollution than low-income countries; and Saboori et al. (2012) found that income enhances environmental improvements at the mature stage of development in an economy.

Yet others, such as Panayotou (1993), and Seldeon and Song (1994) hypothesised that the relationship between economic growth and environmental quality, whether positive or negative, is not fixed along a country's development path; and indeed it may change from positive to negative as a country reaches a level of income at which people demand, and can afford a cleaner environment. In this context, Blakely-Armitage (2012) suggested that countries should frame the relationship between environmental quality and economic benefit in each specific context.

The majority of studies used a particular pollution measurement as the explanatory variable; for example, Seldeon and Song (1994) used Sulphur Dioxide (SO_2) and de Bruyn et al. (1998) used Nitrogen Dioxide (NO_2) for measuring impact on the environment. Among others, Wang et al. (2011a) used CO_2 emissions as a global pollution measurement. Some studies used other environmental pressure indicators as explanatory variables; for example, Mazzanti et al. (2009) used municipal waste; Kohler (2013) used per capita energy use; Thompson (2014) used water pollution; Ehrhardt-Martinez et al. (2002) used deforestation; and Paudel et al. (2005) used water quality. Estimating the emissions–income relationship, Millimet et al. (2003) found a statistically significant association for SO_2 but not NO_2. Mbarek et al. (2014) showed the unidirectional relationship between GDP and CO_2 emissions in the short-run in Tunisia, while Saboori et al. (2012) found an inverted U-shaped relationship between CO_2 emissions and GDP in both the short and long-run in Malaysia.

Grossman and Krueger (1991) estimated EKCs for SO_2 and suspended particles (SPM), and found that increases in income are associated with lower concentrations of both SO_2 and SMP. Shafik and Bandyopadhyay (1992) estimated EKCs for 10 different environmental indicators using three different functional forms. They found that only data for two indicators conformed to an EKC: municipal waste and CO_2 emissions per capita. Seldeon and Song (1994) estimated EKCs for four types of emissions (SO_2, NO_2, SPM, and CO_2) using longitudinal data and their findings supported the results of Grossman and Krueger's (1991) study.

Shahiduzzaman and Alam (2012b) indicated the existence of an inverted U-shaped relationship between CO_2 emissions and GDP in Australia. Saboori et al. (2012) found both a short and long-run relationship between CO_2 emissions and economic growth in Malaysia for the period 1980–2009. Kohler (2013) used another variable, energy use per capita, and showed that it has a significant long-run effect of raising CO_2 emissions. Shafiei and Salim (2014) estimated that a higher level of income within a country acts to raise emissions; however, in an earlier study, Pao and Tsai (2011a) revealed that energy, rather than output, is a more important determinant of emissions. Kearsley and Riddel (2010) examined seven pollutants and found little evidence that pollution plays a significant role in shaping the EKC of 27 OECD member countries in 2004. Fodha and Zaghdaud (2010) showed a long-run co-integrating relationship between per capita emissions of CO_2 and SO_2 and per capita GDP in Tunisia, during the period 1961–2004.

EF represents a powerful indicator of the dynamics of renewable resource use, capturing a significant share of environmental pressure both on the input and output side. Moreover, it has been widely employed in the field of ecology and environmental social science. Wackernagel and Rees (1996) mentioned that the EF measures the biological productive land and sea area needed to meet consumption needs and absorb all of the waste of a given population. Cornelia (2014) viewed it as a reliable indicator of anthropogenic pressure on the environment.

Very few studies have used EF as an explanatory variable. In their study, Bagliani et al. (2008b) analysed the EKC hypothesis using EF data of 2001 for 141 countries. Their results do not support the EKC assumptions. York et al. (2004) analysed cross-country variation in EF, using data for 139 countries, and found that the EKC generally holds in developed countries. However, Caviglia-Harris et al. (2009) did not find any empirical evidence of an EKC relationship between EF and economic development for 146 countries spanning 40 years from 1961 to 2000.

In summary, the EKC literature concludes that as incomes rise, there is a level over which per capita measures of environmental degradation (pollution) decline. In general, neither time-series data or EF as an explanatory variable have been considered in most of the empirical work to date. So the analysis to be performed in this chapter will test the validity of the EKC using the EF variable with time-series data in 27 countries.

4.4 Methodology and Data

Initially the EKC literature discussed GDP per capita or log GDP per capita in quadratic form, as the most appropriate functional form for estimation. The quadratic form theorises a relationship between income per capita and environmental quality that is expressed as an inverted U-shape. In this chapter, only per capita data was used because there is no consensus on the question of logarithms. Recently, researchers have added the cubic functional form of GDP per capita, or log GDP per capita, to test for an N-shape relationship between income and environmental quality (List & Gallet 1999).

In this chapter, GDP per capita was assumed as the income variable, and EF per capita was assumed as the environmental quality variable. The most simple model specification shows a linear relationship between an environmental indicator (I) and income per capita (Y). Thus, the linear, quadratic and cubic forms of the model are generally presented as:

Linear : $I_t = \beta_0 + \beta_1 Y_t + \varepsilon_t$ (1)

Quadratic : $I_t=\beta_0+\beta_1 Y_t+\beta_2 Y_t^2+\varepsilon_t$ (2)

Cubic : $I_t=\beta_0+\beta_1 Y_t+\beta_2 Y_t^2+\beta_3 Y_t^3+\varepsilon_t$ (3)

where I_t is an indicator of environmental degradation (per capita EF) during time t; Y is income per capita (per capita GDP); β_0 and ε_t are the intercept and normally distributed error term, respectively; and β_1, $\beta_{2,} and\ \beta_3$ represent slope coefficients to be estimated. The sign of the parameter β determines whether the EF-GDP relationship has a concave, convex or linear relationship. The coefficient of β_1 represents the influence of economic growth on the levels of EF. If $\beta_1 > 0$, then economic growth has a direct positive influence on EF. Equations 1 to 3 test the various forms of the environment–economic relationships.

$\beta_1 = \beta_2 = \beta_3 = 0$ reveals a flat pattern or no relationship;

$\beta_1 > 0$ and $\beta_2 = \beta_3 = 0$ reveals a monotonic or linear increasing relationship;

$\beta_1 > 0$, $\beta_2 < 0$ and $\beta_3 = 0$ reveals an inverted U-shaped relationship;

$\beta_1 < 0$, $\beta_2 > 0$ and $\beta_3 = 0$ reveals a U-shaped relationship;

$\beta_1 > 0$, $\beta_2 < 0$ and $\beta_3 > 0$ reveals a cubic polynomial or N-shaped relationship;

$\beta_1 < 0$, $\beta_2 > 0$ and $\beta_3 < 0$ reveals an inverse the N-shaped relationship.

The analysis is based on annual data for both EF and economic growth. Economic growth is expressed by real GDP per capita in purchasing power parity (PPP) terms in US dollars. EF is expressed by the global hectare per capita. The real GDP per capita data was obtained from the World Bank (WB 2015) and the Penn World Table Version 7.0 (Heston et al. 2011). The per capita EF data were collected from GFN (2015).

The analysis focuses on 27 countries, including Australia, Belgium, Brazil, Canada, China, Denmark, France, India, Indonesia, Malaysia, Italy, Japan, Mexico, Nepal, Nigeria, Pakistan, Philippines, Singapore, South Korea, Sri Lanka, Sweden, Switzerland, Thailand, Turkey, UK, USA and Vietnam. These countries are selected based on their contribution to EF, level of development, geographical location and economic structure to reveal the economy–environment relationship between developed and developing nations.

4.5 Estimation Strategies

The estimation strategy was structured as follows: first, testing for stationarity in the time series for the income variables was undertaken using the Dickey–Fuller's (1979) Augmented (ADF) unit root test. The ADF test was run under three model specifications:

$$\text{Model 1: } \Delta Y_t = \beta_1 + \Delta Y_{t-1} + ai + e_t \tag{4}$$

$$\text{Model 2: } \Delta Y_t = \beta_1 + \beta_2\, t + \Delta Y_{t-1} + ai + e_t \tag{5}$$

$$\text{Model 3: } \Delta Y_t = \Delta Y_{t-1} + ai + e_t \tag{6}$$

Model 1 refers to an intercept only; Model 2 refers to both trend and intercept, and Model 3 refers to no trend or intercept. All three models are needed to check the hypothesis as to whether the time series are stationary or not. If the variables are non-stationary, as shown by the unit root test, then the second step is to test for co-integration using Johansen's (1995) co-integration test. The relationship between EF and GDP is likely to be lagged, in that last year's EF is correlated with this year's EF. If this is the case, EF lagged for at least one year should be included on the right-hand side of the regression. If the variable in question is persistent, that is, values of the past are still affecting today's values, more lags will be necessary. Therefore, when running regressions using time-series data, it is often important to include lagged values of the dependent variable as independent variables.

To test for co-integration, it is necessary to specify how many lags were to be included. Several selection criteria for an appropriate lag length, namely, the Akaike Information Criterion (AIC), the Schwarz–Bayesian Information Criterion (SBIC), the Hannan–Quinn Information Criterion (HQIC), and the Sequential Likelihood Ratio (LR) were used. The regression was then run using the specified number of lags on the dependent variable on the right-hand side of the equation. If the Johansen tests support the conclusion that the variables are cointegrated of order I(1), then the third step is to check the speed required to adjust long-run values after a short-run shock through the use of an Error Correction Term (ECT), using the following formulation (for the cubic function):

$$I_t = \beta_0 + \beta_1 \mathrm{y} + \beta_2\, Y^2 + \beta_3 Y^3 + + \beta_4 EC_{t-1} + \varepsilon_t \tag{7}$$

$$\Delta I_t = \beta_0 + \beta_1 \Delta Y_{t-1} + \beta_2\, \Delta Y_{t-2} + \beta_3 \Delta Y_{t-3} + + \beta_4 \Delta EC_{t-1} + \varepsilon_t \tag{8}$$

4.6 Empirical Results

To assess the shape of the relationship between GDP and EF, the stationarity of these two variables was determined using the ADF unit root test. The results of the unit root tests presented in Table 4.1 indicate that none of the variables are stationary in every model in the regression analysis. In this test, the null hypothesis was rejected for all variables, because the absolute values of test statistics were smaller than the critical value for all the countries at the 5% level of significance. Therefore, the first differences of each variable were calculated and examined using the stationary test.

For example, in Australia the values of test statistics of EF for Models 1, 2 and 3 were 1.32, 2.29, and 0.31, respectively, whereas the critical values were 1.68, 3.51, and 1.95. The values of test statistics of GDP per capita for Models 1, 2, and 3 were 1.60, 0.65, and 1.16, respectively, whereas the critical values were 2.94, 3.52, and 1.95. In all of the three models, the test statistics for both EF and GDP were smaller than the critical value, which means that the variables for Australia are not stationary. As both the variables were found to be non-stationary, the next step of this study was to determine the existence or otherwise of co-integration amongst the variables.

Table 4.2 shows the optimum number of lags, based on four information criteria: Akaike’s Information Criterion (AIC), Schwarz’s– Bayesian’s Information Criterion (SBIC), and the Hannan–Quinn Information Criterion (HQIC), as well as a sequence of likelihood ratio (LR) tests. In this study, the optimum 1 to 4 lags are found based on likelihood-ratio along with four information criteria.

Table 4.3 shows the Johansen test results for co-integration. The results show that the base on the Johansen`s test, the cointegration rank of one to two, is supported by the Trace and Max-eigenvalue statistics at the 5% significance level. Both the eigenvalue and trace statistics of the Johansen test confirm that the variables are co-integrated. This co-integration between the variables implies a long-run association and that they move together in the long-run.

Table 4.1: Augmented Dickey–Fuller (ADF) Test for Unit Root

Country	Variables	Test Statistics			5% Critical Value		
		Model 1	Model 2	Model 3	Model 1	Model 2	Model 3
Australia	EF	1.32	2.29	0.31	1.68	3.51	1.95
	GDP	1.60	0.65	2.16	2.94	3.52	1.95
Belgium	EF	1.56	2.51	1.70	1.68	3.52	1.95
	GDP	0.76	1.97	1.90	1.68	3.51	1.95
Brazil	EF	1.57	1.93	1.25	1.68	3.51	1.95
	GDP	1.16	0.84	1.74	1.68	3.51	1.95
Canada	EF	2.44	3.16	0.36	2.93	3.50	1.95
	GDP	2.68	0.18	1.70	2.93	3.50	1.95
China	EF	2.80	0.95	1.83	2.93	3.50	1.95
	GDP	2.72	2.70	1.78	2.94	3.52	1.95
Denmark	EF	2.48	0.68	0.25	2.93	3.50	1.95
	GDP	1.34	1.48	1.41	2.93	3.50	1.95
France	EF	2.73	2.03	0.25	2.94	3.51	1.95
	GDP	0.52	2.45	1.84	2.93	3.50	1.95
India	EF	1.04	1.12	1.79	2.93	3.50	1.95
	GDP	1.89	0.28	1.98	2.94	3.51	1.95
Indonesia	EF	0.88	1.32	0.86	1.68	3.45	1.95
	GDP	3.45	1.34	7.42	1.66	3.48	1.95
Malaysia	EF	0.74	3.07	1.45	1.68	3.50	1.95
	GDP	3.56	1.53	4.36	1.68	3.50	1.95
Italy	EF	2.70	1.53	0.44	2.94	3.51	1.95
	GDP	0.21	2.64	1.67	2.93	3.50	1.95
Japan	EF	2.86	2.10	0.93	2.93	3.50	1.95
	GDP	0.07	1.89	1.70	2.93	3.52	1.95
Mexico	EF	1.20	3.07	1.57	2.93	3.51	1.95
	GDP	0.97	1.59	1.61	2.94	3.52	1.95
Nepal	EF	1.68	1.69	1.30	2.94	3.51	1.95
	GDP	2.26	3.22	1.64	2.94	3.51	1.95
Nigeria	EF	1.49	3.48	0.36	2.94	3.51	1.95
	GDP	0.42	1.19	0.70	2.94	3.51	1.95
Pakistan	EF	1.51	3.10	1.11	1.68	3.45	1.95
	GDP	0.11	2.69	2.41	1.68	3.50	1.95
Philippines	EF	2.51	2.54	0.52	2.94	3.51	1.95
	GDP	1.76	0.19	1.94	2.94	3.50	1.95
Singapore	EF	0.28	2.83	1.88	1.68	3.50	1.95
	GDP	2.01	1.40	2.01	2.93	3.50	1.67
South Korea	EF	0.15	1.63	1.21	2.93	3.51	1.95
	GDP	0.94	1.68	1.94	2.93	3.50	1.95
Sri Lanka	EF	0.23	2.65	1.85	2.94	3.51	1.95
	GDP	2.37	1.05	1.21	2.94	3.51	1.95
Sweden	EF	1.51	1.87	0.71	2.94	3.51	1.95
	GDP	0.25	3.23	1.45	2.94	3.52	1.95
Switzerland	EF	2.67	2.68	0.35	2.93	3.50	1.95
	GDP	1.25	1.56	1.91	2.93	3.50	1.95
Thailand	EF	0.54	1.81	1.37	2.94	3.52	1.95
	GDP	0.62	2.27	1.54	2.94	3.52	1.95
Turkey	EF	0.16	2.91	0.97	2.94	3.52	1.95
	GDP	2.28	0.93	0.56	1.71	3.52	1.95
UK	EF	0.74	1.98	1.04	2.93	3.50	1.95
	GDP	0.73	1.97	1.79	1.68	3.50	1.95
USA	EF	2.88	2.77	0.19	2.94	3.51	1.95
	GDP	2.01	2.71	1.36	3.51	3.50	1.95
Vietnam	EF	2.69	1.45	4.17	2.95	3.53	1.95
	GDP	2.89	0.37	3.05	2.95	3.53	1.95

Table 4.2: Lag Selection

Country	Lag	LL	LR	df	p	AIC	HQIC	SBIC
Australia	4	-2676.46	37.05	16	0.00	116.79	117.67	118.94
Belgium	3	-2617.60	30.92	16	0.00	113.60	114.37	115.65
Brazil	3	-2132.34	32.69	16	0.00	92.94	93.70	94.99
Canada	4	-2572.37	45.12	16	0.00	112.36	113.11	113.60
China	4	-1621.28	70.18	16	0.00	71.88	72.89	74.56
Denmark	1	-2751.55	39.08	16	0.00	117.94	118.23	118.72
France	1	-2587.97	28.33	16	0.00	112.51	112.81	113.30
India	3	-1409.94	59.95	16	0.00	62.21	62.98	64.25
Indonesia	1	1194.87	12.68	4	0.01	7.94	8.08	8.26
Malaysia	2	-402.34	10.70	4	0.30	16.49	16.63	16.78
Italy	1	-2530.24	35.80	16	0.00	110.45	110.45	111.24
Japan	1	-1819.91	353.53	9	0.00	77.92	78.13	77.43
Mexico	1	-2250.59	35.19	16	0.00	96.63	96.92	97.41
Nepal	3	-1185.68	117.85	16	0.00	52.66	53.43	54.71
Nigeria	3	-1628.14	47.31	16	0.00	71.50	72.26	73.54
Pakistan	1	-268.45	288.83	4	0.00	10.98	11.06	11.21
Philippines	2	-1695.49	106.15	16	0.00	73.65	74.27	75.09
Singapore	1	-465.77	283.04	4	0.00	18.87	18.95	19.10
S. Korea	1	-2430.01	288.58	16	0.00	104.25	104.55	105.35
Sri Lanka	4	-1104.59	48.71	9	0.00	48.66	49.41	50.20
Sweden	4	-2677.89	49.77	16	0.00	116.85	117.85	119.83
Switzerland	1	-2757.21	479.49	16	0.00	118.18	118.48	118.95
Thailand	4	-1854.11	43.95	16	0.00	80.94	81.96	83.63
Turkey	4	-2107.27	111.78	16	0.00	92.51	93.57	95.24
UK	4	-2472.27	110.48	16	0.00	110.47	111.49	113.18
USA	3	-2425.63	76.63	16	0.00	105.43	106.20	107.48
Vietnam	2	-119.05	33.92	4	0.00	7.10	7.19	7.35

Note: Maximum lags are selected according to the AIC, HQIC and SBIC criteria.

Table 4.4 displays the results of the OLS estimation and Table 4.5 shows the summary of OLS estimation results. The first issue was that the overall fit of the models was not satisfactory. The R^2 range was wide between 2% and 80%. This implied that the variation in EF was not very well explained by the estimated variables. The first parameter, β_0, represented the effect of economic growth on EF. The estimated coefficients values differed substantially among countries. Positive and significant coefficients of β_0 was only applicable for four countries: Malaysia, Indonesia, Pakistan and Singapore. $\beta_1 > 0$ reveals a monotonically increasing linear relationship, indicating that rising income is associated with rising levels of EF. This linear relationship was found to be significant only for Malaysia, India, Pakistan and Vietnam. Conversely, $\beta_1 < 0$ refers to a monotonically decreasing relationship, which was found only for Indonesia, Thailand, Turkey and the UK.

Table 4.3: Johansen Tests for Co-integration

Country	Maximum rank	Parms	LL	Eigenvalue	Trace statistic	5% critical value
Australia	2	64	-2681.77	0.381	10.62*	15.41
Belgium	1	43	-2681.37	0.532	19.63*	29.68
Brazil	2	48	-2181.30	0.397	9.95*	15.41
Canada	1	59	-2586.45	0.385	28.14*	29.69
China	2	64	-1612.97	0.623	11.38*	15.41
Denmark	1	43	-2787.38	0.538	21.50*	29.68
France	0	36	-2677.23	---	42.93*	47.21
India	2	48	-1443.94	0.353	9.50*	15.41
Indonesia	1	9	-194.10	0.190	0.93*	3.76
Malaysia	1	9	-418.64	0.280	3.13*	3.76
Italy	2	16	-2743.31	0.294	12.27*	15.41
Japan	1	27	-2728.62	0.399	25.90*	29.68
Mexico	0	04	-2411.70	---	46.69*	47.21
Nepal	2	48	-1216.69	0.429	13.09*	15.41
Nigeria	1	27	-1729.63	0.556	18.20*	29.68
Pakistan	1	6	-278.31	--	9.06*	15.41
Phillippines	1	27	-1801.02	0.872	27.42*	29.68
Singapore	1	3	-493.96	0.010	0.02*	3.84
S. Korea	1	27	-2525.08	0.580	20.40*	29.68
Sri Lanka	1	59	-1576.39	0.439	28.74*	29.68
Sweden	1	59	-2692.15	0.545	28.50*	29.68
Switzerland	1	27	-2869.82	0.475	18.91*	29.68
Thailand	1	27	-1977.95	0.515	20.75*	29.68
Turkey	2	64	-2111.69	0.641	9.06*	15.41
UK	1	27	-2734.85	0.437	21.05*	29.68
USA	2	48	-2484.09	0.440	14.25*	15.41
Vietnam	1	9	-128.06	0.260	3.38*	3.76

Note: results shown based on 5% significance level.

The EKC hypothesis for an inverted U-shaped ($\beta_1 > 0$, $\beta_2 < 0$) relationship was supported for 12 countries, including Australia, out of 27 countries in the quadratic functional form. This result gives support to the EKC hypothesis that the level of EF initially increases with income, until it reaches its stabilisation point, after which it declines. For example, in Australia β_1 is equal to 0.44 and β_2 is equal to -1.07, which confirms the $\beta_1 > 0$, $\beta_2 < 0$ relationship but is not statistically significant. On the other hand, for Singapore, the coefficient of GDP was 1.83 and its statistically significant positive sign implies a 1% increase in income and will lead to a 1.83% increase in EF. The statistically significant negative sign of GDP^2 confirms the de-linking relationship with EF. The turning point of this representation of the inverted U-shaped curve is obtained by determining the derivatives of (I) equal to zero. A quadratic U-shaped relationship between income and EF was supported for the sample period for four out of twenty-seven countries.

Table 4.4: OLS Estimation Results

Country	Function	β_0	β_1	β_2	β_3	R^2(%)	EKC Interpretation	
							Outcome	Relationship
Australia	Linear	-0.30	0.38	--	--	2.30	$\beta_1 > 0$	No
	Quadratic	-0.02	0.44	-1.07	--	5.40	$\beta_1 < 0, \beta_2 > 0$	Inverted U shape
	Cubic	-0.02	-0.13	-0.04	0.03	6.22	$\beta_1 < 0, \beta_2 < 0,\ \beta_3 > 0$	No
Belgium	Linear	0.06	0.14	--	--	1.67	$\beta_1 > 0$	No
	Quadratic	0.05	0.75	-0.99	--	7.29	$\beta_1 > 0, \beta_2 < 0$	Inverted U-shape
	Cubic	0.09	0.31	1.58	-0.02	8.07	$\beta_1 < 0, \beta_2 < 0,\ \beta_3 > 0$	No
Brazil	Linear	0.04	0.43	--	--	10.53	$\beta_1 > 0$	Increasing
	Quadratic	0.03	0.73	-2.26	--	11.73	$\beta_1 > 0, \beta_2 < 0$	Inverted U-shape
	Cubic	-0.01	2.62	-3.55	0.01	19.03	$\beta_1 < 0, \beta_2 < 0,\ \beta_3 > 0$	No
Canada	Linear	0.03	-0.17	--	--	0.47	$\beta_1 > 0$	No
	Quadratic	0.04	-0.37	0.03	--	0.53	$\beta < 0, \beta_2 > 0$	No
	Cubic	0.04	-0.49	0.07	-0.04	0.77	$\beta_1 < 0, \beta_2 < 0,\ \beta_3 > 0$	No
China	Linear	0.02	1.61	--	--	29.56	$\beta_1 > 0$	Increasing
	Quadratic	0.02	7.44	-1.07	--	30.44	$\beta_1 > 0, \beta_2 < 0$	Inverted U-shape
	Cubic	0.02	2.34	-4.08	0.05	31.05	$\beta > 0, \beta_2 < 0,\ \beta_3 > 0$	N-shaped
Denmark	Linear	0.04	0.04	--	--	0.80	$\beta_1 > 0$	No
	Quadratic	0.03	-0.19	2.80	--	1.11	$\beta < 0, \beta_2 > 0$	No
	Cubic	0.03	0.23	-4.21	0.02	2.01	$\beta_1 < 0, \beta_2 < 0,\ \beta_3 > 0$	No
France	Linear	0.05	0.15	--	--	8.15	$\beta_1 > 0$	No
	Quadratic	0.04	0.22	-0.09	--	8.76	$\beta_1 > 0, \beta_2 < 0$	Inverted U shape
	Cubic	-0.04	2.22	-4.79	0.03	8.96	$\beta > 0, \beta_2 < 0,\ \beta_3 > 0$	N-shaped
Indonesia	Linear	1.09	0.67	--	--	46.50	$\beta_1 > 0$	Decreasing
	Quadratic	1.18	-1.10	3.97	--	45.47	$\beta < 0, \beta_2 > 0$	No
	Cubic	1.19	-1.67	7.79	0.55	73.98	$\beta_1 < 0, \beta_2 < 0,\ \beta_3 > 0$	No
Malaysia	Linear	1.83	0.86	--	--	41.84	$\beta_1 > 0$	Increasing
	Quadratic	1.52	2.23	0.64	--	40.83	$\beta < 0, \beta_2 > 0$	No
	Cubic	1.36	3.68	0.25	0.06	73.89	$\beta_1 < 0, \beta_2 < 0,\ \beta_3 > 0$	No
India	Linear	0.00	1.07	--	--	5.47	$\beta_1 > 0$	No
	Quadratic	0.00	-1.94	1.66	--	10.51	$\beta < 0, \beta_2 > 0$	No
	Cubic	0.00	-.129	6.13	-4.58	10.60	$\beta_1 < 0; \beta_2 > 0\ ,\ \beta_3 < 0$	Opp. of N-shaped
Italy	Linear	0.05	0.86	--	--	1.86	$\beta_1 > 0$	No
	Quadratic	0.03	0.64	-1.14	--	6.52	$\beta_1 > 0, \beta_2 < 0$	Inverted U-shape
	Cubic	0.03	1.08	-3.25	0.02	7.36	$\beta > 0, \beta_2 < 0,\ \beta_3 > 0$	N-shaped
Japan	Linear	0.01	0.20	--	--	6.81	$\beta_1 > 0$	Increasing
	Quadratic	0.08	4.00	-3.31	--	7.44	$\beta_1 > 0, \beta_2 < 0$	Inverted U-shape
	Cubic	-0.03	8.66	-2.43	0.02	8.40	$\beta > 0, \beta_2 < 0,\ \beta_3 > 0$	N-shaped
Mexico	Linear	0.02	0.51	--	--	2.23	$\beta_1 > 0$	Increasing
	Quadratic	0.05	2.97	-2.21	--	12.05	$\beta_1 > 0, \beta_2 < 0$	Inverted U-shape
	Cubic	0.02	4.47	-6.29	0.02	13.01	$\beta > 0, \beta_2 < 0,\ \beta_3 > 0$	N-shaped
Nepal	Linear	-0.05	1.02	--	--	9.20	$\beta_1 > 0$	Increasing
	Quadratic	-0.06	-4.27	6.07	--	9.60	$\beta_1 < 0, \beta_2 > 0$	U shaped
	Cubic	-0.05	0.32	-1.23	9.81	17.30	$\beta > 0, \beta_2 < 0,\ \beta_3 > 0$	N-shaped
Nigeria	Linear	0.07	-0.53	--	--	0.63	$\beta_1 > 0$	No
	Quadratic	0.06	2.29	-1.52	--	5.36	$\beta_1 > 0, \beta_2 < 0$	Inverted U-shape
	Cubic	0.06	-1.53	2.98	-4.92	5.45	$\beta_1 < 0; \beta_2 > 0\ ,\ \beta_3 < 0$	Opp. of N-shaped
Pakistan	Linear	5.69	6.26	--	--	40.70	$\beta_1 > 0$	Increasing
	Quadratic	5.75	4.84	5.52	--	40.67	$\beta < 0, \beta_2 > 0$	No
	Cubic	5.94	-3.43	8.02	01.81	40.91	$\beta > 0, \beta_2 < 0,\ \beta_3 > 0$	N-shaped
Philippines	Linear	-0.15	3.17	--	--	20.00	$\beta_1 > 0$	Increasing
	Quadratic	-0.03	3.74	-1.05	--	25.30	$\beta < 0, \beta_2 > 0$	No
	Cubic	-0.02	9.36	-6.20	2.24	46.00	$\beta_1 < 0, \beta_2 < 0,\ \beta_3 > 0$	No
Singapore	Linear	1.69	8.77	--	--	45.78	$\beta_1 > 0$	Increasing
	Quadratic	1.38	1.83	-1.75	--	67.89	$\beta_1 > 0, \beta_2 < 0$	Inverted U-shape
	Cubic	0.91	2.59	-0.56	005	47.88	$\beta > 0, \beta_2 < 0,\ \beta_3 > 0$	N-shaped
South Korea	Linear	0.06	4.18	--	--	21.09	$\beta_1 > 0$	Increasing
	Quadratic	0.06	4.78	1.89	--	21.15	$\beta < 0, \beta_2 > 0$	No
	Cubic	0.05	1.97	11.09	0.03	25.96	$\beta_1 < 0, \beta_2 < 0,\ \beta_3 > 0$	No
Sri Lanka	Linear	0.12	2.84	--	--	4.00	$\beta_1 > 0$	Increasing
	Quadratic	0.17	-4.37	1.47	--	7.15	$\beta_1 < 0, \beta_2 > 0$	U shaped
	Cubic	0.19	1.98	0.03	-1.24	10.89	$\beta_1 < 0, \beta_2 < 0,\ \beta_3 > 0$	No
Sweden	Linear	0.04	0.15	--	--	8.50	$\beta_1 > 0$	Increasing
	Quadratic	-0.05	2.85	-1.93	--	9.70	$\beta_1 > 0, \beta_2 < 0$	Inverted U-shape
	Cubic	-0.02	-0.18	5.37	-0.54	30.90	$\beta_1 < 0; \beta_2 > 0\ ,\ \beta_3 < 0$	Opp. of N-shaped

Switzerland	Linear	0.15	6.63	--	--	10.09	$\beta_1 > 0$	Increasing
	Quadratic	0.11	0.21	-1.63	--	20.80	$\beta < 0, \beta_2 > 0$	No
	Cubic	0.14	0.34	-3.23	0.09	24.30	$\beta_1 < 0, \beta_2 < 0,\ \beta_3 > 0$	No
Thailand	Linear	0.03	-0.94	--	--	10.70	$\beta_1 > 0$	Decreasing
	Quadratic	0.06	1.04	-1.77	--	11.26	$\beta_1 > 0, \beta_2 < 0$	Inverted U-shape
	Cubic	-0.34	1.26	-2.40	-0.08	16.12	$\beta_1 < 0, \beta_2 < 0,\ \beta_3 > 0$	No
Turkey	Linear	0.04	-4.69	--	--	5.04	$\beta_1 > 0$	Decreasing
	Quadratic	0.05	-1.27	5.69	--	7.28	$\beta_1 < 0, \beta_2 > 0$	U shaped
	Cubic	0.06	-1.32	7.45	-0.09	9.00	$\beta_1 < 0; \beta_2 > 0\ ,\ \beta_3 < 0$	Opp. of N-shaped
UK	Linear	-0.02	-3.92	--	--	2.30	$\beta_1 > 0$	Decreasing
	Quadratic	-0.03	-1.52	2.40	--	5.20	$\beta_1 < 0, \beta_2 > 0$	U shaped
	Cubic	-0.08	-2.36	4.62	-0.04	10.50	$\beta_1 < 0; \beta_2 > 0\ ,\ \beta_3 < 0$	Opp. of N-shaped
USA	Linear	0.13	0.07	--	--	5.63	$\beta_1 > 0$	No
	Quadratic	0.16	-1.85	3.07	--	6.09	$\beta < 0, \beta_2 > 0$	No
	Cubic	0.19	9.09	0.01	-0.06	8.40	$\beta_1 < 0, \beta_2 < 0,\ \beta_3 > 0$	No
Vietnam	Linear	0.63	2.67	--	--	77.84	$\beta_1 > 0$	Increasing
	Quadratic	0.65	2.23	1.21	--	79.31	$\beta < 0, \beta_2 > 0$	No
	Cubic	0.73	-0.53	2.67	3.50	79.70	$\beta_1 < 0, \beta_2 < 0,\ \beta_3 > 0$	No

$\beta_1 > 0$, $\beta_2 < 0$, and $\beta_3 > 0$ reveals a cubic poly-nomial, representing the N-shaped figure. The N-shaped relationship between income and environmental impact was found for China, France, Italy, Japan, Mexico, Nepal, Pakistan and Singapore for the cubic level form. This N-shaped curve may hold in the long run. This curve exhibits the same pattern as the inverted U-shaped curve initially, but beyond a certain income level the relationship between the environental pressure and income was positive again. De-linking is thus considered a temporary phenomenon. The inverse N-shaped relationship between income and environmental impact was found for India, Nigeria, Sweden, Thailand, and the UK in the cubic form; these results also indicate that EF is mainly determined by GDP in the long run.

In Table, 4.4 the OLS results for the model are shown. The adjusted R-squared ranges from 0.47 to 79.70. This clearly shows that the model has predictive power for some countries, but is less effective in explaining EF in a large number of countries.

Table 4.5: Summary of Results

Finding	Number of Countries	Statistically Significant		
		No. of Countries	%	Name of Countries
$\beta_1 > 0$ (Increasing)	13	4	31%	Malaysia, Pakistan, Singapore, Vietnam
$\beta_1 < 0$ (Decreasing)	4	1	25%	Indonesia
$\beta_1 > 0, \beta_2 < 0$ (EKC, Inverted U-Shape)	12	2	8%	Singapore, China
$\beta_1 < 0, \beta_2 > 0$ (U-Shape)	3	0	0%	--
$\beta_1 > 0, \beta_2 < 0,\ \beta_3 > 0$ (N-Shape)	8	2	25%	Pakistan, Singapore
$\beta_1 < 0; \beta_2 > 0,\ \beta_3 < 0$ (Opposite to N-Shape)	5	1	20%	Sweden

Table 4.5 shows the OLS summary results for the model. Level of significance is determined by the value of adjusted R squared and p-value of the respective country. The co-integration problem, as detected by the Johansen Test, requires the use of an error correction model to adjust the speed of long-run values after short-term shocks.

Table 4.6: Long-Run OLS Estimation Results

Country	Function	β_0	β_1	β_2	β_3	β_4	R^2(%)	LL	EF & GDP relationship
Australia	Linear	0.48	1.16	--	--	-0.11	34.94	-485.39	Increasing
	Quadratic	-0.25	5.58	-1.25	--	-0.09	76.91	-1374.25	Inverted U-shape
	Cubic	1.84	6.27	-3.19	0.02	-0.12	94.68	-2603.07	N-shaped
Belgium	Linear	-0.19	0.78	--	--	-0.91	37.95	-386.26	Increasing
	Quadratic	-0.09	1.69	-1.35	--	-0.29	49.48	-1321.72	Inverted U-shape
	Cubic	-0.08	1.78	-0.57	0.04	0.215	65.09	-2681.37	N-shaped
Brazil	Linear	-0.00	0.23	--	--	-0.14	36.86	-313.63	Increasing
	Quadratic	0.02	4.04	-1.33	--	0.09	62.55	-984.74	Inverted U-shape
	Cubic	-0.31	-1.23	1.70	-0.02	-1.32	90.01	-2007.02	Opp. to N-shape
Canada	Linear	2.43	1.23	--	--	-0.25	43.24	-433.30	Increasing
	Quadratic	0.69	-1.75	-0.07	--	-0.23	52.67	-1291.49	No
	Cubic	0.33	8.94	-2.29	0.08	-0.37	77.89	-2586.45	N-shaped
China	Linear	0.01	1.66	--	--	-2.73	89.29	-212.99	Increasing
	Quadratic	-0.02	-0.01	8.90	--	-1.16	91.85	-878.58	U-shaped
	Cubic	-0.01	-0.72	-63.63	2.4	-0.59	99.89	-1615.06	No
Denmark	Linear	-0.33	0.29	--	--	-1.02	56.98	-442.36	Increasing
	Quadratic	-0.73	-0.33	2.86	--	-1.57	73.64	-1424.49	U-shaped
	Cubic	-0.17	4.75	-4.75	0.01	-1.31	79.36	-2826.12	N-shaped
France	Linear	-0.48	0.10	--	--	-0.19	39.06	-406.61	Increasing
	Quadratic	-0.14	-0.22	7.14	--	-0.94	35.11	-1307.50	U-shaped
	Cubic	0.02	2.56	-3.82	0.01	-0.33	38.84	-2667.12	N-shaped
India	Linear	0.01	-0.05	--	--	-1.47	53.79	-115.70	Decreasing
	Quadratic	-0.02	1.35	-2.13	--	-6.19	64.58	-681.32	Inverted U-shape
	Cubic	0.00	-1.02	3.09	-2.67	0.02	67.77	-1578.12	Opp. to N-shape
Indonesia	Linear	-0.04	-0.24	--	--	-1.32	53.95	-203.79	Decreasing
	Quadratic	-0.02	-0.02	-0.04	--	-1.84	55.56	-917.44	No
	Cubic	-0.61	-0.04	-5.96	2.09	-1.37	62.03	-2052.42	No
Italy	Linear	-0.14	0.26	--	--	-0.89	37.39	-382.14	Increasing
	Quadratic	0.09	0.67	-1.37	--	-0.15	36.84	-1206.74	Inverted U-shape
	Cubic	0.04	-1.34	4.22	-0.53	0.04	57.93	-2456.49	Opp. to N-shape
Japan	Linear	0.29	0.17	--	--	-0.18	30.70	-415.25	Increasing
	Quadratic	-0.06	-0.76	1.06	--	-0.64	32.22	-1338.31	U-shaped
	Cubic	0.01	3.02	4.49	-2.36	-0.14	41.14	-2728.62	No
Malaysia	Linear	0.05	0.42	--	--	-1.35	41.84	-418.65	Increasing
	Quadratic	-1.1	2.24	-7.07	--	-1.63	40.83	-1286.68	Inverted U-shape
	Cubic	0.01	0.62	-2.39	-0.18	-1.41	73.89	-2604.25	No
Mexico	Linear	0.14	-3.89	--	--	-1.52	47.05	-340.65	Decreasing
	Quadratic	0.14	-3.85	-3.11	--	-1.65	56.90	-1023.54	No
	Cubic	0.15	4.23	-1.01	0.05	-0.68	70.61	-2288.97	N-shaped
Nepal	Linear	0.11	-5.62	--	--	-0.79	65.54	-96.63	Decreasing
	Quadratic	-0.08	6.72	-11.32	--	-0.93	86.87	-575.45	Inverted U-shape
	Cubic	0.05	3.49	-3.23	4.96	0.13	92.30	-1318.81	N-shaped

Nigeria	Linear	-0.11	-3.63	--	--	-1.26	28.05	-225.61	Decreasing
	Quadratic	-0.01	-1.06	7.79	--	-6.68	52.86	-838.74	U-shaped
	Cubic	-0.18	7.29	-11.20	4.54	-4.58	77.64	-1729.62	N-shaped
Pakistan	Linear	0.42	3.60	--	--	06.65	73.74	-282.91	Increasing
	Quadratic	-1.92	2.69	-1.71	--	-03.56	74.00	-942.17	Inverted U-shape
	Cubic	-0.08	-0.18	1.83	1.30	-11.10	74.83	-1954.15	No
Philippines	Linear	-0.03	6.74	--	--	-2.29	26.02	-238.58	Increasing
	Quadratic	-0.05	14.50	2.67	--	-1.18	58.10	-859.32	No
	Cubic	-0.08	16.72	1.94	3.59	-1.51	82.02	-1801.03	No
Singapore	Linear	0.18	-0.03	--	--	-0.29	41.42	-480.69	Decreasing
	Quadratic	0.02	-0.17	0.11	--	-2.06	49.84	-1494.61	U-shaped
	Cubic	0.10	0.02	0.14	0.28	-3.47	28.11	-1954.15	No
South Korea	Linear	0.03	0.15	--	--	0.87	31.98	-375.94	Increasing
	Quadratic	-0.03	2.86	1.30	--	-0.58	49.67	-1245.32	No
	Cubic	-.002	5.99	4.78	0.10	-0.27	55.11	-2525.08	No
Sri Lanka	Linear	-0.07	-2.79	--	--	-0.82	59.27	-175.19	Decreasing
	Quadratic	0.01	-3.84	3.78	--	0.22	63.91	-786.48	U-shaped
	Cubic	-0.01	-1.16	4.42	-1.26	-0.11	77.31	-1703.84	Opp. to N-shape
Sweden	Linear	-0.75	-2.75	--	--	-4.22	29.93	-482.61	Decreasing
	Quadratic	0.51	1.12	-1.73	--	-5.64	38.43	-1434.49	Inverted U-shape
	Cubic	0.48	-11.9	2.59	0.04	-1.04	67.98	-2853.23	No
Switzerland	Linear	-0.01	-0.72	--	--	-4.07	29.33	437.65	Decreasing
	Quadratic	-0.24	0.15	-14.90	--	-4.57	35.22	-1405.53	Inverted U-shape
	Cubic	-0.05	5.94	-1.49	-1.26	-3.17	44.73	-2869.17	No
Thailand	Linear	0.05	2.62	--	--	-0.93	49.72	-289.76	Increasing
	Quadratic	-0.13	-1.26	1.96	--	-2.22	53.45	-963.11	U-shaped
	Cubic	-0.07	13.9	-2.47	5.16	-6.42	62.31	-1977.24	N-shaped
Turkey	Linear	0.05	0.20	--	--	-1.77	43.71	-279.99	Increasing
	Quadratic	-0.20	-7.37	2.66	--	-1.53	65.98	-1136.35	U-shaped
	Cubic	0.05	-5.06	1.13	-0.97	-1.23	74.45	-2306.04	Opp. to N-shape
UK	Linear	-0.22	-0.12	--	--	-0.13	23.62	-422.03	Decreasing
	Quadratic	-0.04	1.57	2.36	--	0.15	36.98	-1345.08	No
	Cubic	-0.03	7.08	-2.97	0.34	-0.76	76.55	-2734.01	N-shaped
USA	Linear	0.29	0.55	--	--	-1.86	80.78	-375.19	Increasing
	Quadratic	0.34	-7.38	0.09	--	-1.04	88.89	-1210.53	U-shaped
	Cubic	-0.49	-1.71	0.05	-0.05	0.03	90.89	-2498.-3	N-shaped
Vietnam	Linear	0.12	-0.24	--	--	-0.55	97.05	-128.06	Decreasing
	Quadratic	-0.05	0.28	1.26	--	-0.21	97.22	-656.56	No
	Cubic	-0.04	1.36	1.21	-0.18	-0.66	98.59	-1484.64	No

Notes: The table displays the estimation results of long-run OLS.

Table 4.6 shows the results of the VEC model that automatically converted the variables into first differences. Adjusted R-squared ranges from 30.70 to 99.89, confirming the model is well fitted for the analysis of EF and economic growth. Table 4.7 shows the summary of VEC results. In some countries, the Error Correction Term (ECT) was significant, and its sign was negative. This implied that there was a long-run association running from GDP to EF. In some cases, the ECT was significant but the sign was not negative and in some cases it was found that both the ECT and the sign were insignificant.

All the error-correction coefficients (b_4) were correct in (negative) sign and significant, except for Belgium, India, and the USA in cubic form; Brazil, Italy, the UK, and Sri Lanka in quadratic forms; and Brazil and South Korea in linear form. For example, the coefficient of -0.09 for Australia implies that 9.0% of the disequilibria in EF of the previous year's shock adjusts back to the long-run equilibrium in the current year. Note that this long-run relationship improves the R^2 and thus the fit of the model, showing the importance of taking this type of relationship into account. For example, R^2=5.4% from the quadratic relationship for Australia, is transformed to R^2=76.91% by adding the ECT.

Table 4.7: Summary of Long-Run OLS estimation

Finding	No. of Countries	Statistically Significant		
		No. of Countries	%	Name of Countries
$\beta_1 > 0$ (Increasing)	16	4	25%	USA, China, Thailand, Denmark
$\beta_1 < 0$ (Decreasing)	8	5	62.5%	India, Indonesia, Nepal, Sri Lanka, Vietnam
$\beta_1 > 0, \beta_2 < 0$ (EKC, Inverted U-Shape)	9	5	33.3%	Australia, India, Nepal, Pakistan, Brazil
$\beta_1 < 0, \beta_2 > 0$ (U-Shape)	10	6	60%	China, Denmark, Nigeria, USA, Thailand, Turkey
$\beta_1 > 0, \beta_2 < 0,\ \beta_3 > 0$ (N-Shape)	9	6	66.6%	Mexico, UK, Nigeria, USA, Nepal, Thailand
$\beta_1 < 0; \beta_2 > 0,\ \beta_3 < 0$ (Opposite to N-Shape)	4	3	75%	India, Sri Lanka, Turkey

Note: Table 4.7 shows the VEC summary results for the model. Level of significance is determined by the value of adjusted R squared and p-value of the respective country.

The chapter finds a number of considerable differences in the temporal patterns of environmental quality and economic growth relationship between the studied countries including Australia. In OLS regression analysis the value of adjusted R squared ranges from 0.47 to 79.70, which confirms that the model has predictive power for some countries, but is less effective in explaining EF in a large number of countries. On the other hand, in VEC analysis the value of adjusted R squared ranges from 30.70 to 99.89, which confirms that the model has predictive power for most countries, and is less effective in explaining EF in a small number of countries. In OLS regression, five countries show the increasing relationship between EF and economic growth in level form, but in the VEC model this number declined to three countries. The number of decreasing relationships between the variables in linear form is the same for both OLS and VEC analysis. The ratio of significant inverted U-shape and U-shape relationship in the quadratic form for OLS is 2:0, whereas this ratio turned into 5:6 for the VEC model, which confirms the validity of the EKC hypothesis. The number of the N-shape and the inverted N-shape relationship is 2 and 1 respectively for OLS regression in the cubic form, and this number turns into 6 and 3 for the VEC model, which confirms the significant improvement of establishing the relationship.

4.7 Conclusions

Many studies have already provided an understanding of the economy–environment relationship and the environmental consequences of economic growth. This chapter has used the EF as a dependent variable to address this phenomenon, using econometric time-series data and the error correction technique. In this context, 27 countries, including Australia, that reflect different levels of economic development were tested. Co-integration analysis was conducted with the VEC Model. The results obtained suggest the existence of a long-run relationship between real GDP per capita and EF per capita. An inverted U–shaped relationship was found between the variables for some of the countries, including Australia, which validates the EKC hypothesis.

The issue of whether environmental degradation increases monotonically, decreases monotonically, or first increases and then declines along a country`s development path, has critical implications for policy. A monotonic increase of environmental degradation with economic growth calls for stricter environmental regulations, and even limits economic growth, to ensure sustainable economic activity within the ecological life-support system. A monotonic decrease of environmental degradation along a country`s development path suggests that policies that accelerate economic growth lead also to rapid environmental improvements.

As an environmental impact indicator, the size of EF needs to be reduced to some extent for most of the studied countries, but the level of EF cannot be reduced without simultaneously adopting new technologies. Irrespective of the country, environmentally-friendly economic growth is essential. However, this situation cannot be achieved within a very short period of time, because countries in an early stage of development give priority to economic growth, even if the environment suffers to some extent. In the early stage of economic development, economies tend to become more highly polluting because they first adopt inexpensive technologies that are relatively inefficient. As per capita income rises, citizens are much more likely to favor protecting the environment over economic benefits, especially when given a specific example of how the environment might be adversely affected. In this situation, the country may choose to give priority to protecting the environment, even at the risk of curbing economic growth. So countries need to secure long-term economic growth whilst mitigating environmental risks into the future.

CHAPTER 5

ECONOMIC GROWTH AND THE ENVIRONMENT: APPLICATION OF A PANEL DATA MODEL

Summary: This chapter examines the effects of real income, financial development and trade openness on environmental quality using a balanced panel of 27 leading country contributors of ecological footprint, including Australia. Recent studies validate the use of ecological footprint (EF) per capita as an indicator of environmental quality. The chapter conducts three alternative panel unit root tests - Levin, Lin and Chu (LLC); Im, Pesaran and Shin (IPS); and Fisher-ADF. All of these tests confirm that the data are first-difference stationary. Considering the outcome of the unit root tests, the study applies four within-group (panel-υ, panel-ρ, panel-ρρ, and panel-ADF) and three between-group (group-ρ, group-ρρ, and group-ADF) Pedroni co-integration tests to check whether the panel data are co-integrated. The outcome is that six statistics out of seven reject the null hypothesis of no co-integration at the 5% level of significance, which provides evidence in support of the co-integrating association between the variables. Then the chapter estimates the co-integrating vectors using the group dynamic ordinary least squares (DOLS) method. The results from the group DOLS analysis indicate a positive and significant association of ecological footprint, and negative and insignificant impact of trade openness on real income, respectively. Financial development is observed to reduce environmental quality. Afterwards, the group mean fully modified ordinary least squares (GM–FMOLS) method is applied to check the robustness of the obtained long-run vectors from the group DOLS estimates. The findings are partially robust across as only real income confirms the positive significant impact on EF. In addition, the vector error correction (VEC) model also supports a unidirectional impact running from real income to EF. Finally, the variance decomposition and impulse response function analysis forecast that real income will also have an increasing effect on EF in Australia in the future.

5.1 Introduction

Humanity is currently confronted with two major challenges: economic development and preserving the earth's environment. The environment has come to the forefront of contemporary issues for both developed and developing countries primarily as a result of climate change. With the rapid growth in industrialisation over the past 200 years, the world has witnessed a significant rise in energy demand that has made the trade-off between economic development and environmental impact increasingly difficult, as this massive demand is met with energy production dominated by the extraction of non-renewable fossil fuels that produce greenhouse gas (GHG) emissions.

Despite significant efforts by countries to combat emissions through various measures, over 80% of global energy is still produced from fossil fuels. CO_2 emissions is the primary GHG emitted through human activities and comes from a combustion of fossil fuels (coal, natural gas, and oil) that are used for energy and transportation, although certain industrial processes and land-use changes also emit CO_2 (Andres et al. 1996). As a consequence of economic development, environmental quality has deteriorated significantly in many countries. An enormous volume of research has investigated the association between economic growth, energy consumption and emissions. However, based on their mixed and inconclusive findings, these studies have offered a diverse set of policy recommendations for different countries and regions to combat the problems that arise from these emissions.

A major weakness of most of the studies examining the relationship between economic growth, energy consumption, and the environment is that they use CO_2 emissions as an indicator of environmental impact. But CO_2 emissions constitute only one part of the total environmental damage caused by large scale energy consumption (Al-Mulali et al., 2015a). By contrast, the EF represents a powerful indicator of anthropogenic pressure on the environment (Vackar, 2012).

Moreover, EF has been widely employed in the fields of ecology and environmental social science. It measures the biological productive land and sea area needed to meet the consumption needs and includes associated waste assimilation of a given population (Wackernagel & Rees 1996). In support of Wackernagel and Rees' (1996) view on the EF, Cornelia (2014) treats it as a reliable indicator of the dynamics of renewable resource use. Recognising its comprehensiveness as a measure of environmental impact, many recent studies (Al-Mulali et al. 2015c; Wang et al. 2011b; Galli et al. 2012a, 2012b; Mostafa 2010; Caviglia-Harris et al. 2009; Bagliani et al. 2008b) have used EF as an indicator of environmental impact.

Therefore, in order to provide a better and more fine-grained understanding of the relationship between environmental quality and economic growth, this chapter, instead of considering CO_2 emissions, chooses EF as the indicator of environmental impact. Three explanatory variables, real GDP per capita, financial development, and trade openness (Al-Mulali et al., 2015c; Salahuddin et al., 2015), are considered in the analysis, which uses panel data of 27 leading EF contributors in the world. These are drawn from both developed and developing countries.

The rest of the chapter is structured as follows: Section 5.2 discusses the concept, interpretation and application of EF. Section 5.3 reviews the related literature. Methodology and data are presented in Section 5.4. Section 5.5 presents and discusses the results and the chapter concludes in section 5.6.

5.2 Concept, Interpretation and Application of EF

The concept and methodology of EF was first applied by Mathis Wackernagel. EF measures the amount of natural resources needed to satisfy the consumption requirements and waste assimilation needs of an individual, a city, a nation, a country or the entire human world in a given year (Wackernagel and Rees, 1996, Wackernagel et al. 2002; Wood and Garnett 2010). The consumption requirements of these populations are then converted into the amount of productive area, expressed in terms of hectares per capita. There are five types of land and its corresponding consumption categories include: cropland for plant-based foods and fibre products; grazing land for animal-based foods; fishing grounds for marine and inland products; forest areas for timber and other forest products; and carbon uptake land for absorption of anthropogenic CO_2 emissions.

The nation-specific yield factors and land specific equivalence factors are then used to convert actual hectares into global hectares (Galli et al. 2007, Wackernagel and Rees 1996). The yield factor refers to the productivity coefficient for different land types in proportion to the world average. This is specific for each country and each year. The equivalence factor represents the conversion rate from hectare to global hectare which is constant for all countries for a given year. The EF accommodates the demand for natural capital and compares it with earth biological capacity (Wackernagel et al. 1996). The biocapacity (BC) measures the potential for production and thus the availability of biologically productive areas for human economic use (Wackernagel et al. 2002; Ewing et al. 2010). The BC is a counterpart to the EF (Vackar 2012). The EF and BC can be expressed as:

$$EF = N(EF_i) = N\sum_{i=1}^{n} r_i (C_i/Y_i) = N\sum_{i=1}^{n} r_i \frac{P_i + N_i - X_i}{Y_i}$$

$$BC = N \times (1-12\%)\sum_{j=1}^{n} a_j r_j y_j$$

In the above equations, N refers to the total population, i refers to different consumption items, C_i is the per capita consumption of item i, Y_i is the average productivity of item i for a corresponding bio-productive area, r_i is the equivalence factor, $P_i + N_i - X_I$ denotes net consumption, where, P_i is the production of item i, N_i is the import of item i and X_i is the export of item i. a_j is the per capita biological productive area of j type land, y_j is the yield factor of j type land and r_j is the equivalence factor of j type land. The EF is calculated by compiling a matrix in which an area of land is allocated to each consumption category. To calculate the EF per capita, all land areas are added up, and then divided by the population, yielding a result in global hectares per capita.

If this calculation indicates EF>BC, an ecological deficit occurs, which implies that a region's natural capital is being depleted and there is a need to add to its footprint via importation from another region. On the other hand, if EF<BC, this indicates an ecological surplus which estimates the remaining ecological capacity. By providing a means of comparing human demand (EF) and nature's supply (BC) in the same unit of measurements (global hectares), the assessment results clearly show the magnitude of the human load on the biosphere at each graphical scale of analysis (Wackernagel & Yount 1998).

This method has been extensively used as a sustainability indicator for a given population (Lenzen and Murray 2003; Niccolucci et al. 2012; Wackernagel et al. 2004). It has also been used to measure and manage the use of resources throughout the economy. A major advantage of the EF is that it accumulates a large amount of environmental data into a single measure, which can be easily compared to a regions carrying capacity (Costanza, 2000).

Despite these advantages, few researchers have used the EF method to examine the EKC hypothesis, where the environmental impact first rises and then falls with increasing economic development. Hervieux and Darné (2014); Cornelia (2014); Caviglia-Harris et al. (2009) and Daly and Farley (2004) used EF as the primary environmental pressure indicator. Bagliani et al. (2008b) analysed the EKC hypothesis using the EF data of 141 countries. Similarly York et al. (2004) analysed the cross-national variation in the EF per unit of GDP to reveal the impact of the scale of production on the environment.

EF has also been used in the STIRPAT model as a proxy of environmental impact to explore the magnitude of human impact on the environment. York et al. (2003b) have reinterpreted the STIRPAT model from I=PAT identity of Ehrlich and Holdren (1971), where environmental impact is assessed through the Population (P), Affluence (A) and Technology (T) variables. In this model, the EF refers to the responsiveness of environmental impact (I) to a change in any of the driving forces P, A or T.

Galli et al. (2012b) use EF to assess the environmental consequences of economic growth in China and India. Marquart-Pyatt (2015) investigated EF as a measure of environmental sustainability with a focus on West Africa. Results revealed that demographic attributes were key factors that affected EF in these countries. Moran et al. (2008) use EF to analyse the relationship between development and environmental impact. They found a positive relationship between development and environmental impact for Cuba. Best et al. (2008) identified a basket of indicators including EF to monitor de-coupling of economic growth from environmental impacts in the EU. Toth and Szigeti (2016) developed a GDP/EF correlation function and calculated the EF from 10,000 B.C till 1960. They found that the main driver of growth and environment degradation is not population per se, but consumption patterns, especially in developed economies.

Marquat–Pyatt (2015) treated the analysis of EF of nations using an emerging methodological approach of structural human ecology (SHE) theory (Dietz and Jorgenson, 2013). The EF is a widely accepted interactive measure of stress on the environment and treated as the subject of some of the earliest work in SHE (Jorgensen, 2003; York et al. 2003).

Although there is diverse range of authors who have applied EF in their studies, such as Niccolucci et al. 2012; Kissinger et al. 2011; White 2007; Lawrence and Robinson, 2014; Caviglia-Harris et al. 2009; York et al. 2003a, 2003b, 2004, 2009; Ferguson 1999; Costanza 2000; Wiedmann et al. 2006; Hervieux & Darne 2014; Cornelia 2014; Marquart-Pyatt, 2015; Jorgenson 2003; Dietz et al. 2007; Jorgenson and Burns 2007; Jogenson and Rice 2005; Rosa et al. 2004; Rothman 1998 etc., there are some authors (van den Bergh and Grazi 2013; Borucke et al. 2013; Galli 2015, Lin et al. 2015; Giampietro and Saltelli 2014; Kitzes et al. 2009; Goldfinger et al. 2014; Fiala 2008; Loh et al. 2005) who have criticised the EF methodology and its application.

While the ease of interpretation adds to the strengths of the EF, the way of measurement and methodology leads to considerable criticisms, especially in recent times. The notable weakness of EF includes an incapability to capture all environmental aspects of sustainability (Borucke et al. 2013; Galli 2015; Kitzes et al. 2009). There is similar criticism by Lin et al. 2015, who outlined that the EF considers only those resources, pollutants or services that can be measured in terms of biologically productive areas (Lin et al. 2015). It does not track freshwater consumption, soil erosion, GHG emissions other than CO_2, toxicity, and eutrophication (Borucke et al. 2013; Best et al. 2008). Indeed it also does not consider biodiversity (Loh et al. 2005).

The EF offers the metric to track flows in embodied biocapacity (Lin et al. 2015; van den Bergh and Verbruggen 1999) and the metric is computationally ‘laborious’ and at the same time is fragile (Giampietro and Saltelli 2014). In addition, it is historical rather than predictive. Goldfinger et al. (2014) defended the majority of Giampietro and Saltelli’s criticisms, which are incompatible and bears little resemblance to the EF accounting currently practised by GFN, amongst others.

Despite these shortcomings, the EF is well-regarded in scientific and environmental circles. The validity of EF is supportable on empirical grounds and has been adopted by a growing number of governments and their agencies, and policy makers as a measure of ecological performance (Wiedmann et al. 2006).

The EF has been widely used in the field of ecology and in environmental social sciences, and is generally regarded as a reliable indicator of anthropogenic pressure on the environment (Dietz et al. 2007; Jorgenson 2003; Jorgenson and Burns 2007; Jorgenson and Rice 2005; Rosa et al. 2004; Rothman 1998; York et al. 2003a, 2003b, 2004, 2009). A number of countries have tested the validity of the method: Switzerland, Germany, United Arab Emirates, and Belgium (Beast et al. 2008). In this chapter, EF has been selected as the aggregate measure of environmental quality for estimation purposes.

5.3 Literature Review

It is widely believed that environmental quality deteriorates in the early stages of economic development and then improves gradually as economic growth reduce and the material standard of living improves. The income-inequality inverted U-shaped relationship, theorised by Kuznets (1955), has been reinterpreted in the environmental economics literature through the EKC hypothesis. The EKC states that in the initial stages of economic growth, CO_2 emissions increase, but after a certain threshold level, these emissions begin to decline and environmental quality improves. The EKC hypothesis was initially tested by Grossman and Krueger (1991). Numerous studies, such as Stern (2004), Dinda and Coondoo (2006), Ozturk and Acaravci (2010), Al-Mulali et al. (2015a), Apergis and Ozturk (2015), Shahbaz et al. (2015a), and Al-Mulali et al. (2015b), have examined it using various datasets and econometric approaches. However, the empirical outcomes of these studies are mixed and inconclusive.

It is also argued that environmental improvement is not inconsistent with economic growth. Arrow et al. (1995) stated that people spend proportionately more on environmental quality as their income rises. Earlier studies by Bergstrom and Goodman (1973) found that income enhances environmental improvements. Using time-series data from 21 countries from 1980 to 2006, Boulatoff and Jenkins (2010) revealed the existence of a negative long-run relationship between income and CO_2 emissions.

Yet others, Panayotou (1993), and Seldeon and Song (1994), have hypothesised that the relationship between economic growth and environmental quality, whether positive or negative, is not fixed along a country`s development path; and indeed it may change from positive to negative as a country reaches a level of income at which people demand and can afford more efficient infrastructure and a cleaner environment.

Shahiduzzaman and Alam (2012a) and Saboori et al. (2012) found an inverted U-shaped relationship between CO_2 emissions and GDP in both the short and long run for Australia and Malaysia, respectively. Kearsley and Riddel (2010) found little evidence that environmental quality plays a significant role in shaping the EKC of 27 OECD member countries using 2004 data. Fodha and Zaghdaud (2010) showed that there is a long-run co-integrating relationship between per capita emissions of two pollutants and per capita GDP in Tunisia, during the period 1961–2004.

A wide variety of environmental indicators have been used in the literature to examine the EKC, but there is no consensus as yet on which indicator is the most appropriate one. The majority of studies used a particular environmental impact measurement as an explanatory variable. For example, Seldeon and Song (1994), Millimet et al. (2003), and Grossman and Krueger (1991) used Sulphur Dioxide (SO_2), while de Bruyn et al. (1998) used Nitrogen Dioxide (NO_2) to measure impacts on the environment.

Among others, Wang et al. (2011a), Saboori and Sulaiman (2012), Shahiduzzaman and Alam (2012a), Salahuddin and Gow (2014), and Salahuddin et al. (2015) used per capita CO_2 emissions as a measure of environmental impact. Some studies used yet other environmental pressure indicators as explanatory variables. For example, Mazzanti et al. (2009) used municipal waste, Ehrhardt-Martinez et al. (2002) used deforestation, and Paudel et al. (2005) used water quality in their studies.

Despite ample literature on the emissions–growth nexus, very few studies have so far used EF as an indicator of emissions. York et al. (2004) analysed the cross-country variation in the EF, using data from 139 countries. They found that the EKC generally holds in developed countries. In their study, Bagliani et al. (2008a) analysed the EKC hypothesis using EF data from 141 countries. Their results did not support the assumptions of the EKC.

Similarly, Caviglia-Harris et al. (2009) did not find any empirical evidence of an EKC relationship between EF and economic development. Mostafa (2010) used EF as the environmental impact variable to assess the environmental impact on income. He concluded that per capita GDP, exports, services, and urbanisation were the key variables that affected EF in a panel of 140 countries. The findings suggested that the more economically developed countries are responsible for most pollution in the world.

Wang et al. (2011b) did not find any evidence in support of the EKC hypothesis in a cross-sectional study of 150 countries. They used EF of consumption per capita, EF of production per capita, and the national bio capacity per capita as dependent variables, and real GDP per capita as the independent variable. The study applied a relatively uncommon spatial econometric technique to examine the association between economic growth and EF. It also found that domestic EF was affected by the EF of neighbouring countries.

Galli et al. (2012b) assessed the overall EF situation and how it interacted with economic growth of high income, middle income, and low income countries, using a special focus on China and India. The EF of China and India has global environmental implications due to the populations both exceeding 1 billion. They argued that high income countries experienced a rise in EF while EF has declined, or remained constant, in middle and low income countries. The EF of China has increased, offsetting its gains in income over the last 45 years. The per capita footprint of India has fallen slightly over the same period.

Al-Mulali et al. (2015c) tested the validity of the EKC hypothesis for a panel of 93 countries using EF. The countries were categorized based on different income levels: high, upper middle, lower middle, and low income countries. The results indicated that EKC is valid for the high and upper middle income countries but not for low income countries. Ozturk and Al-Mulali (2015) investigated the EKC for Cambodia and could not find evidence for it. They found that GDP, urbanisation, energy consumption, and trade openness all contribute towards a rise in CO_2 emissions. However, better governance and reduced corruption could reduce emissions in the country.

The relationship between CO_2 emissions and financial development has also been investigated in the literature. Tamazian et al. (2009) found that a high degree of financial development improves environmental conditions. Jalil and Feridun (2011) reported that financial development reduces CO_2 emissions in China. However, Zhang

(2011) found that financial development contributes significantly towards increasing CO_2 emissions in China. Al-Mulali et al. (2015c) claimed that financial development reduces EF while trade openness increases it for a panel of 93 countries. Salahuddin et al. (2015) show that financial development causes a decline in CO_2 emissions in GCC countries. Charfeddin and Khediri (2015) confirmed that there was an inverted U-shaped association between financial development and CO_2 emissions in the UAE. That study also found that trade openness improved environmental quality.

Financial development was found to increase energy consumption and CO_2 emissions in sub-Saharan African countries (Al-Mulali et al. 2012), and these findings were corroborated by Shahbaz and Lean (2012) who obtained similar results for Tunisia. Ozturk and Acaravci (2013) found that financial development has no significant effect on per capita CO_2 emissions in the long run for Turkey. Tamazian et al. (2009) showed that a higher degree of economic and financial development decreases environmental quality in the BRICS countries. That study further observed that increased trade openness also caused an increase in environmental pressure. The effect was found to be much stronger for middle income countries than for low and high income countries. Ozturk and Al-Mulali (2015) found that trade openness increased CO_2 emissions in Cambodia.

From the above discussion, it is evident that the empirical literature offers mixed messages about the effects of financial development and trade openness on CO_2 emissions. To the best of the author’s knowledge, so far, no study of EF has involved these two variables. Therefore, further investigation of this relationship is justified.

5.4 Data and Methodology

5.4.1 Data

This study uses dynamic heterogeneous panel data for 27 countries, including Australia, for the period 1991–2012. The dependent variable used in the study is EF per capita while the core explanatory variable is real GDP per capita measured in constant 2005 US$. As bivariate models are likely to suffer from variable omission bias (Lean & Smyth, 2010), this study includes a number of other potential variables — financial development (FD), measured by private sector credit as a share of GDP, and trade openness (TO), measured by the total exports and imports as a share of GDP.

Logarithmic transformations of data were performed. The EF per capita used in this study is expressed as the amount of land required to support a typical individuals present consumption and associated waste assimilation. The consumption figure comes out through balancing exports and imports with domestic production. Thus, a trade corrected consumption figure is used.

5.4.2. The Model

In order to capture the effects of real GDP per capita and other variables on EF per capita, an econometric model of the following form is estimated:

$$LEF_{it} = \beta_0+\beta_1 LGDPCit +\beta_2 LFDit + \beta_3 LTOit + \varepsilon_{it} \quad (1)$$

where LEF is the log of EF per capita, LFD is the log of financial development, and LTO is the log of trade openness. The stochastic error term, $\varepsilon_{it} = \mu_i + \nu_{it}$ while $\mu_i \approx (0, \sigma^2 \mu)$ and $\nu_{it} \approx (0, \sigma^2 \nu)$ are independent of each other and among themselves. μ_i and ν_{it} denote country-specific fixed effects and time variant effects respectively. The subscripts i and t represent country (i= 1....27) and time period (1991–2012) respectively.

The coefficients, β_1, β_2 and β_3 represent the long-run elasticity estimates of EF with respect to real GDP per capita, financial development, and trade openness. The signs of the effects of the independent variables on EF cannot be anticipated a priori as the literature offers mixed evidence on these relationships. The data source for real GDP per capita, financial development, and trade openness was the World Development Indicators database and for EF per capita, the Global Footprint Network.

5.4.3 Estimation Procedures

The estimation starts by testing unit roots of the panel to assess the stationarity of data. Then the Pedroni co-integration test is employed to verify the co-integrating relationship among the variables. Having confirmed the presence of a co-integrating association, the group dynamic ordinary least squares (DOLS) (Stock and Watson 1993) method is employed to estimate the long-run relationship among the variables. Also the group mean fully modified ordinary least squares (GM-FMOLS) (Pedroni 1996, 2001) method is applied to check for the robustness of the obtained long-run coefficients from the group DOLS estimates. A panel Granger causality test is then conducted to assess causal association among the variables. Finally, the robustness of the causal association is checked by the application of the impulse response function and variance decomposition analysis.

5.4.3.1 Panel Unit Root Test

Since macroeconomic data are generally characterised by a unit root process, it is imperative to conduct unit root tests to examine whether the series are stationary or not. Therefore, a battery of appropriate panel unit root tests is conducted. First of all, a Levin, Lin and Chu (LLC) test was undertaken (Levin et al., 2002). The LLC test employs a null hypothesis of a unit root using the basic Augmented Dickey Fuller specification:

$$\Delta y_{i,t} = \rho_i y_{i,t-1} + \sum_{l=1}^{p} \alpha_{i,l} \Delta y_{i,t-1} + \beta_i \, d_{i,t} + \varepsilon_{i,t} \tag{2}$$

where, y_{it} refers to the stochastic process for a panel individual i=1 2, …N and each individual (country) containing t=1, 2, … T time-series observations $d_{it,}$ represents exogenous variables in the model, such as country fixed effects and individual time trends, while ε_{it} refers to the error terms, which are assumed to be mutually independent disturbances. This test determines whether y_{it} is integrated for each individual of the panel. The alternative hypothesis ρ_i is identical and negative. Because ρ_i is fixed across i, this is one of the most complicated of the tests because the data from the different individuals need to be combined into a single final regression.

The residual from regressions of $\Delta y_{i\,t}$ and $y_{i,t-1}$ is obtained using individual regression. Null is unit root, whereas the alternative is common stationary root. The major weakness of this test is that it assumes the individual processes to be cross-sectionally independent, which is unrealistic. To overcome this limitation, the current study conducted an Im, Pesaran and Shin (Im et al. 2003) panel unit root test. Im, Pesaran and Shin (Im et al. 2003) (IPS hereafter) begin by specifying a separate ADF regression for each panel with individual effect and no time trend, and it has the following form:

$$\Delta y_{i,t} = \alpha_i + \rho_i y_{i,t-1} + \sum_{l=1}^{p_i} \beta_{i,l} \Delta y_{i,t-l} + \varepsilon_{i,t} \tag{3}$$

Here, Δ is the first difference operator, and y_{it} is a white noise disturbance term with varianceσ^2. The null hypothesis of a unit root in the panel is defined as $H_0: \rho_i = 0$ for all i. This test allows for heterogeneity on the coefficients of the dependent variable. This test provides separate estimations for each cross-section, allowing different specifications of the parametric values, the residual variance, and the lag lengths. Also, this test was ideal for this empirical exercise in that this study uses balanced panel data considering the same sample period for all cross sectional units. Finally, an alternative approach to a panel unit root test uses Fisher's (1932) results to derive tests that combine the p-values from individual unit root tests. This test is proposed by Maddala and Wu (1999) and Choi (2001). The formula of the test is:

$$P = -2\sum_{i=1}^{N} \log_e \pi_i \tag{4}$$

If the individual unit root tests are augmented Dickey–Fuller tests (ADF) then the combined test performed according to equation (4) is referred to as a Fisher–ADF test. If instead the individual test is a Phillips–Perron test of unit root (PP) then the combined test is performed according to equation (4), which is referred to as a Fisher–PP test. The test is an asymptotically Chi-square distribution with 2N degrees of freedom. A big benefit is that the test can handle unbalanced panels. Furthermore, the lag lengths of the individual ADF tests are allowed to differ.

5.4.3.2 Panel Co-integration Test

Having found that all the series are stationary at first difference, next several panel co-integration tests, as suggested by Pedroni (1997), are conducted to examine whether a co-integrating relationship between the variables does exist. The reason for employing the Pedroni co-integration test is that it controls for country size and heterogeneity allowing for multiple regressors (as in this case). Pedroni (2000) provides seven panel co-integration statistics for seven tests for testing the null hypothesis of no co-integration. Four (i.e., panel-υ, panel-ρ, panel-ρρ, panel-ADF) of those are based on the within-dimension tests while the other three (i.e., group- ρ, group-ρρ, group ADF) are based on the between-dimension or group statistics approach. The relevant panel co-integration statistics provided by Pedroni (1999) use the following expressions.

Panel υ-statistic:

$$Z_v = \left(\sum_{i=1}^{N}\sum_{i=1}^{T}\hat{L}_{11}^{-2}\hat{e}_{it-1}^{2}\right)^{-1} \tag{5}$$

Panel ρ-statistic:

$$Z_p = \left(\sum_{i=1}^{N}\sum_{i=1}^{T}\hat{L}_{11}^{-2}\hat{e}_{it-1}^{2}\right)^{-1}\sum_{i=1}^{N}\sum_{i=1}^{T}\hat{L}_{11}^{-2}\hat{e}_{it-1}^{2}(\hat{e}_{it-1}\Delta\hat{e}_{it} - \hat{\lambda}_i) \tag{6}$$

Panel ρρ-statistic:

$$Z_t = \left(\widehat{\sigma}^2\sum_{i=1}^{N}\sum_{i=1}^{T}\hat{L}_{11}^{-2}\hat{e}_{it-1}^{2}\right)^{-1/2}\sum_{i=1}^{N}\sum_{i=1}^{T}\hat{L}_{11}^{-2}\hat{e}_{it-1}^{2}(\hat{e}_{it-1}\Delta\hat{e}_{it} - \hat{\lambda}_i) \tag{7}$$

Panel ADF statistic:

$$Z^{*}{}_{P} = \left(\hat{s}^{*2}\sum_{i=1}^{N}\sum_{i=1}^{T}\hat{L}_{11}^{-2}\hat{e}_{it-1}^{*2}\right)^{-1/2}\sum_{i=1}^{N}\sum_{i=1}^{T}\hat{L}_{11}^{-2}\hat{e}_{it-1}^{*2}(\widehat{e^{*}}{}_{it-1}\Delta\hat{e}_{it}) \tag{8}$$

Group ρ-statistic:

$$\tilde{Z}_p = \sum_{i=1}^{N}\left(\sum_{i=1}^{T}\hat{e}_{it-1}^{2}\right)^{-1}\sum_{i=1}^{T}(\hat{e}_{it-1}^{2}(\hat{e}_{it-1}\Delta\hat{e}_{it} - \hat{\lambda}_i) \tag{9}$$

Group ρρ-statistic:

$$\tilde{Z}_t = \sum_{i=1}^{N}\left(\widehat{\sigma}^2\sum_{i=1}^{T}\hat{e}_{it-1}^{2}\right)^{-1/2}\sum_{i=1}^{T}(\hat{e}_{it-1}^{2}(\hat{e}_{it-1}\Delta\hat{e}_{it} - \hat{\lambda}_i) \tag{10}$$

Group ADF statistic:

$$\tilde{Z}^{*}{}_{t} = \sum_{i=1}^{N}\left(\sum_{i=1}^{T}\hat{s}^{2}\hat{e}_{it-1}^{*2}\right)^{-1/2}\sum_{i=1}^{T}(\widehat{e^{*}}{}_{it-1}\Delta\hat{e}_{it}) \tag{11}$$

The null hypothesis of no co-integration for the panel co-integration test is the same for all statistics, H_0: $\gamma_i = 1$ for all i=1, … N, whereas the alternative hypothesis for the between-dimension-based and within-dimension-based panel co-integration tests differs. The alternative hypothesis for the between-dimension based statistics is H_1: $\gamma_i < 1$ for all i=1, …N. For within-dimension-based statistics, the alternative hypothesis is H_1: $\gamma = \gamma_i < 1$ for all i=1,…. N.

5.4.3.3 Group DOLS Estimation

Kao and Chiang (2000) apply dynamic OLS (DOLS) to panel co-integration estimation. Here, the DOLS estimator is slightly different from the original formulation because this study is interested in the between group estimator in which DOLS uses the past and future values of $\Delta X_{i,t}$ as additional regressors. The between-group panel DOLS regression can be written as follows:

$$Y_{i,t}^{*} = \alpha_i + \delta_i + \beta X_{i,t} + \sum_{k=-Ki}^{Ki} \gamma_{ik}\, \Delta X_{i,t-k} + u_{i,t}^{*} \tag{12}$$

$$\hat{\beta}_{DOLS}^{*} = \left[\frac{1}{N}\sum_{i=1}^{N}\left(\sum_{t=1}^{T} Z_i \acute{Z}_{i,t}\right)^{-1}\left(\sum_{t=1}^{T} Z_{i,t}\, \acute{Y}_{i,t}\right)\right] \tag{13}$$

where $Z_{i,t}$ is the 2(K+1)×1 vector of regressors $Z_{i,t} = (X_{i,t} - \overline{X}_i,\ \Delta X_{i,t-k} \ldots\ldots \ldots, \Delta X_{i,t+k})$, $\acute{Y}_{i,t} = Y_{i,t} - \overline{Y}_i$. A bar over a letter denotes a mean and the subscript 1 outside the brackets indicates the first elements of the vector, used to obtain the pooled slope coefficient. The associated t-statistic for the group-mean DOLS estimator can be constructed as:

$$t_{\hat{\beta}_{DOLS}^{*}} = \frac{1}{\sqrt{N}}\sum_{i=1}^{N}\left(\hat{\beta}_{D,i}^{*} - \beta\right)\left(\frac{1}{\hat{\sigma}_i^2}\sum_t\left(X_{i,t} - \overline{X}_i\right)^2\right)^{1/2} \tag{14}$$

Where $\hat{\sigma}_i^2$ is the long-run variance of the residuals from the DOLS regression and $\hat{\beta}_{D,i}^{*}$ is the conventional DOLS estimator. This t-statistic is standard normal as T and N approach infinity.

5.4.3.4 GM–FMOLS Estimation

Finally, GM–FMOLS is applied to estimate the long-run coefficients between the variables in order to check for the robustness of the DOLS estimation. The GM–FMOLS panel technique (Pedroni, 2001) takes into account the intercept and the endogeneity issue. The estimates are robust to endogenous regressors. It also removes omission variable bias and homogeneity restrictions on long-run parameters. The group-mean panel FMOLS estimator for Eq. (6) can be written as:

$$\hat{\beta}_{GFM}^{*} = \frac{1}{N}\sum_i\left[\frac{\sum_{t=1}^{T}(X_{i,t} - \bar{X}_i)Y_{i,t}^{*} - \hat{T}\gamma_i}{\sum_{t=1}^{T}\left(\sum_{t=1}^{T}(X_{i,t} - \bar{X}_i)\right)^2}\right] \tag{15}$$

Where, $Y_{i,t}^{*} = \left(Y_{i,t} - \overline{Y}_i\right) - \frac{\hat{\Omega}_{21,i}}{\hat{\Omega}_{22,i}}\Delta X_{i,t}$ and $\hat{\gamma}_i = \hat{T}_{21,i} + \hat{\Omega}_{21,i}^{0} - \frac{\hat{\Omega}_{21,i}}{\hat{\Omega}_{22,i}}\left(\hat{T}_{22,i} + \hat{\Omega}_{22,i}^{0}\right)$. Here, $\hat{\Omega}_i = \hat{\Omega}_{21,i}^{0} + \hat{T}_i + \hat{T}_{\acute{i}}$ is the estimated long-run covariance matrix of the stationary vector, consisting of the estimated residuals from the co-integration regression and the differences in savings rate. $\hat{\Omega}_{21,i}^{0}$ is the long-run covariance between the stationary error terms (ε_{it} in Eq. (6)) and the unit root autoregressive disturbances.

$\hat{\Omega}^2_{22,i}$ is the long-run covariance among the difference in savings rates. $\hat{T}_i$ is a weighted sum of the auto-covariances and a bar over these letters denotes the mean for i members. The associated t-statistic for the between-group FMOLS estimator takes the following form:

$$t_{\hat{\beta}^*_{GFM}} = \frac{1}{\sqrt{N}}\sum_{i=1}^{N}\left(\hat{\beta}^*_{FM,i} - \beta\right)\left(\hat{\Omega}^{-1}_{11,i}\sum_{t}\left(X_{i,t} - \bar{X}_i\right)^2\right)^{1/2} \qquad (16)$$

where β is a value under the null hypothesis. The above t-statistic is standard normal as T and N approach infinity.

5.4.3.5 Panel Vector Error Correction (VEC) Model for Granger Causality Test

In order to assess the causal direction of the relationship between variables, a panel VEC model framework is used (Granger, 1969). Information about the exact direction of the causal link enables a more pragmatic and policy-oriented discussion from the findings (Shahbaz et al., 2013). The potential causality pattern for this study is represented by the following VEC model specification in a multivariate framework:

$$\Delta EF_t = \beta_{0i} + \sum_{i=1}^{p}\beta_{1i}\,\Delta EF_{t-i} + \sum_{i=0}^{p}\beta_{2i}\,\Delta GDP_{t-i} + \sum_{i=0}^{p}\beta_{3i}\,\Delta FD_{t-i} + \sum_{i=0}^{p}\beta_{4i}\,\Delta TO_{t-i} \qquad (17)$$

5.4.3.6 Impulse Response Function and Variance Decomposition Analysis

Despite its importance for policy implications, one of the weaknesses of causality analysis is that it cannot predict the strength of the causal relationship beyond the sample period. Another limitation is that it provides only the direction of the relationship, not the corresponding sign. To overcome these limitations, this study applies an Innovation Accounting Approach (IAA), which consists of variance decomposition and generalised impulse response functions.

The generalised impulse response function indicates whether the impacts of innovations are positive or negative, and whether they have short- or long-term effects. Although the impulse response function traces the effect of a one standard deviation shock on the current and future values of all endogenous variables through the dynamic structure of VEC model, it does not provide the magnitude of such an effect. Consequently, a variance decomposition method is employed to examine this magnitude.

The variance decomposition (Pesaran & Shin, 1998) measures the percentage contribution of each shock in the dependent variable due to shocks in independent variables beyond the selected time period. Engle and Granger (1987) and Ibrahim (2005) argued that the variance decomposition approach produces more reliable results than other traditional approaches as it provides a means for forecasting the future relationship between the variables.

5.5 Results and Discussion

Table 5.1 presents descriptive statistics of the log values of all the variables. It reveals that the data are fairly dispersed around the mean. This justified further estimation of the data.

Table 5.1: Descriptive Statistics

Parameters	Variables			
	LEF	LFD	LGDPC	LTO
Mean	3.791470	4.199024	9.075008	18.31880
Median	4.212330	4.436348	9.843588	17.28067
Maximum	8.990830	5.535614	11.38512	169.5345
Minimum	0.747706	2.164433	5.731835	13.47472
Std. Dev.	2.196129	0.788919	1.574696	11.59797
Skewness	0.386835	-0.564738	-0.530031	12.15977
Kurtosis	2.151152	2.408407	1.840445	152.8446
Jarque-Bera	35.67089	43.96155	66.74697	623171.0
Probability	0.000000	0.000000	0.000000	0.000000
Sum	2460.664	2725.166	5889.680	11888.90
Sum Sq. Dev.	3125.292	403.3109	1606.825	87164.34
Observations	649	649	649	649

Table 5.2 presents the correlation matrix which clearly demonstrates that the model is free from multicollinearity.

Table 5.2: Variance Inflation Factors (VIFs)

Variable	VIFs
LFD	1.181739
LGDPC	1.204073
LTO	1.058342

Results from the panel unit root tests are reported in Table 5.3. All the variables are found to be first difference stationary, indicating the presence of unit root in the data. This implies that there may potentially be a co-integrating relationship among the variables.

Table 5.3: Panel Unit Root Test Results

Method		LEF	LGDPC	LPC	LTO
LLC-t*	Level	1.351 (0.99)	-0.843 (0.71)	-1.372 (0.00)*	-1.784 (0.03)*
	1st difference	-3.188 (0.00)*	-4.915 (0.00)*	-5.89 (0.00)*	-7.086 (0.00)*
IPS-W-stat	Level	2.379 (0.98)	2.413 (0.89)	-2.685 (0.03)*	-1.162 (0.04)*
	1st difference	5.714 (0.00)*	-3.182 (0.00)*	-8.44 (0.00)*	-6.711 (0.00)*
ADF-Fisher Chi-square	Level	34.26 (0.74)	36.75 (0.55)	64.63 (0.05)*	85.34 (0.02)*
	1st difference	108.71 (0.00)*	122.54 (0.00)*	142.12 (0.00)*	115.67 (0.00)*

*Notes: LLC, IPS and ADF-Fisher examine the null hypothesis of non-stationarity, and * indicates statistical significance at the 5% level. Probabilities for Fisher-type tests were computed by using an asymptotic $\chi 2$ distribution. All other tests assume asymptotic normality. The lag length is selected using the Modified Schwarz Information Criteria. All variables are in natural logarithms.*

Table 5.4 presents results from the Pedroni co-integration test. It is evident that the calculated values of six (panel-ρ, panel-ρρ, group-ρ, group-ρρ, and group-ADF) out of seven test statistics were greater than the critical values indicating rejection of the null hypothesis of no co-integration. Five of these six statistics have large negative values with associated probabilities less than 0.05. Therefore, the variables appear to be co-integrated at a reasonable significance level. Thus, it can be concluded that there is a long-run co-integrating relationship among the variables.

Table 5.4: Pedroni Residual Cointegration Test Results

Tests	Statistics	Prob.	Weighted statistic	Prob.
Alternative hypothesis: common AR coefficients (within-dimension)				
Panel υ-Statistic	2.313438	0.0103	0.459354	0.3230
Panel ρ-Statistic	-1.791246	0.0366	-1.527600	0.0633
Panel ρρ-Statistic	-6.792426	0.0000	-6.287883	0.0000
Panel ADF-Statistic	-3.496892	0.0002	-1.701898	0.0444
	Statistics		**Prob.**	
Alternative hypothesis: individual AR coefficients (between-dimension)				
Group ρ-Statistic	0.144494		0.5574	
Group ρρ-Statistic	-7.327811		0.0000	
Group ADF-Statistic	-1.898812		0.0288	

Results from the DOLS estimates are reported in Table 5.5. This indicates a positive and significant association between real income and EF. A 1% increase in real income sparks a 0.27% rise in EF. Financial development reduces EF. Trade openness is found to be insignificant in relation to the EF. This result is also in accordance with the findings of most of the earlier studies that estimated this relationship.

Table 5.5: Dynamic Least Squares (DOLS) Results

Variable	Coefficient	Std. Error	t-Statistic	Prob.
LFD	-0.148161	0.057845	-2.561360	0.0108
LGDPC	0.268220	0.060942	4.401208	0.0000
LTO	-1.51E-05	0.008103	-0.001865	0.9985
R-squared		0.994929	Mean dependent var	3.791470
Adjusted R-squared		0.990923	S.D. dependent var	2.196129
S.E. of regression		0.209227	Sum squared resid	15.84689
Long-run variance		0.044647		

Table 5.6 presents results from the GM–FMOLS estimates. From the estimates, it's found that a 1% increase in real income would stimulate a 0.19% increase in EF. Financial development and trade openness both stimulate EF but they are statistically insignificant in terms of p-value. Thus, the long-run coefficients obtained from the GM–FMOLS estimates are partially robust as the coefficients have no identical signs with equal numeric values except real income.

Table 5.6: Fully Modified Least Squares (FMOLS) Results

Variable	Coefficient	Std. Error	t-Statistic	Prob.
LFD	0.008544	0.049033	0.174247	0.8617
LGDPC	0.190382	0.047547	4.004088	0.0001
LTO	0.001402	0.001666	0.841812	0.4002
R-squared		0.983835	Mean dependent var	3.787875
Adjusted R-squared		0.983035	S.D. dependent var	2.193883
S.E. of regression		0.285754	Sum squared resid	47.84998
Durbin–Watson stat		0.665584	Long-run variance	0.169173

Table 5.7 reports the panel VEC model causality results. It shows that real income causes EF but not the other way round. It implies that there is unidirectional causality running from real income to EF. Financial development and trade openness also cause EF but their vectors are very insignificant. No causality is found between trade openness and real income, and between financial development and trade openness. The causal linkages between the variables are depicted in Figure 5.1.

Figure 5.1: Long-run Causality between Ecological Footprint, GDP, Financial Development and Trade Openness.

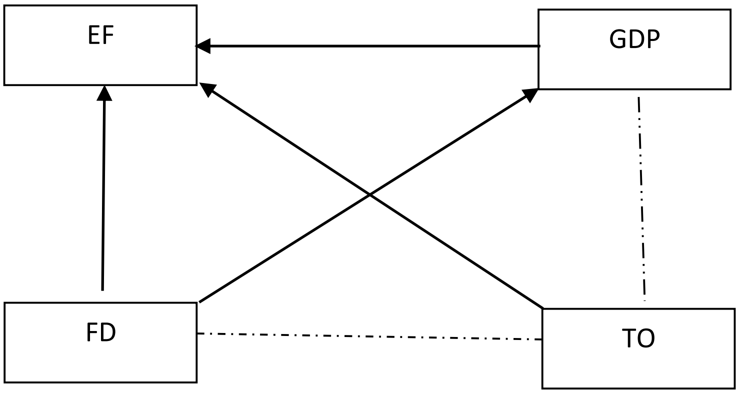


Table 5.7: Granger Causality Test Results

Null Hypothesis:	Observations	F-Statistic	Prob.
LFD does not Granger Cause LEF	618	0.33674	0.5619
LEF does not Granger Cause LFD		4.14392	0.0422
LGDPC does not Granger Cause LEF	646	3.45359	0.0636
LEF does not Granger Cause LGDPC		0.72799	0.3939
LTO does not Granger Cause LEF	641	0.15808	0.6911
LEF does not Granger Cause LTO		0.93353	0.3343
LGDPC does not Granger Cause LFD	618	0.91594	0.3389
LFD does not Granger Cause LGDPC		5.16199	0.0234
LTO does not Granger Cause LFD	616	0.06339	0.8013
LFD does not Granger Cause LTO		0.48019	0.4886
LTO does not Granger Cause LGDPC	641	0.68876	0.4069
LGDPC does not Granger Cause LTO		1.88398	0.1704

From Figure 5.2, it can be seen that the standard deviation of real income leads to a rise in future EF in the 27 countries studied. The responses of real income to the shocks in financial development and trade openness demonstrate expected signs but with different magnitudes. The accumulated response of real income to a shock in EF is positive and significant. The accumulated responses of real income to future shocks in financial development and trade openness are also positive and significant.

Figure 5.2: Impulse Response Functions

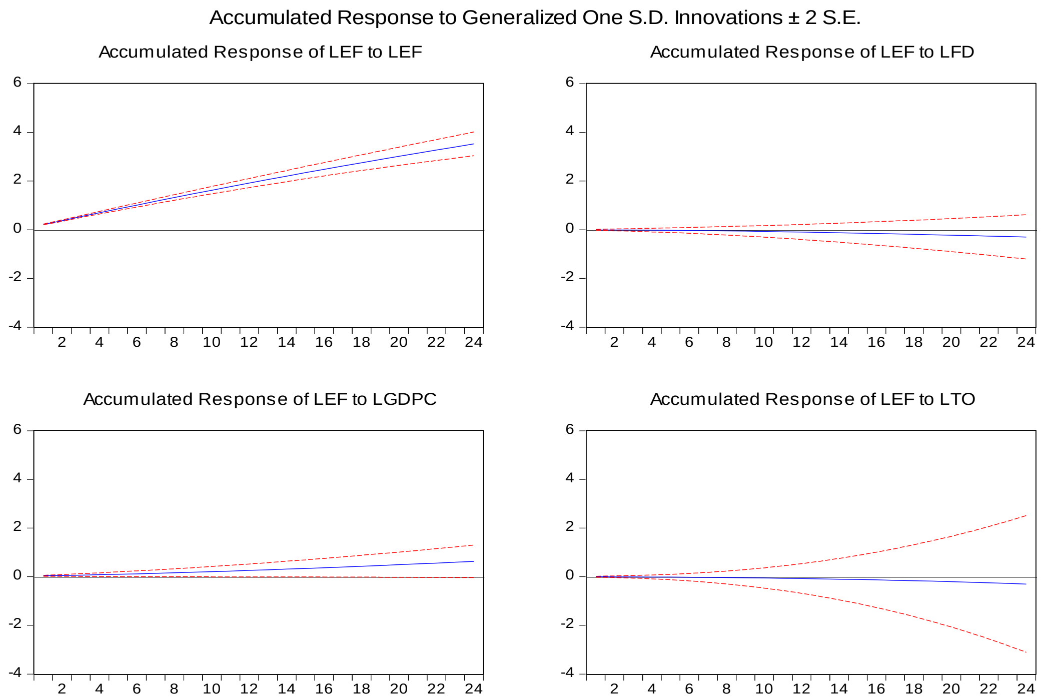


Table 5.8: Variance Decomposition Results

Period	S.E.	LEF	LFD	LGDPC	LTO
1	0.218362	100.0000	0.000000	0.000000	0.000000
2	0.267041	99.59858	0.016743	0.374047	0.010634
3	0.314896	99.55794	0.018146	0.416089	0.007821
4	0.353540	99.54672	0.015016	0.431979	0.006284
5	0.387920	99.56169	0.012792	0.418800	0.006715
6	0.418617	99.58047	0.013613	0.396311	0.009601
7	0.446539	99.59696	0.018040	0.369550	0.015448
8	0.472173	99.60734	0.026058	0.342001	0.024596
9	0.495903	99.60972	0.037411	0.315469	0.037395
10	0.518011	99.60301	0.051751	0.291055	0.054182
11	0.538715	99.58658	0.068701	0.269426	0.075298
12	0.558191	99.56002	0.087893	0.250989	0.101095
13	0.576579	99.52310	0.108979	0.235987	0.131939
14	0.593998	99.47560	0.131639	0.224554	0.168210
15	0.610546	99.41736	0.155588	0.216749	0.210305
16	0.626306	99.34821	0.180568	0.212579	0.258642
17	0.641352	99.26797	0.206355	0.212012	0.313658
18	0.655748	99.17644	0.232755	0.214990	0.375812
19	0.669548	99.07338	0.259599	0.221435	0.445588
20	0.682802	98.95851	0.286744	0.231252	0.523489
21	0.695555	98.83155	0.314070	0.244335	0.610050
22	0.707846	98.69213	0.341476	0.260569	0.705826
23	0.719713	98.53988	0.368882	0.279833	0.811404
24	0.731189	98.37438	0.396223	0.302001	0.927398

The variance decomposition analysis results are presented in Table 5.8. The results forecast that real income will have an increasing effect on EF into the future. In the first 5-year time horizon (up to 2017), 0.43% of the variation in EF is expected to be explained by real income followed by 0.42% and 0.29% in the 5th and 10th year, respectively. In the 21st year, the forecasted variance in the EF, to be explained by real income, stands at 0.24%. Other variables are also forecasted to continue to affect EF during the period. In the 21st year, 0.24%, 0.31% and 0.61% of the variations in EF are explained by real income, financial development, and trade openness respectively.

5.6 Conclusions

This chapter has examined the relationship between per capita EF and real income, financial development, and trade openness for a panel of 27 leading per capita EF contributors for the period 1991–2012. The stationarity of data was tested by a suitable panel unit root test. This was followed by Pedroni (1999) panel co-integration tests, which confirmed a co-integrating relationship among the variables. The DOLS method was applied to estimate the long-run relationship among the variables. Findings from the DOLS estimates indicate that real income (GDP per capita) is positively associated with EF per capita, whereas the impact of trade openness on EF is very minor, negative, and insignificant. Financial development is found to reduce environmental quality. The results are partially robust across another estimation method, GM–FMOLS. Panel VEC model suggests unidirectional causality running from real income to EF. Variance decomposition analysis indicates that real income would continue to contribute towards a rise in EF in these 27 countries into the future.

CO_2 has been the dominant component of humanity’s EF for more than half a century. In 1961 CO_2 was 36% of total EF but by 2010 it comprised 53% (WWF 2012). The carbon footprint is one of the six components of EF which compete the bioproductive surface area, and it represents the area of forest needed to sequester CO_2 emissions from fossil fuel burning at world average forest CO_2 sequestration rates (Lin et al. 2015). So, EF accounts track how much biocapacity is needed to sequester anthropogenic CO_2. If certain policies or actions lead to reduced CO_2 emissions or CO_2 is removed before it is emitted to the atmosphere, the carbon footprint would be smaller, which ultimately would reduce the size of the EF. Currently, CO_2 emissions are in excess of biological sequestration, therefore CO_2 is accumulating in the atmosphere, and the total footprint (including the fossil fuel footprint) exceeds the available productive capacity of the earth.

The empirical findings of this study suggest that countries are required to reduce EF and CO_2 emissions to a greater extent. Some countries have been trying to do so but they are still treated as significant contributors to EF and CO_2 emitters in the world. The UAE, Saudi Arabia, and Qatar have adopted Carbon Capture, Utilisation, and Storage (CCUS) facilities to combat CO_2 emissions. Post-combustion capture and carbon pricing strategies would also be cost-effective methods to reduce emissions. The use of renewable resources, such as solar and wind for power generation should be a priority for those countries.

CHAPTER 6

ECONOMIC GROWTH AND CARBON DIOXIDE EMISSIONS: AN EXTENDED ASSESSMENT

Summary: The use of fossil fuels in Australia has arisen largely as a result of the abundance of these non-renewable resources. However, high carbon dioxide (CO_2) emissions per unit of real GDP, resulting from burning fossil fuels, create new challenges for maintaining the growth–environment nexus sustainably. This chapter examines the dynamic impacts of population and economic growth, and energy consumption on CO_2 emissions, in the Australian context over the period 1961–2015. First, the ARDL bounds testing approach is used along with the Johansen–Juselius co-integration test to examine the long-term dynamic relationship between CO_2 emissions and economic growth. Explicit consideration is given to the impact of energy consumption and population growth in these multivariate models. Tests of the robustness of bounds results are also carried out using two single estimators — the dynamic OLS and fully modified OLS. Second, both the ARDL bounds testing and the Johansen–Juselius co-integration test confirm the long-run dynamic relationship among the variables, when CO_2 emissions level is considered as the regressive in the ARDL model. These results are also supported by the results from estimation using the dynamic OLS and fully modified OLS methods. Third, the study found both economic growth and energy consumption to be emissions intensive. The EKC hypothesis is valid for Australia over the study period, but population growth has no significant impacts on per capita CO_2 emissions. Finally, given its increasing levels of CO_2 emissions, Australia needs to place more emphasis on utilising renewable resources, such as biomass, biogas, biofuels, hydro, solar, and wind power to move toward a more sustainable future. The results of the chapter uphold the planned long-term investment in carbon-free environmentally-benign technologies, which are conducive to reducing CO_2 emissions without harming economic growth.

6.1 Introduction

Every economy, whether it is developed, developing, or under-developed, has a goal to achieve a desired level of economic growth to sustain its standard of living. But a number of environmental difficulties arise throughout the development process due to an excessive use of natural resources. Enhancing economic growth through using natural capital usually makes a country environmentally vulnerable. Global warming and climate change exacerbate this phenomenon, and countries are encouraged to ensure balance among these three important aspects — economic growth, CO_2 emissions, and energy consumption — which dominate the economy, the environment, and resources, respectively.

Levels of natural capital largely depend on the size of the economy, the level of technology, and the sectoral structure of the economy (Panayotou, 1993). A larger economy leads to more rapid depletion of natural resources and usually higher levels of pollution. Energy use is an engine of industrial development and economic growth, while energy inputs have a significant impact on environmental quality. The gradual increase in CO_2 emissions and their impact on the greenhouse effect shows the magnitude of this problem. Academics and policymakers have reached a consensus about the necessity to reduce emissions of GHG in order to mitigate global warming and climate change.

Australia's GDP has grown by more than 3% annually in each of the last three decades. The high correlation between energy consumption and real GDP contributes to high per capita GHG emissions. Its high GHG emissions intensity per unit of GDP is fuelled by the country's heavy reliance on coal-fired energy. These high emissions are mainly the result of the high emissions intensity of energy use, rather than the high energy intensity of the economy.

The energy intensity of an economy is a measure of the amount of energy used per unit of economic activity generated. On the other hand, the emissions intensity of energy is a measure of the amount of GHG emitted per unit of energy used. Energy associated with per capita emissions is the product of per capita GDP, energy intensity (of the economy) and emissions intensity (of energy). Low energy intensity is good for an economy because it enhances productivity, whereas low emissions intensity is good for the environment because it emits less CO_2 into the atmosphere.

According to Department of Environment (DOE), in 2014, Australia's net greenhouse gas emissions were 547.7 mega tonnes (Mt) of CO_2 equivalent (CO_2-e); CO_2 emissions intensity was 0.41 kg CO_2 per 2005 USD; total energy consumption was 5831 PJ; energy intensity was 3.741 GJ/$ million; energy use per capita was close to 248 GJ;

while CO_2 emissions were 18.59 metric tonne per capita (DOE, 2015). Australia's energy consumption relies solely on non-renewable energy. Non-renewable energy is produced by burning fossil fuels such as coal (1845.6 PJ, i.e. 31.7%), oil (2237.8 PJ, i.e. 38.4%), and gas (1401.9 PJ, i.e. 24.0%), which represented 94.1% of total energy needs in Australia in 2013–14 (Department of Industry and Science 2015).

These non-renewable energy resources are finite sources of fossil fuels. One day they will run out due to excessive extraction. On the other hand, renewable energy sources like biomass, biogas, biofuels, hydro, wind, and solar accounted for the remaining almost 6% of total energy needs. Burning fossil fuels is the key determinant of increased CO_2 in the atmosphere, while CO_2 emissions in the atmosphere are the main contributor to the build-up in GHG, which is mostly responsible for global warming through depletion of the ozone layer. For Australia, CO_2 emissions per capita show a gradual increasing pattern with GDP per capita.

Most previous empirical studies have used cross-country panel data to estimate the relationship between income and environmental quality, using the EKC hypothesis postulated by Kuznets (1955). Compared to cross-country studies, time-series studies are fewer in number and their findings have different implications. In support of this view, Dinda (2004) declared that time-series data analysis provides a more complete picture of the relationship between pollution and particular phases of economic development in individual countries. Critically analysing the estimation techniques, Lieb (2003) declared that time-series analyses are more appropriate than cross-country studies in explaining the EKC hypothesis. Lindmark (2002) argued that cross-country studies provide only a general understanding of how the variables are related to each other, and this offers little guidance for policymakers. However, Stern (1998) concluded that there has not been enough explicit empirical testing of the theoretical models, and that there is insufficient rigorous and systematic analysis of the economy–environment relationship. A new trend in the EKC literature is to focus on an individual country instead of multiple countries (Mbarek et al. 2014; Saboori et al. 2012; Kohler 2013; Soytas et al. 2007). In line with this argument, this thesis is an attempt to investigate the dynamic relationship between CO_2 emissions and real GDP per capita for an individual country — Australia.

The purpose of this chapter is to examine the dynamic relationship amongst CO_2 emissions, energy consumption, and economic growth in Australia over the period 1961–2015, using ARDL bounds testing and Johansen co-integration techniques. The robustness of the ARDL and Johansen co-integration results are tested by two single estimators — the dynamic OLS and modified OLS methods. In contrast to previous studies that have investigated the nexus between CO_2 emissions and economic growth for a panel of different countries, this study is concerned only with Australia.

The remainder of this chapter is organised as follows. Section 6.2 presents a review of the relevant literature; Section 6.3 introduces the data, empirical models, and estimation strategies; Section 6.4 outlines the empirical results and the robustness of the model is discussed in Section 6.5; and Section 6.6 concludes the study.

6.2 Literature Review

The post 1945 rates of economic growth are widely recognised as an achievement of modern society (de Bruyn 2000). In the early 1970s, the Club of Rome's report 'The Limits to Growth' (Meadow et al. 1972) warned the world against the detrimental effects of continuous economic growth. Since then, various research, opinions and findings have been put forward for, and against, the effects of economic growth on environmental quality. de Bruyn (2000) categorised four different supporters and their perspectives on the influence of economic growth on environmental quality.

The 'radical supporters' of economic growth postulate that economic growth fuels technological innovations and changes in lifestyles that will improve environmental quality (Simon, 1981; Beckerman, 1992). The policy implications of this perspective are measures to stimulate economic growth and remove barriers which hamper the development of new technology. The second perspective — the 'conditional supporter' — also assumes a positive link between economic growth and environmental quality (Grossman & Krueger, 1995). They believe that economic growth is a pre-requisite for improved environmental quality.

The 'weak antagonist' takes a more sceptical perspective on the desirability of economic growth. The decline in environmental quality can be mitigated by environmental policies, but these are less effective in a growing economy. Reducing the growth of ' dirty sectors' of the economy is also required to enhance environmental quality (Arrow et al. 1995). Finally, the “strong antagonist” states that in the long run, economic growth is always harmful to the environment. Mitigating environmental policies may have a temporary positive effect on environmental quality, but no substantial improvements in environmental quality can be made without affecting the growth path (Meadows et al. 1972).

The various theoretical perspectives have merely illustrated the important mechanisms that shape the relationship between growth and the environment, but have not solved the controversies in the growth-versus-environment debate. With the invention and diffusion of computer technology, economists started to incorporate environmental aspects into their micro and macro-economic models (Solow 1956), but these models did not solve the growth–environment controversies. Since the early 1990s, the empirical validation of the influence of economic growth on environmental quality has reached a new and challenging stage. Grossman and Krueger (1991, 1995), Shafik and Bandyopadhyay (1992), Panayotou (1993), and Seldeon and Song (1994) interpreted the EKC hypothesis in their studies. They showed that there is an inverted-U relationship between the type of pollutants and income level.

A sizeable amount of literature on the pollution–income relationship of the EKC hypothesis has grown in recent decades. The common theme of most of these studies is the assertion that environmental quality deteriorates in the early stages of economic development and improves in the later stages (Bond et al., 2015). Dinda (2004) showed that pollution increases rapidly in the first stage of development because there is higher priority given to increasing material output. This rapid growth inevitably results in greater use of natural resources and emissions of pollutants, which in turn puts more pressure on the environment. In the later stages of development, as income rises, people value the environment more, and regulatory institutions become more efficient and pollution levels decline.

Although the EKC hypothesis with the U-shaped relationship has been confirmed by some previous studies, most studies have revealed non-conformity to the EKC hypothesis by evidencing the inverse relationship between CO_2 emissions and economic growth. Arrow et al. (1995) remarked that nothing has been proven; although the EKC may show that environmental policy is effective in reducing some types of pollution, this is not related to fundamental characteristics of environmental quality.

A large number of empirical studies have explored the dynamic relationship between economic growth and the environment in the past few decades. In most cases, CO_2 emissions were used as the main indicator of environmental quality as the dependent variable for some specific areas or regions, such as GCC countries (Salahuddin, 2013); BRIC countries (Pao & Tsai 2011a); MENA countries (Arouri et al. 2012); OECD countries (Shafiei & Salim 2014); CIS countries (Apergis & Payne 2010); and ASEAN countries (Lean & Smyth 2010).

Single-country studies have also been conducted to study this relationship, for instance, Tunisia (Mbarek et al., 2014); China (Bloch et al., 2012); South Africa (Kohler 2013); Brazil (Pao & Tsai 2011b); Vietnam (Binh 2011); Canada (He & Richard 2010); Malaysia (Saboori et al. 2012); Turkey (Seker & Cetin 2015); South Korea (Baek & Kim 2013); the USA (Soytas et al. 2007); India (Tiwari 2011); and Nigeria (Essien 2011). In these studies, the dynamic relationships between economic growth and CO_2 emissions show U-shaped, inverted U-shaped, N-shaped, and inverted N-shaped relationships based on the distinct characteristics of each individual economy.

In Australia, there is very limited research on the dynamic relationship between economic growth, CO_2 emissions, and other variables. Table 6.1 summarises the variables used, findings, analytical techniques, and empirical results and limitations of previous studies. To date, only four studies have been found in Australia that have focused on economic growth and environmental implications. Using data for the period 1965 to 2006, Shahiduzzaman and Alam (2012a) investigated the relationship between per capita CO_2 emissions and per capita GDP in Australia, while controlling for technological state as measured by multifactor productivity and export of black coal. The empirical findings in their study showed evidence of the existence of both short and long-run EKC relationships among the variables, applying the ARDL bounds testing and Johansen–Juselius maximum likelihood approaches. However, their study ignored the other variables such as energy consumption and population growth. The researchers used black coal as a proxy for energy consumption, but coal represents only 31.7% of the entire energy consumption by fuel type in Australia, while an earlier study by Narayan and Smyth (2003) used electricity consumption as a proxy for energy consumption, which represents only 27.1% of net energy consumption by industry type in Australia (DIS, 2015), to reveal the interdependency with real income. Hence, the representation of energy consumption in these two studies did not capture the robust impact on CO_2 emissions for Australia.

The most recent two studies are Salahuddin and Khan (2013) and Shahbaz et al. (2015b). Salahuddin and Khan (2013) attempted to reveal the empirical link between economic growth, energy consumption and CO_2 emissions in Australia using VAR with generalised impulse response function techniques, but they did not accommodate the possibility of structural breaks in the time-series data used in their study. Shahbaz et al. (2015b) introduced single, instead of multiple, structural breaks in their study. Nevertheless, each of these studies has its own merits to better understand the economic growth–environmental quality nexus.

Table 6.1: Summary of Studies on CO_2 Emissions, Economic growth and other Variables in Australia

References	Variables used	Techniques	Results	Limitations
Shahiduzzaman and Alam 2012a	CO_2, GDP, export of black coal	ARDL bounds testing to co-integration	Existence of EKC between CO_2 and GDP	Ignore other variables such as energy consumption and population
Shahbaz et al. 2015	CO_2, GDP, energy consumption, population, globalisation	VEC model Granger Causality test with variance decomposition	Energy consumption is emissions intensive	Absence of stability check of the VEC model. Single structural break instead of multiple structural break test
Salahuddin and Khan 2013	CO_2, GDP, energy consumption	VAR with Generalised Impulse Response	Energy consumption has positive impact on CO_2 emissions	Absence of checking structural break of time series data
Narayan and Smyth 2003	Electricity consumption, employment and real income	Multivariate Granger Causality test	Both long- and short-run relationships among the variables	Absence of checking structural break of time-series data

Considering the above empirical literature, the outcomes demonstrated a mixed relationship between economic growth and CO_2 emissions. This might be due to different stages of economic development of the studied countries, different time periods, and the design and nature of estimation techniques. However, this current study would be the first attempt to investigate the dynamic relationship between the variables in Australia, accounting for the limitations of earlier Australian studies. Energy consumption and population growth are included as explanatory variables, because omitted variables often produce misleading results from the OLS estimation; this also helps to fill the research gaps. It seems that none of the earlier research conducted on Australian time-series data accounted for multiple structural breaks, which has important implications for theories and empirical studies in macroeconomics.

6.3 Methodology

6.3.1 Data and Models

Economists have devised a number of distinct models for studying the determinants of CO_2 emissions. For example, Saboori et al. (2012) derived an empirical model from the standard EKC hypothesis and estimated an ARDL version of the VEC model to determine the magnitude of the impacts of economic growth on CO_2 emissions; Shafiei and Salim (2014) applied the STIRPAT model, while Pao and Tsai (2011a) used the autoregressive integrated moving average (ARIMA) model to predict the variables. Many studies (Alshehry & Belloumi 2015; Masih & Masih 1996; Asafu-Adjaye 2000) also used the EKC hypothesis within the VAR–ECM framework to find the determinants of environmental pollution.

Most of the existing literature supports the dependency of income/output on energy consumption, which is considered as one of the most important impacting factors of CO_2 emissions. Therefore, this chapter aims to investigate the interrelationship between CO_2 emissions, energy consumption, and economic growth. For this purpose, the Cobb–Douglas (1928) production function is employed to investigate the linkage between the variables including labour as an additional factor of production. The standard form of the Cobb–Douglas production function is as follows:

$$Y_i = \int(AL_i, K_i) \tag{1}$$

where, $\int(K,\ L)$ = $AK^{\alpha}L^{1-\alpha}$. Y_i is the total production (the real value of all goods produced in i period) measured by real GDP per capita, while K_i represents capital (the real value of all machines, equipment, and building). AL_i refers to effective worker (as the labour input signifies the number of effective labour hours). Since CO_2 emissions are enhanced by economic activities according to the EKC (Grossman and Kruger 1995; Seldeon and Song 1994) and decomposition literatures (Zhang and Ang 2001; Lindmark 2004), therefore, the function of CO_2 emissions can be written as:

$$CO_{2i} = \delta \int (AL_i, K_i) = \delta \int Y_i) \tag{2}$$

where, δ represents the share of CO_2 emissions. In the Cobb–Douglas functional form, capital assets (K) is composed of renewable and non-renewable resources. Non-renewable resources, such as coal, natural gas, and oil, are responsible for almost 96% of CO_2 emissions in Australia. Therefore, the CO_2 emissions function in respect of non-renewable resources can be written as:

$$CO_{2i} = \tau \int (EC_i(AL_i\,, K_i) = \tau\ \int (EC_i(\,Y_i) \tag{3}$$

where τ represents the share of CO_2 emissions responsible for non-renewable (EC_i) resources from the Cobb–Douglas functional form. In addition, population is considered the key driving force for environmental impact, taken from the IPAT identity designed by Ehrlich and Holdren (1971). Thus, the model can be reformulated accommodating the population variable in the following form:

$$CO_{2i} = \lambda_0 + \lambda_1 GDP_i + \lambda_2 EC_i + \lambda_3 P_i + \varepsilon_i \tag{4}$$

Since the EKC hypothesis (Stern 2003; Grossman & Kruger 1995) places emphasis on the possibility of a U-shaped relationship between the CO_2 emissions and GDP per capita, this study also incorporates the quadratic term of GDP per capita into the model in the following way:

$$lnCO_{2i} = \lambda_0 + \lambda_1 lnGDP_i + \lambda_2 GDP_i^2 + \lambda_3 lnEC_i + \lambda_4 lnP_i + \varepsilon_i \tag{5}$$

where the coefficients of real GDP per capita (GDP), the quadratic term of GDP per capita (GDP^2), energy consumption per capita (EC), and population (P) are $\lambda_1, \lambda_2,\ \lambda_3$ and λ_4 respectively, with an error term ε_t. All variables were transformed to natural logarithms for regression analysis; therefore, the coefficients present the long-run elasticity estimates of CO_2 emissions per capita with respect to the other variables. Real GDP per capita was measured in US dollars, using purchasing power parity rates and adjusted for inflation. CO_2 emissions are those stemming from the burning of fossil fuels — including CO_2 produced during consumption of solid, liquid and gas fuels and gas flaring — and were measured in metric tonnes per capita. Energy consumption was measured in gigajoules (GJ) per capita, where 1000 kg of oil equivalent is equal to 42 GJ. Energy use refers to use of primary energy before transformation to other end-use fuels, which is equal to indigenous production plus imports and stock changes, minus exports. It includes energy consumed in energy conversion activities, such as electricity generation and petroleum refining, but excludes derived fuels produced domestically, in order to avoid double counting. Population size is taken as a proxy of labour input. Data for these variables are annual and were obtained from three different sources: (i) World Development Indicators, World Bank (2015), (ii) International Monetary Fund (IMF 2015), and (iii) Australian Government, Department of Industry and Science (DIS 2015).

6.3.2 Estimation Strategies

In line with the methodologies used in earlier studies, this study used the autoregressive distributed lag (ARDL) bounds testing approach along with the Johansen and Juselius (1990) co-integration technique to reveal the dynamic relationships among the variables. Then the robustness of the ARDL results was tested by employing single estimators, dynamic OLS and modified OLS. In the initial stage of the estimation process, this study employed unit root tests to find out the order of integration. Most previous researchers have used the ADF (Dickey & Fuller, 1979) and PP (Philip & Perron, 1988) tests, but these tests are low power against $I(0)$ alternatives that are close to being $I(1)$; and the power of unit root tests diminishes as deterministic terms are added to the test regressions. So, they are size distorted to reject $I(1)$ too often, when in fact it is true. Using a generalised least squares (GLS) rationale, Elliot, Rothenberg and Stock's (ERS) modified DF unit root test (Elliott et al. 1996) seems to solve these small sample and power problems. They constructed the DF-GLS test for unit root as follows:

$$\Delta y_t^d = \pi y_{t-1}^d + \sum_{j=1}^{p} \varphi_j \, \Delta y_{t-j}^d + \varepsilon_t \tag{6}$$

where y_t^d is the de-trended series, and the null hypothesis of this test is that y_t has a random walk trend with drift term. The Kwiatkowski, Phillips, Schmidt, and Shin test (KPSS) (Kwiatkowski et al. 1992) was also conducted in this study complementary to the DF–GLS test, since it may be used to verify the results and to investigate the possibility that a series is fractionally integrated (that is, neither $I(1)$ nor $I(0)$). It has perhaps a more intuitive null in that the series being tested is stationary, that is, $H_0 = Y \tilde{} I(0)$. The KPSS test statistic is the Lagrange Multiplier (LM) or score statistic for testing $\sigma_\epsilon^2 = 0$ against the alternative that $\sigma_\epsilon^2 > 0$, and is given by:

$$KPSS = \left(T^{-2} \sum_{t=1}^{T} \hat{S}_t^2\right) / \hat{\lambda}^2 \tag{7}$$

where T is the sample size, S^2 is the Newey-West estimate, and S_t is the partial sum of errors. If the DF–GLS test fails to reject its null of a unit root, and the KPSS test rejects, then the evidence from both tests is supportive of a unit root in the series. The maximum lag order for the test was calculated using a rule provided by Schwert (1989).

Once the integration process was confirmed, the next stage of estimation employed ARDL bounds testing by Pesaran and Shin (1998) and Pesaran et al. (2001) to estimate the co-integrating relationships among the studied variables. To execute the ARDL bounds testing process, it was necessary to determine the optimum lag length of the model for the value of joint F-statistics. This study used the general to the specific modelling approach guided by Schwarz–Bayesian Information Criterion (SBIC). Pesaran and Shin (1998) showed that with the ARDL framework, the OLS estimators of the short-run parameters are consistent and the ARDL-based estimators of the long-run coefficients are consistent, even in small sample sizes. The ARDL approach was estimated using the following unrestricted error correction mechanism:

$$\Delta lnCO_2 = \delta_1 + \sum_{k=1}^{n} \beta_{1,k}\, \Delta lnCO_{2\,t-k} + \sum_{k=1}^{n} \beta_{2,k}\, \Delta lnGDP_{t-k} + \sum_{k=1}^{n} \beta_{3,k}\, \Delta lnGDP_{t-k}^2 + \sum_{k=1}^{n} \beta_{4,k}\, \Delta lnEC_{t-k} + \sum_{k=1}^{n} \beta_{5,k}\, \Delta lnP_{t-k} + \lambda_1 LnCO_{2\,t-1} + \lambda_2 lnGDP_{t-1} + \lambda_3 lnGDP_{t-1}^2 + \lambda_4 lnP_{t-1} + \nu_{1,t} \tag{8}$$

The null hypothesis of the joint F-test resulting from Equation 8, $H_0\colon \lambda_1 = \lambda_2 = \lambda_3 = \lambda_4 = 0$, implied that there is no co-integration among the variables. A rejection of H_0 implies that the variables have a long-run relationship. The acceptance or rejection of the hypothesis depends on the computed F-statistic and the critical value provided by Pesaran et al. (2001). However, exact critical values for the F-test are not available for an arbitrary mix of $I(0)$ and $I(1)$ variables. Pesaran et al. (2001) supplied bounds on the critical values for the asymptotic distribution of the F-statistic. For different numbers of variables (k+1), they provided lower and upper bounds of the critical values. In each case, the lower bound is based on the assumption that all of the variables are $I(0)$, and the upper bound is based on the assumption that all of the variables are $I(1)$. If the computed F-statistic falls below the lower bound, the study would conclude the absence of co-integration, by definition. If the F-statistic exceeds the upper bound, the study would conclude that there is co-integration. Finally, if the F-statistic falls between the bounds, the test would be inconclusive. Following the ARDL approach, the Johansen and Juselius (1990) co-integration test was carried out to reinforce the findings of the study. The Johansen and Juselius (1990) co-integration test based on the error correction representation is as follows:

$$\Delta \Upsilon_t = \alpha + \varphi C_t + \sum_{i=1}^{N-1} \Gamma_i \Delta \Upsilon_{t-i} + \Pi \Upsilon_{t-n} + \varepsilon_t \tag{9}$$

where either Υ_t or Υ_{t-i} represents the column vector of n variables and includes the natural logarithm of the variables; Δ is the first difference operator; α is the vector intercept term; C_t represents the trend term; Γ and Π refer to coefficient matrices; N is the lag order of the model; and ε is a white noise disturbance term. The coefficient matrix Π is known as the impact matrix and it contains information about the long-run relationships. The number of co-integrating vectors (r) that exist among the variables is determined by estimating the rank of the matrix Π based on the trace and maximum eigenvalue statistics. The trace and maximum statistics were calculated by the equations as follows, respectively:

$$\lambda max = -\mathrm{T} \ln(1 - \lambda_i) \tag{10}$$

$$\mathrm{Trace} = -\mathrm{T} \sum_{i=r+1}^{n} \ln(1 - \lambda_i) \tag{11}$$

The Max-Eigen test statistic of Equation 10 was determined under the null hypothesis $\mathrm{H}_0: r_0 = r$, against the alternative hypothesis $\mathrm{H}_A: r_0 > r$. The trace test statistic of Equation 11 was determined under the null hypothesis $\mathrm{H}_0: r_0 \leq r$, against the alternative hypothesis $\mathrm{H}_A: r_0 > r$, where r_0 represents the number of cointegrating vectors. The two tests were performed sequentially for $r = 0$ to $r = N - 1$ until the study failed to reject the null hypothesis. Once the co-integration procedure was completed, the next step was to proceed with the estimation of the long-run coefficient of the ARDL model using Equation 12 as follows:

$$lnCO_{2\,t} = \delta_1 + \sum_{k=1}^{n} \alpha_{1,k}\, lnCO_{2\,t-k} + \sum_{k=1}^{n} \alpha_{2,k}\, lnGDP_{t-k} + \sum_{k=1}^{n} \alpha_{3,k}\, lnGDP_{t-k}^{2} + \sum_{k=1}^{n} \alpha_{4,\ k}\, lnEC_{t-k} + \sum_{k=1}^{n} \alpha_{5\,,k}\, lnP_{t-k} + \nu_{1,t} \tag{12}$$

Next the error-correction framework was estimated to represent the short-run dynamics of the respective variables along with speed of adjustment towards the long-run equilibrium rate. The error correction presentation of the ARDL model shows how quickly the variables return to the long-run equilibrium, and takes the form of:

$$\Delta lnCO_{2\,t} = \delta_1 + \sum_{k=1}^{n} \vartheta_{1,\ k} \Delta lnCO_{2\,t-k} + \sum_{k=1}^{n} \vartheta_{2,\ k} \Delta lnGDP_{t-k} + \sum_{k=1}^{n} \vartheta_{3,\ k} \Delta lnGDP_{t-k}^{2} + \sum_{k=1}^{n} \vartheta_{4,\ k} \Delta lnEC_{t-k} + \sum_{k=1}^{n} \vartheta_{5,\ k} \Delta lnP_{t-k} + \varphi ect_{t-1} + \nu_{1,t} \quad (13)$$

where φ represents the adjustment coefficient and ect is the error correction term. In the following stage of estimation, this study examined the stability of the coefficients of the ARDL model by testing the cumulative sum of recursive residuals (CUSUM) and the cumulative sum of square of recursive residuals (CUSUMsq) methods by Pesaran and Pesaran (1997). Concurrently, the stability of the ARDL model further verified whether all of the inverse roots of the characteristics equations associated with the model lie strictly inside the unit circle.

Conventional unit root tests do not accommodate structural breaks in the time-series data. Hence, the outcomes of these unit root tests lead to a bias that reduces the ability to reject a false unit root null hypothesis (Perron 1989). Several studies (Ben-David et al. 2003; Lumsdaine & Papell, 1997) even argued that merely accommodating a single break is insufficient and leads to a loss of information when actually more than one break exists. So the sequential Bai–Perron (Bai–Perron 2003) multiple structural breaks test measured in favour and was used for both the asymptotic theory and empirical applications.

Once the nature of the relationships among the variables was established this study used variance decomposition analysis to assess how each variable responds to innovations in other variables. These innovations are carried out through an ARDL framework with vector error corrector (VEC) model, within Cholesky ordering. Following the decomposition analysis, this study also applied the impulse response function to trace the effects of a shock to one endogenous variable on other variables.

Based on the distinct natures of single estimators, dynamic OLS (Stock and Watson 1993) and modified OLS, this study finally demonstrated the robustness of the outcome of the models. This study used the dynamic OLS for two reasons. First, it can easily be applied in nonstationary time-series regressions; second, it accounts for potential endogeneities among the variables. Apart from correcting for endogeneity and the serial correlation effect, the fully modified OLS also asymptotically eliminates the sample bias in a semi-parametric way (Phillips & Hansen 1990).

6.4 Empirical Results

Prior to estimation of co-integration, it is not inevitable to verify the unit root in favour of the ARDL methodology prescribed by Pesaran et al. (2001). Nevertheless, this study estimated the integration using DF–GLS and KPSS unit root tests to ensure that no variable exceeded the order of *I*(1). The results of DF–GLS and KPSS tests are presented in Table 6.2.

Table 6.2: DF–GLS and KPSS Unit Root Test Results

Variables	**DF-GLS test**			**KPSS test**		
	t-Stat.		Critical values at 5% level	t-Stat.		Critical values at 5% level
	Levels	First differences		Levels	First differences	
CO_2	-1.111	-7.721	-3.174	0.236	0.097	0.146
GDP	-1.630	-5.714	-3.174	0.204	0.093	0.146
GDP^2	0.043	-6.318	-3.174	0.204	0.133	0.146
EC	-1.112	-9.550	-3.174	0.199	0.033	0.146
P	0.951	-3.593	-3.174	0.161	0.168	0.216

Notes: The DF–GLS unit root test for all the variables is carried out at the 5% level of significance. All the results are given with intercept and trend term in regression. Each DF–GLS t-statistic is reported for shortest lag length, which has been chosen based on minimum AIC.

The DF–GLS test statistics for all the series are below the critical values in levels form but higher than the critical values in first-differenced form in absolute terms. But the KPSS test outcome is opposite to that of the DF–GLS test. As the DF–GLS test fails to reject its null hypothesis but the KPSS test rejects it, these two unit root tests clearly reveal that the time series variables are non-stationary in nature. Therefore, the presence of opposite results from the DF–GLS and KPSS tests confirm the application of the ARDL approach and consequently, CO_2 emissions per capita, GDP per capita, the quadratic term of GDP per capita, energy consumption, and population variables are integrated of order one (1).

The choice of optimum lag length is necessary in the ARDL bounds test because the appropriate selection of lag order determines the value of the F-statistics. Usually, the maximum lags are determined by using one or more of the "information criteria", namely Akaike Information Criterion (AIC), Schwarz–Bayesian Information Criterion (SBIC), and HQ (Pesaran et al. 2001). These criteria are based on a high log-likelihood value, with a "penalty" for including more lags to achieve this. The form of the penalty varies from one criterion to another; the smaller the value of an information criterion, the better the result. Given the VAR-based lag order selection presented in Table 6.3, a maximum lag of 1 was chosen for each variable according to the results of the selecting lag order criteria, which is valid due to the absence of residual serial correlation.

Table 6.3: Test Statistics and Choice for Selecting Lag Order in the Model

Lag	LR	FPE	AIC	SBC	HQ
0	NA	1.83e+14	47.03101	47.21863	47.10294
1	638.9087	4.47e+08*	34.10323*	35.22894*	34.53480*
2	38.90465*	4.46e+08	34.11587	36.17969	34.90709
3	22.34919	7.03e+08	34.45660	37.34851	35.60746
4	25.01971	9.44e+08	34.61105	38.55106	36.12156

*Notes: LR: Sequential modified LR test statistic (each test at the 5% level). FPE: Final prediction error. AIC: Akaike Information Criterion. SBIC: Schwarz-Bayesian Information Criterion. HQ: Hannan-Quinn Information Criterion. *denotes lag order selected by each criterion.*

Subsequently, the existence of a co-integrating relationship based on the F-test for the joint significance of the coefficient of the lagged variables was examined. The results of the bounds tests for co-integration are summarised in Table 6.4, in which each variable was normalised as a dependent variable.

When CO_2 emissions is the response variable, the estimated F-statistic value is 5.743, which is higher than the upper bound critical value of 3.79 of Pesaran et al. (2001) at the 5% significance level. This result indicates that the null hypothesis of no co-integration is rejected, which means that there is a co-integrating relationship among CO_2 emissions, energy consumption, population, and economic growth. In addition to Pesaran critical value, this chapter also applied Narayan's (2005) critical value to compare the estimated F-statistics obtained from the Wald joint test of significance for the respective lagged variables.

Table 6.4: Bounds Tests for Co-integration Results

Dep. Var.	F-stat.	Prob.	Outcome* (5% level of significance)	
			Pesaran et al. (2001)	Narayan (2005)
F_{CO2}(CO2, GDP, GDP^2, EC, P)	5.743	0.000	Cointegration	Cointegration
F_{GDP}(GDP, CO_2, GDP^2, EC, P)	1.792	0.139	No co-integration	No co-integration
F_{GDP2}(GDP^2, GDP, CO_2, EC, P)	1.585	0.188	No co-integration	No co-integration
F_{EC}(EC, CO_2, GDP, GDP^2, P)	4.232	0.003	Co-integration	Inconclusive
F_P(P, CO2, GDP, GDP2, EC)	2.517	0.027	No cointegration	No co-integration

Significance level	Critical value			
	Pesaran et al. (2001)*		Narayan (2005)**	
	Lower bound, I(0)	Upper bound, I(1)	Lower bound, I(0)	Upper bound, I(1)
1%	3.41	4.68	3.95	5.58
5%	2.62	3.79	2.90	4.28
10%	2.26	3.35	2.43	3.60

*Notes: *Critical value based on CI (iii) on p. 300 of Pesaran et al. (2001) table. **Narayan (2005), Table CIII (III): unrestricted intercept and no trend, p. 1990. Outcome presented at 5% level of significance.*

When CO_2 emissions is the dependent variable, the estimated F-statistic value is 5.743, which is higher than the upper bound critical value of 4.28 of Narayan (2005) at the 5% significance level. Consequently, the long-run co-integrating relationship among the respective variables was recognised when CO_2 emissions were normalised as a response variable. Likewise, when economic growth and population are considered as dependent variables, the estimated F-statistic values, 1.792 and 2.517, respectively fall below the lower bound of the critical value of both Pesaran et al. (2001) and Narayan (2005) statistics, which implies that no long-run co-integration is present. Conversely, when energy consumption is considered as a dependent variable, the estimated F-statistic value, 4.232, falls above the upper bound of the critical values of both Pesaran et al. (2001) and falls between the upper and lower bounds of Narayan (2005) statistics, which implies co-integration and inconclusive evidence respectively of co-integration.

The Johansen–Juselius co-integration test was also applied in order to strengthen the results obtained from the ARDL bounds testing. The results are reported in Table 6.5. The value of the trace statistic is equal to 81.73, which is higher than the 5% critical value of 69.82, which infers rejection of the null hypothesis of no co-integration, $r_0 \leq 0$. On the other hand, the null hypothesis of one cointegrating equation $r_0 \leq 1$, cannot be rejected given that the trace statistic value 47.40 is not superior to the 5% critical value 47.86. Hence, the trace test indicates the significance of one co-integrating equation at the 5% level of significance.

Table 6.5: Results of Johansen–Juselius Co-integration Tests

Hypothesised No. of CE(s)	**Trace test**			**Max-Eigen test**	
	Eigenvalue	Trace Statistic	5% critical value	Max-Eigen statistic	5% critical value
None ($r=0$)	0.476744	81.72941	69.81889	34.32730	33.87687
At most 1* ($r\leq1$)	0.359443	47.40210	47.85613	23.60710	27.58434
At most 2($r\leq2$)	0.249409	23.79500	29.79707	15.20542	21.13162
At most 3($r\leq3$)	0.110938	8.589579	15.49471	6.232194	14.26460
At most 4($r\leq14$	0.043504	2.357384	3.841466	2.357384	3.841466

*Note: *Trace and Max-eigenvalue test indicates 1 co-integrating equation at the 0.05 level. *denotes rejection of the hypothesis at the 5% level.*

In the same way, the value of the Max–Eigen statistic is equal to 34.33, which is higher than the 5% critical value of 33.87, which infers rejection of the null hypothesis of no co-integration $r_0 \leq 0$. On the other hand, the null hypothesis of one cointegrating equation $r_0 \leq 1$, cannot be rejected, given that the Max–Eigen statistic value 23.61 is not superior to the 5% critical value 27.58. Hence, the Max-Eigen test also indicates the significance of one co-integrating equation at the 5% level of significance. Therefore, both the value of the trace statistic and the Max–Eigen statistic are statistically significant, indicating the presence of at least one co-integrating equation at the 5% level of significance between CO_2 emissions per capita and its determinants. This indicates the existence of a long-run relationship between per capita CO_2 emissions, real GDP, population, and energy consumption for Australia.

Table 6.6: Long-run Relationship: ARDL Model

Regressor	**Coefficient**	**Standard error**	**T-ratio**	**Prob.**
GDP	0.2028	0.0478	4.2518	0.000
GDP^2	-0.0353	0.008	-4.3166	0.000
EC	0.4176	0.1718	2.4296	0.018
P	0.3711	0.1882	1.9719	0.054
Diagnosis test-statistic	*Serial correlation*	*p-value*	*D-W statistic*	*Adj. R-squared*
	0.9238	0.0657	1.9966	97.18%

Note: Estimated long-run coefficients using the ARDL approach based on the SBIC. The dependent variable is per capita CO_2 emissions. Significant at the 5% level.

Once co-integration was established, Equation 12 could be estimated to identify the long-run elasticity of the respective variables on CO_2 emissions. The estimated long-run coefficient of GDP per capita is positive and statistically significant, which implies that the CO_2 emissions initially rise with an increase in GDP per capita, as shown in Table 6.6. Nonetheless, the coefficient of the quadratic form of GDP per capita is negative but statistically significant, which indicates that the relationship between CO_2

emissions and economic growth is monotonic. This delinking relationship between CO_2 emissions and the quadratic form of GDP per capita confirms the inverted U-shaped pattern of the EKC, which demonstrates the inverse relationship between environmental degradation and increased affluence. The estimated coefficient for GDP is significant at the 5% level and implies that a 1% increase in per capita GDP will increase per capita CO_2 emissions by 0.20% in the long run. The coefficient of GDP^2 is also significant at the 5% level and has the expected negative sign. This result is similar to the earlier study by Shahiduzzaman and Alam (2012a) of 0.34% for GDP and 0.23% for GDP^2, respectively. The positive sign for GDP and negative sign for GDP^2 suggest a delinking relationship between per capita CO_2 emissions and per capita GDP in the case of Australia. This test also finds the significant impact of energy consumption to CO_2 emissions but population growth shows less emissions intensity.

Table 6.7 ARDL Model: ECM Estimates

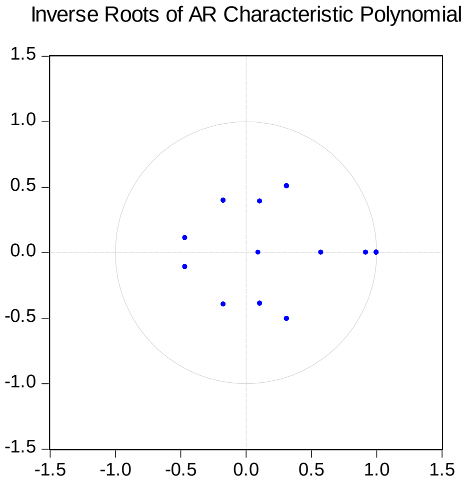
Regressor	Coefficient	Standard error	T-ratio	Prob.
ΔGDP	0.0698	0.1868	0.3739	0.710
ΔGDP^2	-0.0573	0.3031	-0.1890	0.851
ΔEC	0.0480	0.2722	0.1766	0.860
ΔP	1.4150	1.0226	1.3833	0.173
ΔECT (-1)	-0.4856	0.1729	-2.803	0.007
Diagnosis test-statistic	***Serial correlation*** 0.7388	***p-value*** 0.9537	***D-W statistic*** 1.9892	

Note: Error correction representation of the ARDL model based on SIC. The dependent variable is per capita CO_2 emissions for estimations from 1960 to 2015. Significance of 5% level.

To investigate the short-run dynamics, the error correction presentation in Equation 9 was estimated, and results are presented in Table 6.7. Results indicate that the short-run dynamic behaviour of the variables is not consistent with the long-run relationship found earlier. The coefficients are not significant for the short-run, but the coefficient of the error correction term, ECT (-1), is negative and significant, which confirms the existence of a long-run relationship, as revealed by both the Johansen–Juselius test and ARDL bounds testing approach of co-integration. The magnitude of the coefficient of ECT (-1) implies that nearly 5% of any disequilibrium among the variables is corrected within one year. The coefficient of the equilibrium correction mechanism (ECM) is 0.49, which is significant at the 5% level and implies that disequilibrium in the short-run is adjusted by 0.49% per year towards the long-run equilibrium.

The ARDL model passed several diagnostic tests in order to validate the results with Durban Watson statistics, serial correlation with the Breusch Godfrey Lagrange Multiplier (LM) test (Breusch, 1978; Godfrey, 1980), and misspecification of functional form, normality of the residuals, or heteroscedasticity problems of the model estimated in the study. This chapter also provides information about the dynamic stability of the estimated ARDL model, in terms of whether or not the inverted roots of the characteristic polynomial lie within the unit root circle. Figure 6.1 shows the roots are all inside the unit circle, which confirms the stability of the ARDL model.

Figure 6.1: Inverse Roots of AR Characteristic Polynomial



To check the stability of the coefficients, the cumulative sum of recursive residual (CUSUM) and sum of squares of recursive residual (CUSUM of squares) were tested. Graphically, these statistics are plotted within two straight lines bounded by the 5% significance level. It is clear from Figure 6.2 and 6.3 that the plots of both the CUSUM and the CUSUMsq are within the boundaries and hence these statistics confirm the non-rejection of the null hypothesis, implying the stability of the long-run coefficients of the ARDL model.

Figure 6.2: Cumulative Sum of Recursive Residual

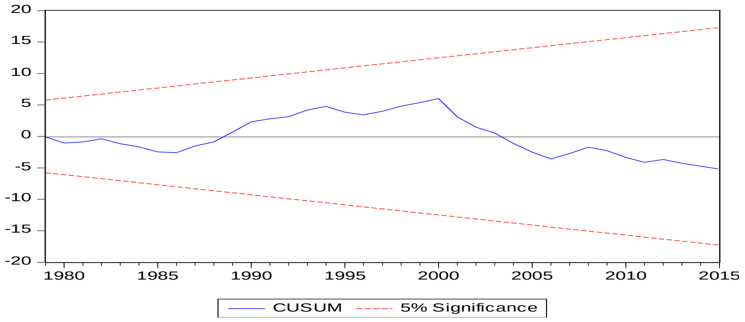
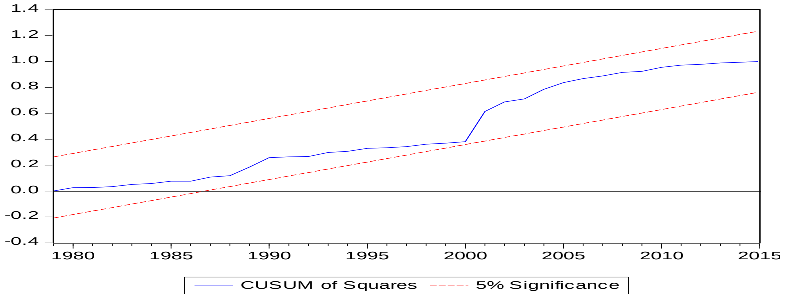


Figure 6.3: Sum of Squares of Recursive Residual



The sequential Bai–Perron (Bai–Perron, 2003) test was also conducted to check whether there are any structural breaks in the time series data and their impact on estimated parameters. The findings from Bai–Perron multiple structural breaks are presented in Table 6.8. This test allows for a maximum number of 5 breaks, employing a trimming percentage of 15%, and using the 5% significance level. The test selects the error distributions to differ across breaks to allow for error heterogeneity. The study rejects the nulls of 0 and 1 breakpoints in favour of the alternatives of 1 and 2 breakpoints, but the test of 2 versus 3 breakpoints does not reject the null hypothesis. The sequential test results indicate there are two breaks (1978 and 1990) in the time series data.

Table 6.8: Bai–Perron (2003) Sequential Structural Break Test Result

Sequential F-statistic determined breaks: 3			
Break Test	**F-statistic**	**Scaled F-statistic**	**Critical Value****
0 vs. 1 *	16.92268	67.69072	16.19
1 vs. 2 *	6.290937	25.16375	18.11
2 vs. 3	4.358232	17.43293	18.93
Break dates: Sequential (1990;1978) Repartition (1978;1990)			

*Notes: *Significant at the 0.05 level. **Bai–Perron critical values.*

The 1990–91 recession and the culmination of financial deregulation and innovation in the 1980s in the Australian economy are associated with different structural breaks found in the time-series data. These findings are identical to those of earlier studies by

Layton et al. (2005) and Shahbaz et al. (2015b), but the results did not capture the oil/wages shocks occurring in the early 1970s, and the Asian Crisis in 1997. Apart from substantial exchange rate depreciation, the impact of the Asian Crisis on the Australian economy was surprisingly mild (Duncan & Yang 2000).

This study presents the findings using the generalised forecast error variance decomposition to forecast over a 10-year period, with results presented in Appendix 6A. Results indicate that 47.27% of the variation in CO_2 emissions is attributable to its own innovative shocks, whereas the contribution of GDP, GDP square, energy consumption and population growth to variations in CO_2 emissions are equal to 36.98%, 4.44%, 2.70%, and 8.60%, respectively. One standard deviation shock in GDP per capita explains 84.23% of its own innovative shocks. CO_2 emissions are responsible for 0.03% of the variance in GDP per capita, and energy consumption is responsible for 0.44% of the variance in GDP per capita. The results also show that 53.72% of the variance in energy consumption is explained by its own innovative shocks. The contribution of CO_2 emissions per capita, GDP per capita, GDP quadratic term and population growth to variance in energy consumption are equal to 3.57%, 9.34%, 11.49%, and 21.86%, respectively.

Results of the impulse response function are shown in Appendix 6B and 6C. The impulse response function shows the reaction of one variable to shocks in other variables. The response of per capita CO_2 emissions to a shock in per capita GDP gradually decreases over the 10-year period, and to a shock in per capita energy consumption, initially decreases, then makes balances from the 4th year up to the 10th year. The response of per capita GDP to a shock in per capita CO_2 emissions and energy consumption is identical. The response of per capita energy consumption to a shock in per capita CO_2 emissions increases rapidly from the initial year, and to a shock in per capita GDP, it increases gradually.

6.5 Robustness Analysis

This study tested two additional econometric single estimation approaches — dynamic OLS and fully modified OLS — to reinforce the results of the ARDL bounds and Johansen co-integration tests. The prime benefit of the dynamic OLS approach is that it considers the presence of a mixed order of integration of the respective variables in the co-integrated framework. The fully modified OLS test (Phillips & Hansen, 1990) was conducted over the dynamic OLS (Stock & Watson, 1993), subject to eliminating endogeneity in the regressors and serial correlation in the errors.

The result from dynamic OLS is less consistent than that of the fully modified OLS with the ARDL, according to the sign and significance of the coefficient, as presented in Table 6.9. The fully modified OLS test displays the Durbin–Watson statistic of 1.61, which differs qualitatively from the dynamic OLS results. The comparative test statistics indicate that a more significant result is achieved using the fully modified OLS compared to the dynamic OLS, to establish the long-run relationships among the variables. The positive sign with GDP and negative sign with GDP^2 suggest the delinking relationship between per capita CO_2 emissions and per capita GDP in the case of Australia. The positive and statistically significant coefficient of GDP indicates that CO_2 emissions increase with a rise in GDP growth during the initial stages of the sample period. The negative sign and significant coefficient of GDP square confirms the EKC hypothesis in the case of Australia. These findings are compatible with the history of economic growth and CO_2 emissions in Australia. The coefficients of energy consumption and population growth are positive but not significant, implying that these two variables are not emissions intensive when estimated using the dynamic and fully modified OLS methods.

Table 6.9 Results of the DOLS and FMOLS Methods

Variables	**Coefficients**		**t-Statistic**		**Prob.**	
	DOLS	FMOLS	DOLS	FMOLS	DOLS	FMOLS
GDP	0.4603	0.2028	2.6499	4.1862	0.013	0.00
GDP^2	-0.0725	-0.0393	-3.4889	-4.9330	0.01	0.00
EC	0.1707	0.3801	0.4416	2.6904	0.66	0.00
P	0.9877	0.9883	0.9178	3.1206	0.35	0.00
	DOLS			**FMOLS**		
Adjusted R-squared	96.38%			97.57%		
Durbin–Watson statistic	1.5763			1.6116		

6.6 Conclusions

This chapter has investigated the dynamic relationship between economic growth and environmental quality in Australia. CO_2 emissions per capita was considered a proxy for environmental quality, and real GDP per capita was considered a proxy for economic growth in the estimation process. Energy consumption per capita and population growth were hypothesised as key determinants of CO_2 emissions, and the quadratic term of real GDP per capita was applied to test the existence of the EKC hypothesis in the growth–environment nexus. This chapter has focused on the question of whether continued economic growth will degrade or alleviate environmental quality in Australia.

This chapter used the modified ADF (ADF–GLS) and KPSS tests to measure the order of integration of the time series data. The ADF–GLS test was used considering the overall performance of the small sample size, power, and de-trending capabilities of the series; on the other hand, the KPSS test was used complementary to the ADF–GLS test, since it accommodates any order of integration, i.e. either $I(0)$, $I(1)$ or mutually integrated series, to avoid spurious regression. Both tests confirmed the validity of the non-stationarity of the series in levels form but stationarity for first-differenced form.

The ARDL bounds test is performed in comparing the value of the joint F-statistic of the coefficients with the Pesaran et al. (2001) and Narayan (2005) critical values, to reveal the nature of co-integrating relationship among the variables. In addition to ARDL bounds testing, the Johansen co-integration test was also deployed to support the outcome of the ARDL test more firmly. Both tests confirmed the co-integrating relationship, while CO_2 emissions per capita was used as the dependent variable in the model. Optimum lag length was also determined by SBC to execute the ARDL bounds and Johansen co-integration tests. A maximum lag of one was chosen for each variable in this study.

Following the co-integration process, the long-run elasticity of the respective variables on CO_2 emissions was then traced, followed by the short-run dynamics through the error correction mechanism of the ARDL framework. The results obtained suggest the existence of a robust long-run relationship among per capita CO_2 emissions, real GDP per capita, population growth and energy consumption, when CO_2 emissions levels are the regressive in the model. However, the error correction mechanism of the ARDL framework showed the non-significance of short-run coefficients; the coefficient of the error correction term (ECT) was 0.49, which is significant at the 5% level and implied disequilibrium in the short run is adjusted by 0.49% per year towards the long-run equilibrium. Overall, an inverted-U shaped relationship among CO_2 emissions and income was found in the long run, according to the time series analysis. Hence, the results support the EKC hypothesis for Australia. In this study, consistency of the parameters was assessed through applying the CUSUM and the CUSUMsq tests proposed by Brown et al. (1975). The results clearly indicate the absence of any instability of the coefficients, because the plot of the CUSUMsq statistics is confined within the 5% bounds of parameter stability.

Next, the presence of multiple structural breaks was tested using the method proposed by Bai and Perron (1998). The test detected two structural break dates — 1978 and 1990 — which are associated with the second oil price shock and financial deregulation in the early 1980s, and the 1990—91 recession in the Australian economy (Narayan & Smyth 2005). However, the structural break test did not address the possibility of the commodity booms and the first oil price shock in the early to mid-1970s, and another break date of 1997 in the Australian economy resulting from the Asian Crisis, which seems inconclusive in this study.

Using variance decomposition analysis, it was forecasted how each variable responded to innovations in other variables during a 10-year period. The results showed that the contribution of GDP, quadratic term of real GDP per capita, energy consumption, and population growth to CO_2 emissions per capita are equal to 36.98%, 4.44%, 2.70%, and 8.60% respectively. On the other hand, the impulse response function was used to trace the effects of a shock to one endogenous variable on the other variables. The results depicted the response of per capita real GDP, per capita energy consumption, and population growth to changes in per capita CO_2 emissions. Finally, dynamic OLS and fully modified OLS methods were used to measure the robustness of the earlier results. The results of long-run relationships among the variables achieved by the ARDL and Johansen co-integration tests are identical to the dynamic OLS and fully modified OLS results.

The finding of a positive relationship between economic growth and CO_2 emissions is partially in line with the results of other Australian studies by Shahbaz et al. (2015a) and Shahiduzzaman and Alam (2013). The differences in the study findings may be due to the different control variables, the longer study period, and different estimation strategies. Energy consumption per capita has a strong and positive impact on CO_2 emissions, because a huge proportion of CO_2 emissions in Australia comes from energy consumption. This relationship is also supported by many other studies, e.g.

Begum et al. (2015); Alshehry and Belloumi (2015); Apergis and Payne (2011); and Salahuddin and Khan (2013).

Despite the contemporary initiatives taken by Australia to reduce CO_2 emissions, the country is still releasing a significant level of emissions into the atmosphere. The rise in per capita CO_2 emissions is of huge concern in light of increasing demand for energy consumption and continuing high rates of economic growth. Therefore, this study recommends several policy options, which are discussed in chapter 8, to minimise this environmental pressure.

CHAPTER 7

POPULATION CHANGES AND IMPLICATIONS FOR THE ECONOMY AND THE ENVIRONMENT IN REGIONAL AUSTRALIA

Summary: Australia is made up of many diverse regions, from busy interconnected urban areas to isolated remote communities. Over one-third of Australians live outside of the capital cities, commonly referred to as 'regional Australia'. The overall growth of the population has been faster in recent times than ever before, but there are enormous spatial variations and changes of age-structure of population within regional Australia. Having these variations and changes in age-structure had significant impacts on the regional economy and the environment in Australia? To answer this question, this part of the thesis offers a critical review of the literature. The aim of this review is to provide an overview of population dynamics and their impacts on the regional economy and the environment. They then need to be compared to the empirical results obtained in the previous chapters of this thesis. The review reveals that the majority of the studies report positive effects of population changes with regional economic growth, and negative effects with regional environments. The results differ in various regional, social, cultural, and economic contexts and there is no uniform accepted direction among regional population changes, economic growth, and environmental quality. Nevertheless, the findings of this review of regional Australia confirm the similarities to the empirical findings of previous chapters of the thesis of Australia as a whole. This chapter fulfils the need of a comprehensive review of regional population changes and their impact on regional economies and the environment. From a regional policy perspective, the findings of the study recommend that there is a need for quantitative research to critically assess how regional population changes affect the regional economy and the environment.

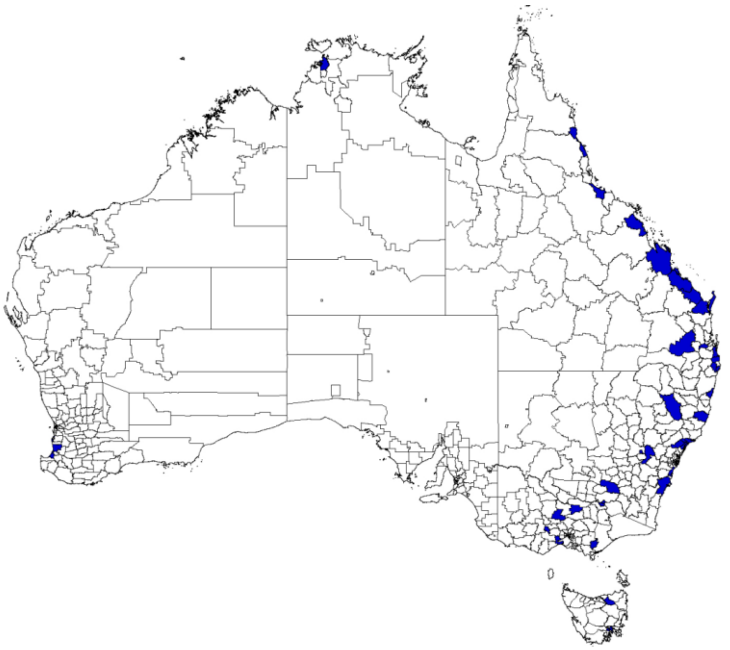
7.1 Introduction

'Regional Australia' refers to the non-metropolitan areas of the nation that lie beyond the major capital cities and their immediate surrounding suburbs (RAI 2015a). Generally, there is no rigid specification to classify the regions in Australia (Freebairn, 2003). Any given specification would vary with the nature of the analysis, the purpose of the research, the cost, and the availability of data. For analysis of census data, the

ABS (2005) has categorised these data into four regions of remoteness criteria: major cities; inner regional and outer regional; remote; and very remote and migratory. Based on the Accessibility/Remoteness Index (ARIA), the Department of Health of Aged Care (DHAC) has used the regional classification as rural, remote and metropolitan areas (DHAC 2001). By contrast, the Australian Bureau of Agricultural and Resource Economics (ABARE) has categorised the spatial areas into: capital cities; other metropolitans; coastal; remote and inland (ABARE 2001). In its latest classification, RAI (2015a) has divided Australia into four regional areas: regional cities; connected lifestyle regions; industry and service hubs; and heartland regions, based on their diversities and challenges.

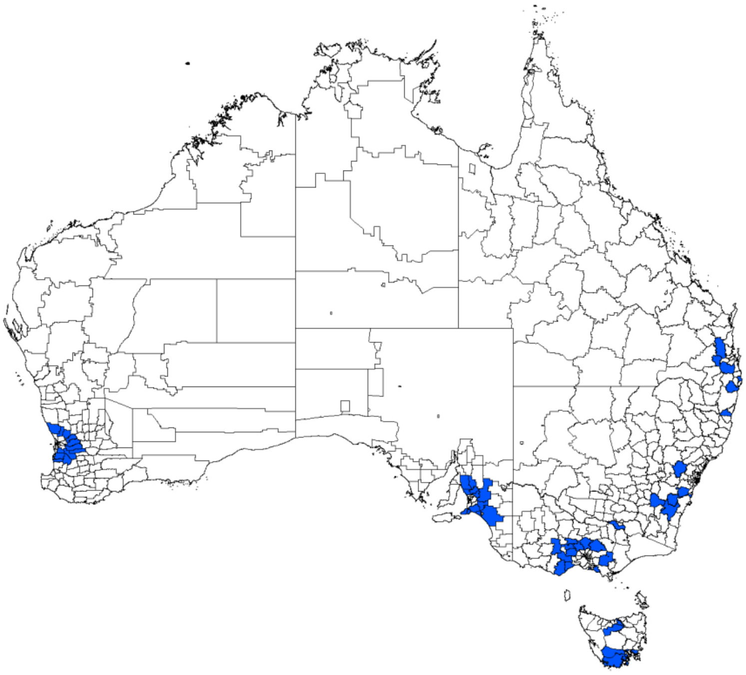
The first type of region of RAI ‘regional cities’ comprises 50 regions of over 50,000 people in each region (Appendix 7A). These regional cities are spread all over Australia (Figure 7.1). There is no dominating industry that accounts for more than 20% of the workforce in the region. The second type of area is called the ‘connected lifestyle region’ (Appendix 7C). Technology and human capital are the two major assets in these areas and, as they have close proximity to the metropolitan cities, they are influenced by the connectivity of the cities (Figure 7.2).

Figure 7.1: **Regional Cities**



Source: Regional Australia Institute (RAI), 2015a.
(Note: The name of the shaded region is mentioned in Appendix 7A.)

Figure 7.2: Connected Lifestyle Areas



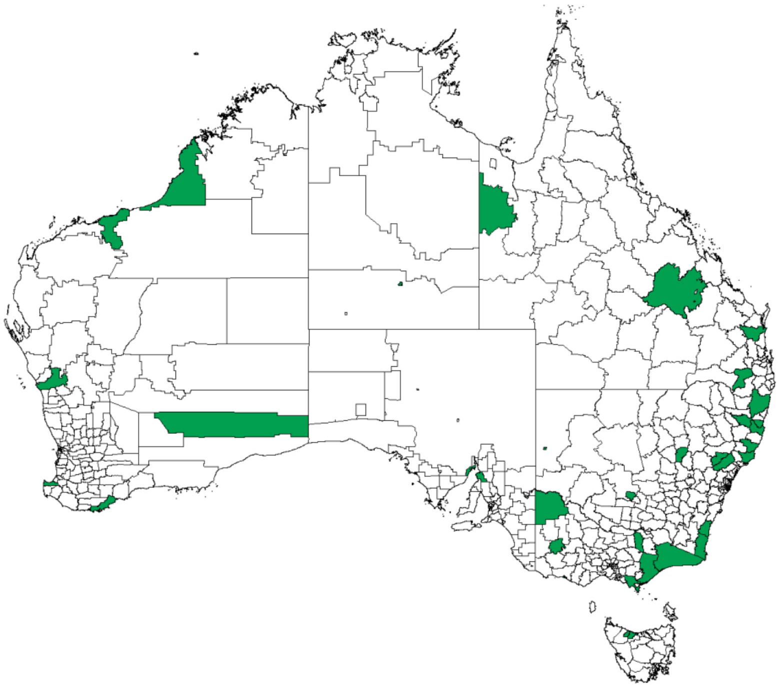
Source: Regional Australia Institute (RAI), 2015a.
(Note: The name of the shaded region is mentioned in Appendix 7B.)

'Industry and Service Hub' is the third type of regional area, and refers to 15,000–50,000 people in each area (Appendix 7E). Around 6% of people live in these areas. The mining and agriculture sectors dominate this region. Some of Australia's oldest towns are included in this type (Figure 7.3). The people of these regions have learned to survive with the inevitable ups and downs that affect the two main local industries. The last type of regional area, 'heartland region' (Appendix 7G), is the smallest of the regional areas. These are the most diverse and include more than 250 smaller and remote rural and coastal places (Figure 7.4). The future of these regions depends on a few dominant industries and the creativity of local leaders and institutions.

There are hundreds of regional communities in Australia and each one is unique in terms of its varied characteristics. Each regional economy has strong connections to the national economy through the key drivers of economic growth. The regional areas include 15% of the Australian population (Department of Transport, 2015); however, they cover 85% of the Australian land mass. Due to natural resources and primary industries, regional areas produce 40% of Australia's GDP and almost 67% of exports.

Nevertheless, this area is significantly disadvantaged in comparison with the capital cities in terms of incomes, services and opportunities (Sorensen, 2000).

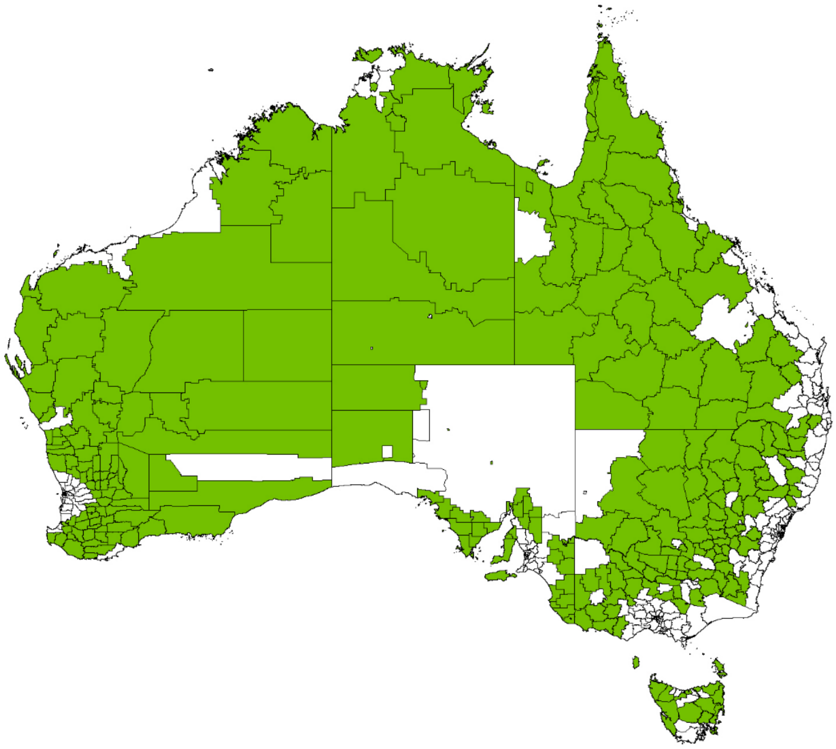
Figure 7.3: Industry and Service Hubs



Source: Regional Australia Institute (RAI), 2015a.
(Note: The name of the shaded region is mentioned in Appendix 7C.)

Presently there is considerable variation in population changes and disparities amongst different regions in Australia. Almost all countries are experiencing growth in regional disparities, although the extent and form these take can differ significantly (Tomaney, 2012). Generally, large cities have grown at the expense of smaller cities and rural areas. In Australia, this phenomenon is often expressed as the emergence of a 'two speed' or 'patch-work' economy (Dufty-Jones & Wray 2013). These changes are not simply the function of economic changes, they result from an important and complex relationship with the regional economy and environment (RAI 2015b). Many environmental threats and impacts are linked to growing human population (Hobday & McDonald 2014).

Figure 7.4: Heartland Regions



Source: Regional Australia Institute (RAI), 2015a.
(Note: The name of the shaded region is mentioned in Appendix 7D.)

Many studies (Sorensen 2000; McGuirk & Argent 2011) have considered the influence of population changes either on the economy or the environment. The consideration of future numbers of people, their changes, variation, and where they live is of national significance (Hugo 2010). However, there is a scarcity of research on regional Australia that considers both economic and environmental implications of regional population changes. This chapter aims to conduct a comprehensive review of regional population changes and their impact on regional economies and the environment.

This chapter is organised as follows: Section 7.2 describes the methodology; Section 7.3 describes the population dynamics of regional Australia; Section 7.4 presents the findings of a review of population changes on regional economies and environment; and finally, conclusions are outlined in Section 7.5.

7.2 Methodology

This part of the thesis attempts to reveal the dynamics of population changes and their implications for economic growth and the environment of regional Australia. To explore this objective an investigation of past research has undertaken. Australian research papers and related documents were collected from different online databases using the key words: regional Australia, population changes, economic growth, and environment. Google Scholar yielded a collection of more than 200 articles including journal articles, government documents, conference proceedings, book chapters, book reviews, and reports. A total of more 100 documents were studied and assessed in terms of the nature of their research, level of analysis and their application.

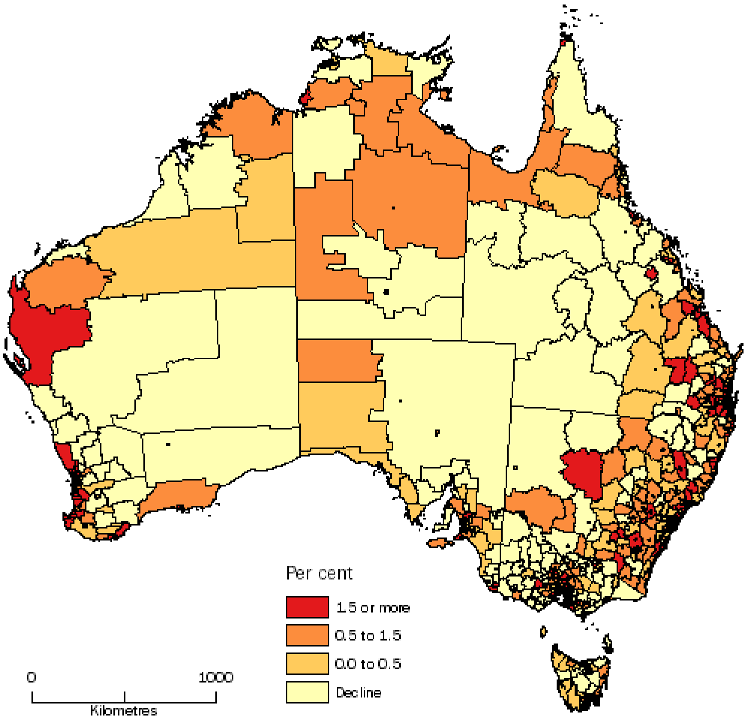
After filtering, all research was categorised into three groups: dynamics of regional population changes, regional economy, and the environment. In comparison to regional environmental issues, the majority of the research dealt with regional population changes and their impact on regional economic activities. When compiling the list of most influential pieces of research, the Google Scholar citations function was used indicating how many citations a particular piece of research has achieved within the database. Eighty-five studies were identified as significant in this systematic review.

7.3 Population Dynamics in Regional Australia

Australia's population has grown by about 18 million since Federation in 1901 and is currently around 23.2 million (ABS 2015). The growth of population in Australia has occurred mainly around the big cities, high amenity coastal regions, and the larger regional centres (ABS 2005). Historically, there is a distinctive pattern of population change across Australia. The distinctive pattern includes low population density – 2 persons per km^2; a high level of urbanisation – 89% living in urban areas; strong coastal orientation – 82% living within 50km of the coast; and uneven distribution of population – 90.5% of people living on 0.22% of the land area (Hugo 2013). In 2014–15, the population grew at 1.80% per annum. This is more than three times the average of other high income countries and double the average of low-income countries (ABS 2015).

Whilst the overall growth of the population is foremost, there are enormous spatial variations and changes of age-structure of the population within regional Australia. The population of regional areas changes through three mechanisms. Natural increase – the excess of fertility over mortality; net internal migration – the difference between the number of people moving into an area from, and the number of residents moving to other parts of Australia; and net international migration – the difference between the numbers settling in an area overseas and the number of residents moving overseas. There are significant differences in the rates of population changes, not only between urban and non-urban regions, but also between coastal, inland, and remote regions (Garnett & Lewis 2007).

Figure 7.5: Population Change by SA2, Australia, 2013–14



Source: ABS, 2015 Cat no.3218.0

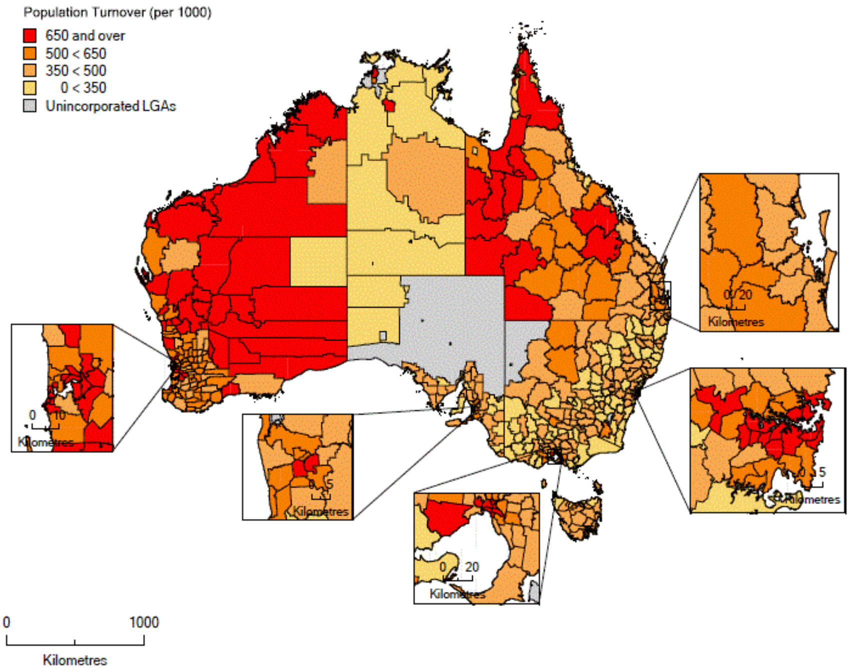
In the last few decades, there has been a slight increase of population in the remote areas of inland Australia. This pattern is far from the stereotype of regional Australia being in population decline (Hugo 2013). Coastal areas are experiencing strong growth, whereas inland Australia is experiencing stability and slight growth (Holmes 1994). Figure 7.5 shows population change by Statistical Area (SA2), with a clear pattern of growth being concentrated in coastal and major regional cities. Some of the areas of inland Australia also show growth because of natural resource exploitation (mining).

A key feature of Australia’s population growth has been the emphasis on cities, and more recently coastal areas. Only the areas of inland Australia, which have mining resources, have shown considerable population growth (Reeson et al. 2012). This kind of region is known as a ‘sponge city’ that pulls the population from surrounding small towns and villages. Dubbo and Toowoomba are two examples of ‘sponge cities’, whose populations have increased gradually with regional economic growth (Houghton, 2011). Carter (1978) argued that this kind of regional area is the backbone in terms of the sources of Australia’s national wealth and growth.

Another dimension of population change in regional Australia is population mobility. Normally, people move from rural areas to the cities but this movement is not always one way. A large number of people also move away from cities to rural areas to live within rural landscapes, enjoy socially-connected networks, and enjoy more affordable housing (Jordan et al. 2011). In general, the number of arrivals and departures in a region is the most important factor in causing differences between areas in population growth or decline and it creates the greatest impact on the population of small areas in Australia (Hugo 2010). In particular, the process of internal migration (Hugo 2003) affects the absolute size and age structure, and qualitative characteristics of the regions. The spatial pattern of population turnover is shown in Figure 7.2. The Queensland and Western Australia regions show the highest turnover rates while the South Australian region is much lower. Mining areas represents the highest turnover in remote Australia where both inward and outward movement are high.

In recent times, there has been movement from metropolitan cities to inland regional centres mainly for ‘lifestyle reasons’ (Ragusa 2011). These people are termed ‘tree-changers’, a newly identified social group in Australian culture. This is a new and significant social direction in Australian society that affects population changes in Australia`s regional areas (Ragusa 2011). Concern about changes in the size and composition of the population along Australia’s coasts has been growing for several decades (Smith & Doherty 2011). In 2004, coastal councils from around Australia established the National Sea Change Taskforce (NSCT) to document and promote their concerns (NSCT 2011). This led to two major pieces of research on demographic changes: Gurran et al. (2005) and Smith & Doherty (2011).

Figure 7.6: Spatial Pattern of Population Turnover



Source: ABS, 2011

Over time, regional population change occurs not only through births, deaths, in-migration and out-migration, but also because of ‘ageing in place’ of the resident populations (Hugo 2005). The most important dynamics of population changes at a regional level of Australia can be found in ageing, which is considered the greatest challenge over the next three decades (Hugo 2013). Warburton and Winterton (2011) reported that the ageing Australian population is predicted to almost double over the next fifty years. The average annual growth rate of the Australian population aged 65 plus across all regional areas from 2006 to 2011 was 2.8%. This compares to 1.5% for the population aged under 65 years and 1.6% for Australia’s total population (ABS 2013).

Review findings suggest that the older population of regional Australia is growing faster than that in the cities (Murphy, 2002). This phenomenon is also evident in other OECD countries like Canada (Dandy & Bollman, 2008). One quarter of Australians will be aged 65 years or over by 2044–45, roughly double the present proportion. The proportion of the ‘oldest old’ will increase even more (Richmond, 2008). People aged 55 years and over have significant lower labour force participation rates than younger people. As more people move into the older age groups, overall participation rates are projected to drop from around 63.5% in 2003–04 to 56.3% by 2044–45 (Productivity Commission 2005).

Baby boomers, who are currently aged between 47 and 67 (people born in the post-World War II baby boom between 1946 and 1961) are significant for regional Australia. They make up 24.4% of the population in capital cities and 27.1% in regional Australia as well as 39% of its workforce. (Hugo 2013). This over-representation of baby boomers and the increasing permanent and temporary flow of baby boomers, especially to coastal locations, is one of the most significant aspects of contemporary population dynamics in regional Australia (Hugo 2013).

7.4 Review Results

7.4.1 Economic Implications

The economic and social performance and environmental consequences of Australia’s regional areas have been receiving considerable attention in recent literature. Significant works includes Holmes (1994), Beer (1995), Beer and Maude (1995), Saupin (1997), Hugo and Bell (1998), and Tisdell (1998). In earlier studies, Paris (1992) and Sorensen (1993) studied changing regional populations and their economic systems. Going back some decades, Smith (1965) conducted the first national study of regional development policy in Australia. Work in the 1970s includes Carter (1978), and Frisbe and Poston (1978), while Logan et al. (1981) focused their work on regional Australia. The most recent work includes relevant studies by Beer et al. (2006), Collits (2011), Daley and Lancy (2011), Massey and Parr (2012), Polese (2013), Ragusa (2010), Tomaney (2012), and Hobday and McDonald (2014).

The nature of population changes shapes the degree of socio-economic outcomes in regional Australia. The changes of age structure in regional areas are also a fundamentally important issue having a major influence on the labour and housing markets, economic development potential and demand for all goods and services (Hugo 2013). The size of the population at a regional level has also significant impacts on the growth and decline of local markets (Stimson et al. 1998). Furthermore, Stimson et al. (2001) reveal the existence of a high degree of differentiation of performance on economic and social indicators in regional Australia caused by variations in population levels.

Many studies have also considered the influence of a range of socio-economic factors on regional population changes. These socio-economic factors include population density, per capita income, educational index, fertility and mortality (Adelman 1963); employment, racial composition, age and proximity to metropolitan areas (Frisbie & Poston 1978); net migration (Shumway & Davis, 1996); land price, income and employment (Goetz & Debertin 1996); unemployment rate, household income, resource-industry employment (Millward 2005); and age group, education level (Mardaneh 2012). Using a Canadian case study Polese (2013) considered resource dependency, distance, and income to be the major predictors of population changes in regional areas.

Faulkner et al. (2013) conducted a review of 55 regions of Australia to identify the dominating issues within the social, economic and environmental profiles of those regions. The most commonly raised economic threat — identified by 39 regions — was the reliance on one or a few main industries. Another frequently raised economic issue — identified by 44 regions — was a current or potential shortage of skilled workers. The most commonly raised population issue — reported by 45 regions — was a current or predicted rapid growth in population. Uneven distribution of population growth, both geographically and seasonally, was an issue raised by 13 regions. In some regions there are seasonal variations in population, mainly due to fly-in fly-out workers or a high number of tourists during particular seasons. Forty-four regions reported that their population was ageing.

Higher population in a region denotes larger internal economies and more diverse business communities. Moreover, a dense population indicates expanding networks and business connections. Population mobility is also the yardstick of regional economic development. Low levels of mobility mean a more stable population, which provides the foundation for rich social capital. A lower youth dependency ratio indicates a more robust regional economy, as higher youth dependency enhances the burden on the economy, worsening regional development as it reduces the volume of the working age population available for economic activities. RAI (2015a) illustrates the population parameters and associated economic effects in Table 7.1:

Table 7.1: Population Parameters and Associated Economic Consequences

Indicators	Definition	Economic effects
Population size	The number of people who live in an area.	Larger populations offer bigger markets for goods and services as well as more skilled workers.
Population growth	The rate of change in the size of population over the last year.	Growing populations expand local and regional economies.
Population density	The number of people per square kilometre.	Density concentrates market demand and enables people to better connect with each other to drive innovation and change.
Population turnover	The rate at which people are moving to and from a region.	Lower turnover indicates stability in a regional population, supporting stronger social capital and institutions.
Senior dependency	The number of people aged over 64 years compared to the working age population (15–64 years).	Populations with higher proportions of older people may require a greater focus on service delivery than economic development.
Youth dependency	The number of people under 15 years compared to the working age population (15–64 years).	Younger populations tend also to require a greater level of services.

Source: Regional Australia Institute(RAI), 2015a

The link between population growth and economic growth is an important one for regional areas in Australia. The consequence of local population decline is serious for the places losing residents, with many small towns and villages deeply concerned about their long-term viability as a result of diminishing population and economic activity. In this context, population growth is often seen as synonymous with economic growth. Small populations need to grow and reach a certain size threshold before they can exit a ‘vicious circle’ of decline. Conversely, regions that have high population growth are often concerned with negative impacts on their social infrastructure.

The ageing of the population is one of the most important dimensions of population dynamics in regional Australia and presents significant opportunities as well as challenges (Martin et al. 2011; O’Connor et al. 2001). The ageing trend varies for every region but as a whole, regional Australia is ageing faster than the rest of Australia. Tunstall (2001) and Barr (2005) found strong links between ageing populations and declines in regional economies.

Baby boomers are not only the largest generation to enter old age in Australian history, they are also the most educated, diverse, and wealthy, and they have an unparalleled body of experience. They may be leaders in achieving more sustainable regional settlement outcomes. They bring wealth, expertise, demand for services, and new ideas into regional areas and they create jobs (Hugo et al., 2013). A healthy ageing population can increase social capital and reduce expenditure on certain regional services. Retirees are more likely to participate in volunteer activities that are of benefit to the region and build social capital. They are better able to share their knowledge, skills, and experience with younger generations.

Inversely, as more people retire, there will be a reduction in the working population or skilled labour force, which will impact negatively on the economy. The Productivity Commission (2005) is concerned that Australian economic growth will be slowed because of the economic implications of ageing. A concern related to this in Australia is that most of the baby boomer generation is set to retire soon.

Population change can facilitate and bolster regional economic development by providing skilled and unskilled labour needed for the economic potential of a region to be maximised (Massy & Parr 2012). Skilled people and their participation in the workforce are at the heart of every economy. Higher participation rates indicate a dynamic labour market and high levels of skilled labour make a region more adaptable and better able to respond to shifts in the economy (Birrell & O’Connor 2000). Lack of an appropriately skilled labour force can be a severe constraint on regional development. However, as Daley & Lancy (2011) clearly demonstrates, population growth is not a substitute for the economic potential of a region. Population is a key element and facilitator of regional development but not a pivotal cause of that development. However, population is an important factor in realising the potential in regions that do have resources available for exploitation.

The review findings illustrate that the dynamics of population changes shape both economic opportunities and challenges for regional Australia. A larger population in a region provides more competitive advantages as it provides more labour in the market to support economic development. On the other hand, the regions that are less populated and more remote from metropolitan areas face more challenges to maintain their economic base. The regions that have large populations, steady population growth, low turnover, and a large proportion of working-age people, enjoy a more favourable position to face the challenges of regional economies.

However, few studies have empirically explored the impact of population changes on regional economies. It is worth noting that the studies that focus on regional economic development through population changes on a regional scale are limited. Thus, research into exploring population changes and the economic growth relationship from a regional perspective will help ensure consistent and accessible insights into the performance and development prospects of regional Australia into the future.

7.4.2 Environmental Implications

The changes of population can affect regional areas in various ways. An increasing population brings additional pressure on the environment through the exploitation and consumption of natural resources. The linkages between population changes and their impacts on the environment are strongly debated in the literature (Smith 2003). Population changes have long been considered a determinant of environmental impact, and environmental constraints also determine the shape of population changes (Hugo 2013).

Foran and Poldy (2002) defined various kinds of impacts of population growth on the Australian environment. These firstly include individuals, who require food; households that require accommodation, cars, televisions, and refrigerators; and communities that require schools, hospitals, and public transport; secondly, these are linked to affluence, lifestyle, and scale; and finally, these occur when the domestic requirements for imported goods and services have to be covered by revenue from the goods and services from the nation’s export industries.

Human activity is having a significant and escalating impact on the global environment. These environmental threats and impacts are linked to the growing human population (Hobday & McDonald 2014). Most environmental issues arise as a result of human-induced habitat modification, resource use or waste disposal. Examples include air and water pollution, biodiversity reduction as a result of direct (e.g., hunting and fishing) or indirect activities (habitat clearing, pesticides etc.), and reduction of freshwater flow as a result of diversion (irrigation) or storage (dams) for human use. Contemporary drivers of environmental changes that contribute to environmental degradation include population growth and associated development, production of goods and services, resource use, and climate change.

The population impact on the environment in Australia started following the first arrival of humans at around 50,000 BC and accelerated following European settlement in 1788 through agriculture and land use practices. The extinction and depletion of many species, owing to hunting, as well as poor soils and limited fresh water, have eroded environmental quality in many regions. Australia's current population is heavily concentrated along the coast, as approximately 85% of its 23 million citizens live within 50 km of the coast (Hobday & McDonald 2014). Coastal stressors, along with coastal development, such as habitat clearance, pollution and sedimentation, have modified the environment in many areas.

State of the Environment Australia (SEA) reported that the Australian settlement patterns have had a pervasive influence on the natural environment (SEA 1996). The settlement structure indicates that about 85% of the population occupy less than 1% of the country's total land area. They use more resources and produce more waste than those in many other industrialised nations. Although governments in Australia have often intervened to protect such resources, their interventions have often been delayed and are flawed (Tisdell 1998). Australia also faces significant environmental problems on land and at sea. Clearing of woodland and natural forests continues to have serious consequences for CO_2 emissions and for the quality of the aquatic environment (Tisdell 1998). These scenarios reflect the dominance of anthropocentric impacts in Australia.

A simple framework for understanding the environmental impact from population changes is described through the IPAT formula. According to this formula, the degree of reduction of population enhances the degree of reduction in environmental degradation. However, some scholars have argued that population is not the only, nor necessarily the most important, factor. Rather, it is absolutely necessary that people in affluent societies learn how to consume, not just differently and more efficiently, but less. This is supported by the Australian Conservation Foundation (ACF), which found that most of the impacts on the environment actually come from water and land used in the production and distribution of goods and services (ACF 2007).

Beder (1996) reviewed several links between human activities and environmental degradation. The expansion of human activities has already caused the extinction of many Australia species, and many on the endangered. Beder (1996) continued that there is huge mismatch between sustainable allocation of water and the population, and that the land is being seriously degraded. The impact that a population has on an area obviously depends on how many resources they consume and the volume of waste they discharge (Beder 1996). The ACF (2007) has indicated that population growth is a key threat to Australia's biodiversity. Foran and Poldy (2002) mentioned that population changes affect the environment in many ways: consumption of energy and resources, discharge of wastes and pollutants, displacement of plants and animals, and modification of the natural ecosystem by agriculture and by cities, through transport systems, and industry.

Several Australian states and territories have calculated their EF, which assesses the impact of individuals, cities, or countries on the environment. For example, the average Victorian resident has an EF of 6.83 global hectares per person, which is almost three times higher than the world average of 2.63 (Wiedmann et al. 2008). Unsustainable populations are populations with a higher EF (Lenzen 2006). The per capita EF of Sydney (8.1 gha) is above that of NSW (7.01 gha), and in turn the latter is above that of the average Australian (6.25 gha) (WWF 2014). This is most likely due to the greater affluence of households in Sydney, compared with broader NSW.

The pressures of rapid population growth on infrastructure, and the environment and natural resources are especially felt in hotspot areas such as south-east Queensland, Sydney, and coastal NSW and Melbourne (Hugo, 2010). Water is a key environmental issue with an all-important population dimension. Climate change will result in changes in the availability of water in different areas. A water shortage in the Murray–Darling Basin is also the cause of population decline. In fact, population numbers are only one of the elements creating pressure on the environment. Levels of consumption per capita and the way in which the resources are exploited are also very important elements in creating environment degradation (Hugo 2010).

In the future, the long term changes in weather patterns induced by the warming planet may see long term changes in population mobility. In addition, Australia's population growth is worsening some of the other environmental problems such as traffic congestion, waste disposal, droughts, floods, CO_2 emissions, the warming climate, and rainfall variability. These problems together affect the quality of life in regional areas, and Australia as a whole.

7.5 Conclusions

Population has long been thought to be the driver of economic growth, but on the other hand it puts pressure on the environment. The aim of this review has been to provide an overview of population dynamics and their impacts on both regional economies and the environment. To explore this objective, it has investigated past research in this area. Eighty five influential pieces of research were identified based on various criteria for this systematic review.

In the literature, there are broadly two views — the ‘regional Australia is dying’ view, and the ‘regional Australia is doing well’ view (Collits 2000; 2004). The former is mainly argued by the media, and the latter one is supported primarily by the government. Collits (2000) implied that the truth lies somewhere in between. There are many regions that are not losing population and doing well economically. Also, there is widespread evidence that many small regional areas are experiencing declining populations and economic activity. These regional variations are the outcome of disparities within and between regions in Australia.

The review findings illustrate that the dynamics of population changes enhance both economic opportunities and challenges, and they simultaneously put pressure on the regional environment. One of the most important dynamics of population changes at the regional level of Australia is ageing. The trend of ageing for every region is not the same but, as a whole, regional Australia is ageing and this is occurring faster than for Australia as a whole. As the population of Australia continues to grow rapidly, most of the reviewed papers suggest that the size of the population is one of the major elements that create pressure on the environment.

Hence, Australia needs to ensure a sustainable population strategy, which refers to the size of the population that it can support without damaging the natural environment. Some researchers have argued that the issue of population size is not the only important factor, but that the uneven distribution of population in Australian regions is a major concern. Baby boomers are also found more dominant in number in regional Australia than in urban capital cities. They make up 27.1% of the population in regional Australia (Hugo, 2013).

From a regional environment perspective, the levels of consumption per capita and the way in which the resources are exploited are also very important elements. Some regions cry out for more people, services, infrastructure, businesses, and employees (Beer & Keane, 2000). Policy makers need to seriously address this population squeeze and pull the policy levers that can re-energise and build dynamic, stable, secure, and viable regional economies, which is essential for Australia's future.

Changes to the population structure will continue to be significant in Australia over the next few decades. However, those changes must be environmentally sustainable. Population size, growth, structure, and distribution must operate not only by the market mechanism of economic activity but also via government interventions which aim to ensure environmental quality.

CHAPTER 8

SUMMARY OF FINDINGS, POLICY IMPLICATIONS AND DIRECTIONS FOR FUTURE RESEARCH

8.1 Key Findings

The objectives of this research have been to empirically estimate the impacts of population changes on economic growth (Chapter 2), the impacts of anthropogenic factors on the environment (Chapter 3), and to analyse the inter-relationship and causal direction (Chapters 4, 5 and 6) between economic growth and the environment (ecological footprint and CO_2 emissions). It has also investigated the interaction between variables in the post-sample period using impulse response and variance decomposition analysis. Lastly, the impacts of population changes in regional Australia on economic growth and environmental quality were reviewed (Chapter 7). Based on the research questions as outlined in Chapter 1, the key findings from the estimation process are summarised below:

> RQ 1. What is the impact of population changes on economic growth in Australia?
>
> RQ 2. What is the nature of the relationship between dependency ratio, savings rate, trade openness, and capital formation?

Specific Findings:

The empirical findings that address research questions 1 and 2 are described in Chapter 2. It analysed the relationship between population changes and economic growth. The level of working age population in the economy depends on the dependency ratio. In Australia, the rate of working age population has been decreasing in comparison to the rate of people in retirement. The elderly dependency ratio has also been increasing. In the literature it is claimed that the higher dependency ratio in any country hinders the productivity of the economy to accumulate savings, which are needed to sustain economic growth through investment. This chapter investigated the impact of the dependency ratio on real GDP per capita in Australia while considering other determining factors, such as savings rate, trade openness, and capital formation. Here, the dependency ratio was used as a proxy of changes of population age-structure.

The findings supported the population-driven economic growth hypothesis, which states that population changes in a country promote economic development. The results confirm the economic performance of Australia. The results imply that the effects of population age structure, savings rates, trade openness, and capital formation on economic growth are statistically significant and that this impact is more pronounced in the long-run as opposed to the short-run. The ARDL analysis indicates the dependency ratio, including the largest impacting factors on economic growth.

RQ 3. How can the impact of the population on the environment be assessed?

RQ 4. Are there any other factors associated with the population–environment relationship?

Specific Findings:

The empirical findings of research questions 3 and 4 were outlined in Chapter 3. This chapter analysed the population changes and environment quality relationship. EF per capita was applied as the index of environmental impacts. The driving forces of EF in Australia were the main concern in this chapter. In the empirical analysis, the results showed that population has the most significant effect on EF, followed by GDP per capita and urbanisation rate. Results also showed the negative effect of affluence on environmental change in Australia.

The negative sign of the affluence coefficient could be explained by the fact that GDP per capita in Australia, as in most developed countries, enhances the standard of living of the people, which leads to the reduction of environmental impact. Urbanisation also clearly affects the EF; this result is in accordance with Australia's rapid urbanisation. However, CO_2 emissions and industry share of GDP are not significant contributors to EF in Australia.

RQ 5. What is the relationship between EF and economic growth?

RQ 6. What are the directions of causality among EF, economic growth, financial development, and trade openness?

Specific Findings:

The empirical findings of research questions 5 and 6 were described in Chapters 4 and 5. These chapters analysed the economic growth and environmental quality relationship. Research question 5 was analysed using a time-series approach for multiple countries including Australia. EF per capita was used as the explanatory variable, while real GDP per capita was used as the predictor variable in the model. The EKC hypothesis was tested via the link between EF and GDP through linear, quadratic, and cubic functional forms. In addition, VEC model was used to investigate the long-run relationship between the variables. The results depict a co-integrated relationship between the variables in almost all countries. The EKC hypothesis is supported for Australia. Most of the error correction terms are also correct with expected signs and levels of significance. The negative sign of ECT implies that some percentage of disequilibria in EF, in the previous year adjusts back to the long-run equilibrium in the current year.

Research question 6 was analysed using a panel of a number of countries, including Australia. The results of group DOLS analysis indicate the positive impact of EF, with a negative impact of trade openness, on real income. Environmental quality deteriorates with the impact of financial development. The long-run vectors of group DOLS estimation were verified using the GM–FMOLS estimators. Only real income confirmed the positive significant impact on EF, which indicates the partial robustness of the results. Uni-directional causality, running from real income to EF, was identified by the VEC model analysis.

> RQ 7. What is the dynamic relationship among CO_2 emissions, energy consumption, and economic growth in Australia?

Specific Findings:

The empirical findings of research question 7 were discussed in Chapter 6. This chapter was an extended assessment of the material presented in Chapters 4 and 5, where, EF was used to determine the environmental impact, but in Chapter 6, CO_2 emissions per capita were considered a proxy for environmental quality. Energy consumption per capita and population growth were hypothesised as key determinants of CO_2 emissions, and the quadratic term of real GDP per capita was applied to test the existence of the EKC hypothesis in the growth–environment nexus. This chapter focused on the question of whether continued economic growth will degrade environmental quality in Australia. The ARDL bounds testing and Johansen–Juselius co-integration test confirmed the long-run dynamic relationship among the variables, when the CO_2 emissions level was considered as the regressive of the model. These results were also supported by estimation using the dynamic OLS and fully modified OLS methods. In addition, the study found both economic growth and energy consumption to be emissions intensive, and the EKC hypothesis was valid for Australia for the study period but population growth had no significant impacts on per capita CO_2 emissions.

> RQ 8. Does variation of population changes have an impact on regional economies and the environment in Australia?

Specific Findings:

This question was addressed in Chapter 7. Overall, the Australian population has been growing quite rapidly compared to other high income nations. There is a lot of variation in population growth and changes between Australia a whole and its regional areas. Has this variation and changes of population had significant impacts on the regional economy and the environment? To answer this question, this part of the thesis offered a critical review of the literature. The review revealed a large number of research studies that have placed emphasis on the impact of population changes on regional economic growth instead of on the regional environment. Most of the review findings suggest that an enlarged population can facilitate regional economic growth by creating demand for goods and services, but on the other hand, this brings additional pressure to the environment through exploitation and consumption of natural resources. There is no uniformly accepted direction among regional population changes, economic growth, and environmental quality. Nevertheless, the findings of this review confirm similarities to the empirical findings of previous chapters.

8.2 Policy Recommendations

This study has examined the impact of population changes on both the economy and the environment of Australia. In doing so, various econometric techniques and different models were used and the findings were summarised in the previous section. The following specific recommendations are based on those findings:

1. The economic performance of Australia during the study period has been influenced by a changing population age structure. Presently, Australia is enjoying a favourable population age structure position as the total dependency ratio has gradually decreased due to net migration and a large working-age population. The advantages of this age structure, however, may disappear in the near future due to an imbalance between the young and the elderly age dependency ratios. This may ultimately lead to a slowdown in the growth of the economy. Australia needs demographic and economic policies that target increasing the working-age population in the economy.

2. In Australia, the demographic changes have occurred relatively rapidly, so it can be expected that these changes might have a significant impact on Australia’s economic performance in the future. Skilled immigration intake can be increased progressively year to year, and as migrants are predominantly of working age, this will assist in maintaining overall workforce growth and age balance. Moreover, as many migrants are skilled, this will also raise general skill levels and productivity. Australia, characterised by an ageing population, requires policies that are capable of adapting to these demographic dynamics. It cannot afford to risk a future in which its population age structure hinders productivity and stability.

3. The study has found a significant impact of population and urbanisation on the environment in Australia. Both population size and rate of urbanisation influence the EF. The implication of the findings for the sustainability of the environment in Australia is that appropriate policy measures should be put in place to reduce the impacts on the environment. In order to live in harmony with nature, ecological capacity needs to increase, or economic activity (consumption) needs to reduce. Therefore, to increase ecological capacity or reduce the EF, population impacts need to be controlled.

4. The study has also found that environmental degradation is strongly associated with economic development. As real GDP increases, the EF increases. The results of this study show that economic growth could be compatible with environmental improvement if appropriate policies are in place. It is significant that usually only when income grows, effective environmental policies can be implemented. Clearly before adopting these policies it is important to understand the nature and causal relationship between economic development and environmental degradation. Changes in consumption patterns, technological choices, more investment in pollution abatement, and efficient use of resources are the main policy tools to alleviate the increasing EF problem.

5. The study has also found both economic growth and energy consumption to be emissions intensive. Despite the contemporary initiatives taken by Australia to reduce CO_2 emissions, the country is still producing a significant level of emissions per capita. The rise in per capita CO_2 emissions is of huge concern in light of increasing demand for energy consumption and high rates of economic growth. Australia’s EF is very high, therefore this study recommends several policy options to minimise these environmental pressure indicators.

i) The first option is to increase the utilisation of renewable resources. As global warming becomes more concerning, investment in renewable resources such as solar and wind power generation are sustainable options for Australia. Carbon-free new technologies (e.g. wind, nuclear, solar, biogas, biomass, hydro, and biofuels) are conducive to reducing CO_2 emissions without impairing or impeding economic growth. The renewable energy industry sector could play a key role in satisfying Australia’s energy needs on a sustainable basis, as well as meeting environmental obligations. Significant renewable energy targets can be an important driver to develop innovative and creative solutions to the problem of GHG management.

ii) A second option is to adopt and expand existing Carbon Capture, Utilisation and Storage (CCUS) facilities. This method has already proven to be an effective tool in reducing CO_2 emissions in United Aram Emirates, Saudi Arabia and Qatar. It involves capturing CO_2, transporting it via pipelines or ships, and finally injecting it into suitable rock formations. Promoting CCUS may be a viable option. From a policy perspective, Australia needs to boost initiatives to ensure a favourable regulatory framework to guide CCUS-based activities that will promote the growth of CO_2 capture.

iii) Apart from adopting and expanding CCUS and solar energy technologies, building nuclear energy is another valid option for low emissions power generation. Usually nuclear energy plants involve a huge investment and the benefits are likely to be realised only in the very long term. Since the GDP of Australia is large, large scale investment in nuclear energy may be viable. However, the success and sustainability of nuclear energy plants also depends on the political environment within countries.

iv) Finally, lowering consumption per person, altering consumption patterns, or introducing technologies that reduce resource use or increase efficiency are necessary. Australia needs to make a commitment to pursuing and promoting policies that stabilise population and consumption levels so that the regional economy can be transformed and EF and CO_2 emissions can be reduced to sustainable levels.

6. The review results also suggest that the uneven distribution, varied age-structures, different growth, and high turnover of the population are common features of regional Australia. More importantly Australia has been facing a significant shortfall of working age people in the labour market. To overcome this situation, regional policy needs to be formulated which incorporates a number of strategies, including the following:

i) The age of retirement should be increased. This kind of structural change, however, should be approached with extra caution for implementation as it may create inequality.

ii) The workforce participation rate needs to be increased. There are still low levels of participation among many groups including Indigenous Australians, women, some migrant groups, disabled persons, and younger workers.

iii) The skill levels of the Australian workforce also need to be increased by providing education and training.

iv) The stability of regional Australia depends on not just attracting increasing numbers of people, but more importantly on retaining them in the longer term. It therefore requires sufficient jobs creation and facilities to retain the workforce in regional areas.

7. The workforce is considered a core asset of the economy and must be actively engaged in the economy. How well a region allocates and engages its people within the economy indicates the efficiency of the regional labour market. Efficiency suggests a strong match between workforce capacity — its size and skills — and the needs of local firms. Maintaining efficiency over time requires workforce size and skills to adapt to changing needs so that the smaller regional labour market can easily be adjusted to the ups and downs of the economy.

8. Governments have been spending huge amounts of money on programs for regional Australia but in most cases they fail to produce the economic growth that they are explicitly designed to achieve. Policy makers need to consider the fast changing reality of regional Australia, which is that while some regions are growing faster and often missing out on services, others are growing slowly or even shrinking.

9. The regional growth process operates within the complex relationship between population changes and environmental quality. Many problems arise: some of them are seasonal, such as drought or flood; some are ongoing structural changes, such as the ageing of regional people and the lack of a skilled workforce and high workforce turnover; and some are external, such as unstable international markets. Government faces many challenges in directly influencing the situation. This situation also implies that the existence of policy is not sufficient in its capacity to overcome the problem. In this context governments should delegate the authority and responsibility to regional authorities to determine their own futures.

10. A new 'place-based' approach for regional development has been used in many places around the world. It requires the capacity to strengthen local and regional institutions so that they are able to assess and develop local economic assets in ways that all parts of cities and regions can complementarily contribute to national development. It could be applied with equal value both in metropolitan regions and regional Australia.

11. Regional Australia is crying out for more people, services, infrastructure, businesses, and employees. The authority is needed to seriously address this population squeeze and pull the policy levers that can build dynamic, stable, secure, and viable regional economies for the future of regional development.

12. Australia needs to ensure a sustainable population strategy that refers to the number of people that they can support without damaging the natural environment. The Australian historical settlement experience needs to be considered when developing Australian population policy. This does not mean a major shift of the existing population but it could have significant implications for the direction of future policies.

8.3 Key Contributions to the Literature

Australia's most important resource is its people. The consideration of future numbers of people, their distribution, and where and how they live is of the greatest significance. Population change and its implications for the economy and the environment has been the focus of research for a long time but there is a significant shortage of research in Australia that considers both economic and environmental consequences. This thesis is by no means the first to report on the changing age structure and its impact on the economy and the environment in Australia, including regional areas; however, what makes this study different from earlier studies is that it is a more careful empirical econometric investigation using multivariate approaches. This is the first known study in Australia, and one of the few studies in general, that consider both EF and CO_2 emissions as environmental impact variables. The STRIPAT, EKC and Cobb–Douglas production function approaches using both time-series and panel data models are also a new contribution.

The empirical evidence presented in Chapter 2 suggests that the changes in population age structure have had a significant impact on real GDP per capita in Australia. Previous empirical research on the influence of demographics on economic performance has paid little attention to time-series co-integrated data for a single country. Most of the studies have been cross-country comparisons. Single country studies are very limited to emphasise the age structure and savings interdependency instead of the economic growth relationship. No study to date in Australia has used the dependency ratio as a proxy for the age structure of the population.

The econometric analysis using STIRPAT and ridge regression in Chapter 3 revealed that urbanisation and population are the two important determinants which worsen environmental quality in Australia. Although the EF measures the environmental impacts caused by human activities, the specific forces driving those impacts are not yet fully understood. Researchers have traced environmental impacts using different dependent variables. A number of studies have also utilised EF as a proxy for environmental impact, but most of them used cross-country data. Very few studies measured environmental impact using single-country data with EF as the dependent variable. Especially in Australia, no studies have been identified that trace the driving forces of environmental impacts using EF as a proxy for the dependent variable.

A major weakness of most of the studies examining the relationship between economic growth, energy consumption and the environment is that they use CO_2 emissions as an indicator of total pollution or environmental degradation. CO_2 emissions, however, constitute only one part of the total environmental damage caused by large scale energy consumption. On the other hand, EF is a more comprehensive measure of pollution and represents a powerful indicator of anthropogenic pressure on the environment.

Empirical evidence was presented in Chapters 4 to 6 using various interdisciplinary models and variables to reveal the economy–environment relationship. Chapter 4 used the EKC hypothesis while Chapter 6 tested the Cobb–Douglas production function. EF was used as the dependent variable both in Chapters 4 and 5, while CO_2 emissions were used in Chapter 6. Chapter 4 used time series data with multiple countries, along with Australia, Chapter 5 used panel data including Australia, and Chapter 6 used single country time series for Australia. The combination of multi-disciplinary techniques, different variables, and the distinct nature of data ensured the robustness of the analysis.

Most of the previous empirical studies have used cross-country panel data to estimate the relationship between income and environmental quality using the EKC hypothesis.

In comparison to cross-country studies, time-series studies are fewer in number and their findings have different implications. It is a new trend in the EKC literature to focus on an individual country instead of multiple countries when using time series data. This current study was an attempt to investigate the dynamic relationship between CO_2 emissions and real GDP per capita for an individual country — Australia.

The use of fossil fuels in Australia has risen largely as a result of the abundance of these non-renewable resources. However, high CO_2 emissions per unit of real GDP resulting from burning fossil fuels create new challenges for maintaining the growth–environment nexus at a sustainable level. In Australia, there has been very limited research on the dynamic relationship between economic growth, CO_2 emissions, and other variables. To date, only four studies have been found in Australia that have focused on economic growth and environmental implications. These studies could not capture the robust impact of environmental impact on economy and environment in Australia.

This current study was the first attempt to investigate the dynamic relationship between these variables in Australia, accounting for the limitations of earlier Australian studies. It seems that none of the earlier research conducted on Australian time-series data accounted for multiple structural breaks, which has important implications for the theories and empirics in macroeconomics. The findings of this study will enable policymakers, environmental authorities and other stakeholders to fully appreciate environmental concerns and give them due weight. More importantly, the study is significant because it indicates the applicability of environmental impact models, particularly the STIRPAT model, to a single country's situation.

8.4 Limitations and Directions of Future Research

Methodology: The STIRPAT analysis is mainly used at the macro level of countries to measure the population and affluence impact on environment. This study also used the model at the macro level for Australia but the model is applicable to any spatial scale from national to regional levels. There is a scarcity of regional level data analysis in Australia; hence, there is ample scope to use this model at a regional scale in Australia, subject to availability of data sources.

Longer data series: The relationships between the study variables used to test the EKC hypothesis have changed over time. Such changes were not possible to be incorporated due to the limited sample period. Longer historical time-series data therefore would be preferable for better estimation outcomes.

Income–environment incompatibility: The results suggest that the growth of per capita income is not always accompanied by improvements in some dimensions of environmental quality in existing high income countries like Australia. It is thus assumed that there are some other reasons behind the observed relationship between real GDP per capita and EF per capita which are not revealed in this study.

Structural breaks: The study tested for structural breaks in the time-series data and their impact on the estimated parameters. The sequential test results indicate there are two breaks (1978 and 1990) in the time-series data. Interestingly, the oil/wages shocks occurring in the early 1970s, and the Asian Crisis in 1997 were not captured as structural breaks in the data.

Quantitative analysis on a regional scale: As regional towns and cities constitute significant amounts of industrial activities, the output of which significantly impacts the national economy, future research, which explores how population changes can impact innovations and productivity within local economies and environment, is crucial. This study has used analysis based on reviewed literature for regional Australia. From a regional policy perspective, the review findings ascertained that there is a need for quantitative and econometric analytical research to be carried out on a regional scale to critically assess how the regional population’s changes affect both the regional economy and the environment.

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APPENDICES

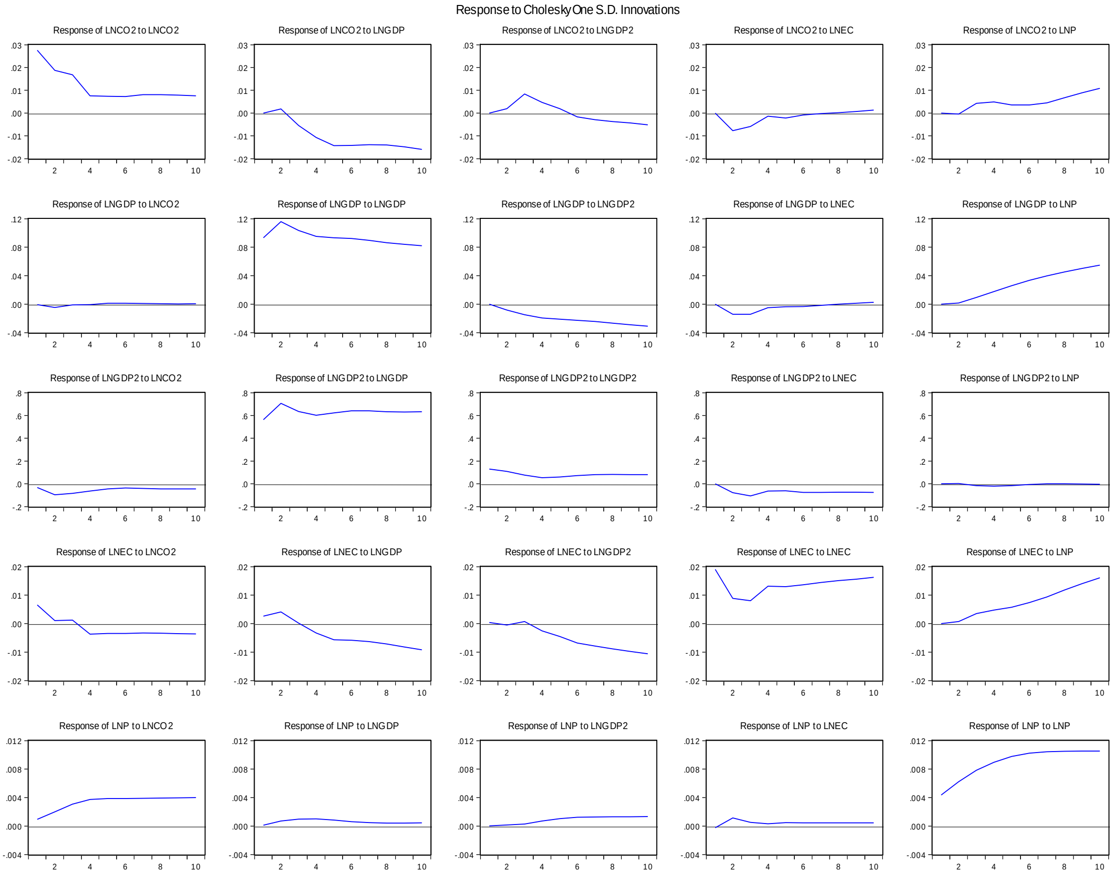
Appendix 4A: Descriptive Statistics

Country	Variable	Mean	Min	Max	Std. Dev	Skewness	Excess Kurtosis
Australia	EF	7.413	5.000	10.374	1.528	0.636	2.038
	GDP	16647.58	1878.21	62133.61	14082.41	1.317	4.475
Belgium	EF	6.613	4.000	7.534	0.964	-0.304	2.230
	GDP	17096.85	1350.198	47801.60	13819.10	0.692	2.432
Brazil	EF	2.705	2.293	3.061	0.238	-0.678	2.131
	GDP	2864.76	203.19	12279.45	2701.35	1.644	5.659
Canada	EF	7.058	5.042	8.307	0.732	-0.637	3.197
	GDP	17482.64	2231.294	52086.53	13294.33	0.916	3.114
China	EF	1.378	0.940	2.457	0.353	1.043	3.731
	GDP	782.73	70.122	5574.187	1192.71	2.446	8.576
Denmark	EF	7.617	4.954	8.991	1.066	-0.832	2.705
	GDP	22022.99	1503.537	62596.49	18169.89	0.702	2.424
France	EF	4.598	3.479	5.096	0.402	-1.109	3.412
	GDP	16576.90	1445.152	43991.72	12686.37	0.551	2.209
India	EF	0.759	0.674	0.967	0.055	0.756	3.163
	GDP	358.65	87.043	1303.34	287.32	1.681	5.379
Indonesia	EF	1.21	1.02	1.65	0.15	1.23	4.27
	GDP	1715.95	97.18	4883.08	1506.62	0.55	2.05
Italy	EF	3.927	1.991	4.974	0.794	-0.863	2.824
	GDP	14106.82	887.33	39222.18	11751.87	0.557	2.095
Malaysia	EF	2.34	1.30	3.46	0.68	0.07	1.67
	GDP	5887.08	286.88	24714.84	6505.38	1.47	4.40
Japan	EF	4.068	2.683	4.786	0.521	-1.152	3.784
	GDP	19314.12	563.58	44203.71	15409.74	0.122	1.362
Mexico	EF	2.365	1.441	3.299	0.491	0.106	2.253
	GDP	3530.12	354.38	9559.81	2903.93	0.689	2.158
Nepal	EF	0.838	0.728	0.985	0.071	0.564	2.080
	GDP	195.21	48.41	696.47	137.42	1.731	6.229
Nigeria	EF	1.260	1.075	1.658	0.129	0.736	3.198
	GDP	421.22	92.81	1507.68	336.78	1.505	4.787
Pakistan	EF	6.47	5.46	7.60	0.58	0.20	2.04
	GDP	1240.13	157.93	2579.30	801.32	0.12	1.72
Phillippines	EF	1.119	0.813	1.445	0.093	0.053	6.400
	GDP	724.61	156.69	2358.02	499.28	1.136	4.260
Singapore	EF	3.44	0.96	6.30	1.75	0.89	0.00
	GDP	19952.63	821.29	60143.23	18696.85	0.03	0.09
South Korea	EF	2.539	0.714	4.532	1.309	0.213	1.499
	GDP	6891.41	91.48	24155.83	7402.18	0.883	2.534
Sri Lanka	EF	1.029	0.774	1.456	0.158	0.412	2.501
	GDP	575.65	117.31	2235.81	523.93	1.657	5.203
Sweden	EF	5.9112	5.074	7.497	0.5491	1.170	4.067
	GDP	20763.64	2147.22	55393.68	15192.95	0.5784	2.361
Switzerland	EF	4.738	3.771	5.291	0.377	-0.769	2.819
	GDP	26792.39	1971.31	75002.62	20977.03	0.537	2.274
Thailand	EF	1.637	0.986	2.918	0.528	0.461	1.776
	GDP	1331.98	100.89	4192.11	1211.74	0.833	2.617
Turkey	EF	2.611	1.466	2.675	0.331	0.262	2.052
	GDP	2681.08	284.01	10604.85	2693.23	1.589	4.734
United Kingdom	EF	4.987	4.367	5.812	0.423	0.520	2.114
	GDP	14945.14	1380.31	46591.13	13354.06	0.814	2.513
USA	EF	7.869	6.712	8.778	0.518	-0.526	2.655
	GDP	20682.97	2881.10	49781.35	15130.11	0.466	1.913
Viet Nam	EF	0.98	0.68	1.65	0.31	0.96	2.40
	GDP	1299.66	147.85	3902.42	1147.94	0.92	2.51

Appendix 6A: Forecast Error Variance Decomposition for Four Variables

Variance Decomposition of CO_2					
Period	CO_2	GDP	GDP^2	EC	P
1	100.0000	0.000000	0.000000	0.000000	0.000000
2	94.38159	0.294213	0.303287	5.007349	0.013561
3	86.42752	2.090222	4.541145	5.808923	1.132191
4	79.27388	8.033528	5.191916	5.222069	2.278606
5	71.31665	16.66176	4.671973	4.757818	2.591801
6	65.41161	23.25362	4.261611	4.249775	2.823380
7	60.83245	27.95557	4.128564	3.796225	3.287193
8	56.52707	31.46771	4.162461	3.391691	4.451064
9	51.99138	34.44826	4.256084	3.023403	6.280878
10	47.27179	36.98357	4.443950	2.703983	8.596706
Variance Decomposition of GDP					
Period	CO_2	GDP	GDP^2	EC	P
1	0.009030	99.99097	0.000000	0.000000	0.000000
2	0.096087	98.67839	0.298914	0.915110	0.011495
3	0.068200	97.61495	0.845622	1.205745	0.265479
4	0.053682	96.51803	1.521377	0.994222	0.912685
5	0.046136	95.05929	2.067446	0.836254	1.990873
6	0.041522	93.26513	2.543295	0.720969	3.429082
7	0.036655	91.22286	3.008162	0.625529	5.106790
8	0.032382	88.98203	3.497738	0.549179	6.938671
9	0.028965	86.63257	4.001684	0.490027	8.846749
10	0.026209	84.23337	4.503350	0.445579	10.79149
Variance Decomposition of GDP^2					
Period	CO_2	GDP	GDP^2	EC	P
1	0.332254	94.62398	5.043761	0.000000	0.000000
2	1.187076	94.77562	3.322086	0.714655	0.000562
3	1.329144	94.61649	2.681970	1.353379	0.019016
4	1.276768	95.14022	2.254370	1.291138	0.037501
5	1.129301	95.60107	1.998329	1.227279	0.044023
6	0.993861	95.85522	1.869184	1.243569	0.038164
7	0.908348	95.98069	1.817110	1.261248	0.032609
8	0.856432	96.05179	1.791754	1.271484	0.028540
9	0.817958	96.10535	1.770854	1.280339	0.025495
10	0.784053	96.15123	1.752482	1.288725	0.023510
Variance Decomposition of EC					
Period	CO_2	GDP	GDP^2	EC	P
1	10.50401	1.705256	0.043435	87.74730	0.000000
2	8.725718	4.714970	0.088637	86.36148	0.109197
3	7.798103	4.087585	0.174516	85.77166	2.168137
4	7.310652	4.298545	0.938157	83.15806	4.294587
5	6.631073	6.178502	2.594029	78.33086	6.265540
6	5.924580	7.150318	5.239743	73.03697	8.648393
7	5.174751	7.753448	7.479895	68.08769	11.50422
8	4.533371	8.256307	9.237887	63.00836	14.96408
9	4.005715	8.799858	10.52160	58.15426	18.51856
10	3.570173	9.343196	11.49182	53.72732	21.86749
Variance Decomposition of P					
Period	CO_2	GDP	GDP^2	EC	P
1	4.569952	0.080705	0.002080	0.301665	95.04560
2	7.451197	0.802413	0.035606	2.136770	89.57401
3	10.37476	1.062205	0.072064	1.208640	87.28233
4	12.08173	1.064334	0.261350	0.755350	85.83724
5	12.44403	0.918936	0.490292	0.581045	85.56569
6	12.42123	0.758864	0.689577	0.476590	85.65374
7	12.34495	0.635486	0.821462	0.409191	85.78891
8	12.30307	0.547871	0.907909	0.366704	85.87445
9	12.29733	0.486641	0.970521	0.336094	85.90941
10	12.30582	0.443064	1.021665	0.312282	85.91716

Appendix 6B: Accumulated Impulse Response Functions Result



Appendix 6C: Accumulated Impulse Response functions Result

Accumulated Response of CO_2 as Cholesky Ordering					
Period	CO_2	*GDP*	*GDP2*	*EC*	*P*
1	0.027612	0.000000	0.000000	0.000000	0.000000
2	0.018760	0.001864	0.001892	-0.007689	-0.000400
3	0.016829	-0.005507	0.008358	-0.005900	0.004260
4	0.007583	-0.010661	0.004676	-0.001385	0.004849
5	0.007380	-0.014325	0.001895	-0.002204	0.003611
6	0.007260	-0.014237	-0.001700	-0.000889	0.003546
7	0.008056	-0.013870	-0.002941	-0.000206	0.004527
8	0.008107	-0.013951	-0.003772	0.000180	0.006736
9	0.007853	-0.014837	-0.004356	0.000675	0.008869
10	0.007559	-0.015964	-0.005166	0.001265	0.010840
Accumulated Response of GDP as Cholesky Ordering					
Period	CO_2	*GDP*	*GDP2*	*EC*	*P*
1	0.000000	0.093321	0.000000	0.000000	0.000000
2	-0.000562	0.245255	-0.035082	-0.015198	0.001647
3	-0.001183	0.412864	-0.099533	-0.029731	0.011194
4	-0.007468	0.591883	-0.185758	-0.034104	0.029149
5	-0.014860	0.775998	-0.279480	-0.036519	0.055565
6	-0.024327	0.966172	-0.380760	-0.038219	0.089798
7	-0.036878	1.161512	-0.490818	-0.037769	0.130619
8	-0.052275	1.363412	-0.611310	-0.035189	0.177144
9	-0.069819	1.572204	-0.741713	-0.030888	0.228632
10	-0.089222	1.787409	-0.880926	-0.025037	0.284679

Accumulated Response of GDP^2 as Cholesky Ordering

Period	CO_2	*GDP*	*GDP2*	*EC*	*P*
1	0.000000	0.000000	0.579400	0.000000	0.000000
2	-0.038350	0.241391	1.068997	-0.083667	0.002259
3	-0.057645	0.547079	1.422126	-0.197944	-0.013636
4	-0.077288	0.918003	1.669804	-0.266876	-0.033590
5	-0.077570	1.280434	1.945841	-0.333713	-0.050842
6	-0.065620	1.610826	2.275986	-0.413954	-0.057395
7	-0.056925	1.907663	2.640121	-0.495203	-0.058057
8	-0.052324	2.189371	3.011951	-0.574879	-0.057582
9	-0.047803	2.471188	3.380917	-0.654612	-0.059580
10	-0.041194	2.755493	3.749049	-0.735068	-0.064509

Accumulated Response of EC as Cholesky Ordering

Period	CO_2	*GDP*	*GDP2*	*EC*	*P*
1	0.000000	0.000000	0.000000	0.020365	0.000000
2	-0.002294	0.006014	-0.003233	0.029897	0.000768
3	-0.004616	0.002478	-0.000736	0.038710	0.004362
4	-0.014675	0.009711	-0.013648	0.053045	0.009209
5	-0.025116	0.023035	-0.035217	0.067239	0.015081
6	-0.036699	0.045932	-0.067021	0.082255	0.022667
7	-0.049076	0.073091	-0.103906	0.098276	0.032277
8	-0.062566	0.103677	-0.145308	0.115076	0.044383
9	-0.077135	0.136836	-0.190578	0.132617	0.058783
10	-0.092760	0.172807	-0.239953	0.150926	0.075305

Accumulated Response of P as Cholesky Ordering

Period	CO_2	*GDP*	*GDP2*	*EC*	*P*
1	0.000000	0.000000	0.000000	0.000000	0.004485
2	0.000111	-6.23E-05	0.000392	0.001606	0.010895
3	0.001175	-0.000398	0.001359	0.002633	0.018946
4	0.002804	-0.002596	0.004272	0.003516	0.028147
5	0.004363	-0.006408	0.008604	0.004635	0.038178
6	0.005891	-0.011291	0.013793	0.005750	0.048669
7	0.007407	-0.016523	0.019197	0.006856	0.059369
8	0.008936	-0.021840	0.024634	0.007984	0.070140
9	0.010502	-0.027200	0.030120	0.009109	0.080943
10	0.012098	-0.032631	0.035700	0.010223	0.091765

Appendix 7A: Regional Cities

Albury (NSW)
Ballarat (VIC)
Ballina (NSW)
Bathurst Regional (NSW)
Bunbury (WA)
Bundaberg (QLD)
Cairns (QLD)
Capel (WA)
Cessnock (NSW)
Clarence (TAS)
Coffs Harbour (NSW)
Darwin (NT)
Fraser Coast (QLD)
Gladstone (QLD)
Glenorchy (TAS)
Gold Coast (QLD)
Greater Bendigo (VIC)
Greater Geelong (VIC)
Greater Shepparton (VIC)
Harvey (WA)
Hobart (TAS)
Ipswich (QLD)
Lake Macquarie (NSW)
Latrobe (VIC)
Launceston (TAS)
Lismore (NSW)
Litchfield (NT)
Mackay (QLD)
Maitland (NSW)
Mandurah (WA)
Newcastle (NSW)
Noosa (QLD)
Orange (NSW)
Palmerston (NT)
Port Macquarie-Hastings (NSW)
Port Stephens (NSW)
Redland (QLD)
Rockhampton (QLD)
Shellharbour (NSW)
Shoalhaven (NSW)
Tamworth Regional (NSW)
Toowoomba (QLD)
Townsville (QLD)
Tweed (NSW)
Wagga Wagga (NSW)
Wodonga (VIC)
Wollongong (NSW)

Appendix 7B: Connected Lifestyle Areas

Alexandrina (SA)
Barossa (SA)
Bass Coast (VIC)
Baw Baw (VIC)
Bellingen (NSW)
Beverley (WA)
Boddington (WA)
Brighton (TAS)
Brookton (WA)
Byron (NSW)
Chittering (WA)
Clare and Gilbert Valleys (SA)
Colac-Otway (VIC)
Derwent Valley (TAS)
Gawler (SA)
Gingin (WA)
Golden Plains (VIC)
Goulburn Mulwaree (NSW)
Hepburn (VIC)
Huon Valley (TAS)
Indigo (VIC)
Kiama (NSW)
Kingborough (TAS)
Light (R (SA)
Lithgow (NSW)
Livingstone (QLD)
Lockyer Valley (QLD)
Macedon Ranges (VIC)
Mallala (SA)
Meander Valley (TAS)
Mid Murray (SA)
Mitchell (VIC)
Moorabool (VIC)
Mount Alexander (VIC)
Murray (WA)
Murray Bridge (SA)
Murrindindi (VIC)
Northam (WA)
Palerang (NSW)
Pyrenees (VIC)
Queanbeyan (NSW)
Queenscliffe (VIC)
Richmond Valley (NSW)
Scenic Rim (QLD)
Serpentine-Jarrahdale (WA)
Somerset (QLD)
Sorell (TAS)
Sunshine Coast (QLD)
Surf Coast (VIC)
The Coorong (SA)
Toodyay (WA)
Victor Harbor (SA)
Wakefield (SA)
Wandering (WA)
Waroona (WA)
West Tamar (TAS)
Wingecarribee (NSW)
Yankalilla (SA)
Yass Valley (NSW)
York (WA)

Appendix 7C: Industry and Service Hub

Albany (WA)
Alice Springs (NT)
Armidale Dumaresq (NSW)
Bega Valley (NSW)
Broken Hill (NSW)
Broome (WA)
Burnie (TAS)
Busselton (WA)
Central Coast (TAS)
Central Highlands (QLD)
Clarence Valley (NSW)
Devonport (TAS)
Dubbo (NSW)
East Gippsland (VIC)
Eurobodalla (NSW)
Great Lakes (NSW)
Greater Geraldton (WA)
Greater Taree (NS
Gympie (QLD)
Horsham (VIC)
Kalgoorlie/Boulder (WA)
Karratha (WA)
Kempsey (NSW)
Mildura (VIC)
Mount Gambier (SA)
Mount Isa (QLD)
Muswellbrook (NSW)
Nambucca (NSW)
Port Hedland (WA)
Port Pirie City and Districts (SA)
Singleton (NSW)
South Gippsland (VIC)
Southern Downs (QLD)
Wangaratta (VIC)
Warrnambool (VIC)
Wellington (VIC)
Whyalla (SA)

Appendix 7D: Heartland Regions

Alpine (VIC)
Anangu Pitjantjatjara (SA)
Ararat (VIC)
Ashburton (WA)
Augusta-Margaret River (WA)
Aurukun (QLD)
Balonne (QLD)
Balranald (NSW)
Banana (QLD)
Barcaldine (QLD)
Barcoo (QLD)
Barkly (NT)
Barunga West (SA)
Belyuen (NT)
Benalla (VIC)
Berri and Barmera (SA)
Berrigan (NSW)
Blackall-Tambo (QLD)
Bland (NSW)
Blayney (NSW)
Bogan (NSW)
Bombala (NSW)
Boorowa (NSW)
Boulia (QLD)
Bourke (NSW)
Boyup Brook (WA)
Break O'Day (TAS)
Brewarrina (NSW)
Bridgetown-Greenbushes (WA)
Broomehill-Tambellup (WA)
Bruce Rock (WA)
Bulloo (QLD)
Buloke (VIC)
Burdekin (QLD)
Burke (QLD)
Cabonne (NSW)
Campaspe (VIC)
Carnamah (WA)
Carnarvon (WA)
Carpentaria (QLD)
Carrathool (NSW)
Cassowary Coast (QLD)
Ceduna (SA)
Central Darling (NSW)
Central Desert (NT)
Central Goldfields (VIC)
Central Highlands (TAS)
Chapman Valley (WA)
Charters Towers (QLD)
Cherbourg (QLD)
Circular Head (TAS)
Cleve (SA)
Cloncurry (QLD)
Cobar (NSW)
Collie (WA)
Conargo (NSW)
Coober Pedy (SA)
Cook (QLD)
Coolamon (NSW)
Coolgardie (WA)
Coomalie (NT)
Cooma-Monaro (NSW)
Coonamble (NSW)
Coorow (WA)
Cootamundra (NSW)
Copper Coast (SA)
Corangamite (VIC)
Corowa Shire (NSW)
Corrigin (WA)
Cowra (NSW)
Cranbrook (WA)
Croydon (QLD)
Cuballing (WA)
Cue (WA)
Cunderdin (WA)
Dalwallinu (WA)
Dandaragan (WA)
Dardanup (WA)
Deniliquin (NSW)
Denmark (WA)
Derby-West Kimberley (WA)
Diamantina (QLD)
Donnybrook-Balingup (WA)
Doomadgee (QLD)
Dorset (TAS)
Douglas (QLD)
Dowerin (WA)
Dumbleyung (WA)
Dundas (WA)
Dungog (NSW)
East Arnhem (NT)
East Pilbara (WA)
Elliston (SA)
Esperance (WA)
Etheridge (QLD)
Exmouth (WA)
Flinders (QLD)
Flinders (TAS)
Flinders Ranges (SA)
Forbes (NSW)
Franklin Harbour (SA)
Gannawarra (VIC)
George Town (TAS)
Gilgandra (NSW)
Glamorgan/Spring Bay (TAS)
Glen Innes Severn (NSW)
Glenelg (VIC)
Gloucester (NSW)
Gnowangerup (WA)
Goomalling (WA)
Goondiwindi (QLD)
Goyder (SA)
Grant (SA)
Greater Hume Shire (NSW)
Gundagai (NSW)
Gunnedah (NSW)
Guyra (NSW)
Gwydir (NSW)
Halls Creek (WA)
Harden (NSW)
Hay (NSW)
Hinchinbrook (QLD)
Hindmarsh (VIC)
Hope Vale (QLD)
Inverell (NSW)
Irwin (WA)
Isaac (QLD)
Jerilderie (NSW)
Jerramungup (WA)
Junee (NSW)
Kangaroo Island (SA)
Karoonda East Murray (SA)
Katanning (WA)
Katherine (NT)
Kellerberrin (WA)
Kent (WA)
Kentish (TAS)
Kimba (SA)
King Island (TAS)
Kingston (SA)
Kojonup (WA)
Kondinin (WA)
Koorda (WA)
Kowanyama (QLD)
Kulin (WA)
Kyogle (NSW)
Lachlan (NSW)
Lake Grace (WA)
Latrobe (TAS)
Laverton (WA)
Leeton (NSW)
Leonora (WA)
Liverpool Plains (NSW)
Lockhart (NSW)
Lockhart River (QLD)
Loddon (VIC)
Longreach (QLD)
Lower Eyre Peninsula (SA)
Loxton Waikerie (SA)
MacDonnell (NT)
Manjimup (WA)
Mansfield (VIC)
Mapoon (QLD)
Maralinga Tjarutja (SA)
Maranoa (QLD)
Mareeba (QLD)
McKinlay (QLD)
Meekatharra (WA)

Menzies (WA)
Merredin (WA)
Mid-Western Regional (NSW)
Mingenew (WA)
Moira (VIC)
Moora (WA)
Morawa (WA)
Moree Plains (NSW)
Mornington (QLD)
Mount Magnet (WA)
Mount Marshall (WA)
Mount Remarkable (SA)
Moyne (VIC)
Mukinbudin (WA)
Murchison (WA)
Murray (NSW)
Murrumbidgee (NSW)
Murweh (QLD)
Nannup (WA)
Napranum (QLD)
Naracoorte and Lucindale (SA)
Narembeen (WA)
Narrabri (NSW)
Narrandera (NSW)
Narrogin (WA)
Narromine (NSW)
Ngaanyatjarraku (WA)
North Burnett (QLD)
Northampton (WA)
Northern Areas (SA)
Northern Grampians (VIC)
Northern Midlands (TAS)
Northern Peninsula Area (QLD)
Nungarin (WA)
Oberon (NSW)
Orroroo/Carrieton (SA)
Palm Island (QLD)
Parkes (NSW)
Paroo (QLD)
Perenjori (WA)
Peterborough (SA)
Pingelly (WA)
Plantagenet (WA)
Pormpuraaw (QLD)
Port Augusta (SA)
Port Lincoln (SA)
Quairading (WA)
Quilpie (QLD)
Ravensthorpe (WA)
Renmark Paringa (SA)
Richmond (QLD)
Robe (SA)
Roper Gulf (NT)
Roxby Downs (SA)
Sandstone (WA)
Shark Bay (WA)
Snowy River (NSW)
South Burnett (QLD)
Southern Grampians (VIC)
Southern Mallee (SA)
Southern Midlands (TAS)
Strathbogie (VIC)
Streaky Bay (SA)
Swan Hill (VIC)
Tablelands (QLD)
Tammin (WA)
Tasman (TAS)
Tatiara (SA)
Temora (NSW)
Tenterfield (NSW)
Three Springs (WA)
Tiwi Islands (NT)
Torres (QLD)
Torres Strait Island (QLD)
Towong (VIC)
Trayning (WA)
Tumbarumba (NSW)
Tumby Bay (SA)
Tumut Shire (NSW)
Upper Gascoyne (WA)
Upper Hunter Shire (NSW)
Upper Lachlan Shire (NSW)
Uralla (NSW)
Urana (NSW)
Victoria Daly (NT)
Victoria Plains (WA)
Wagait (NT)
Wagin (WA)
Wakool (NSW)
Walcha (NSW)
Walgett (NSW)
Waratah/Wynyard (TAS)
Warren (NSW)
Warrumbungle Shire (NSW)
Wattle Range (SA)
Weddin (NSW)
Weipa (QLD)
Wellington (NSW)
Wentworth (NSW)
West Arnhem (NT)
West Arthur (WA)
West Coast (TAS)
West Daly (NT)
West Wimmera (VIC)
Western Downs (QLD)
Westonia (WA)
Whitsunday (QLD)
Wickepin (WA)
Williams (WA)
Wiluna (WA)
Winton (QLD)
Wongan-Ballidu (WA)
Woodanilling (WA)
Woorabinda (QLD)
Wudinna (SA)
Wujal Wujal (QLD)
Wyalkatchem (WA)
Wyndham-East Kimberley (WA)
Yalgoo (WA)
Yarrabah (QLD)
Yarriambiack (VIC)
Yilgarn (WA)
Yorke Peninsula (SA)
Young (NSW)