UNIVERSITY OF SOUTHERN QUEENSLAND

# CONTRIBUTION OF THE INTERNET TOWARDS SUSTAINABLE DEVELOPMENT THROUGH ITS ECONOMIC GROWTH, SOCIAL CAPITAL AND ENVIRONMENTAL EFFECTS

A Thesis submitted by

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School of Commerce
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# Certificate of Thesis

I certify that the ideas, findings, analyses and conclusions in this dissertation are entirely my own efforts, except where otherwise acknowledged. I also certify that the work is original in full and has not been submitted elsewhere for any other award except where due references are provided.

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4. Salahuddin, M., Tisdell, C., Burton, L., & Alam, K. (2016). Does internet stimulate the accumulation of social capital? A macro-perspective from Australia. *Economic Analysis and Policy*, 49, 43–55

5. Salahuddin, M. & Alam, K. (2016). Does Internet use generate social capital? Fresh evidence from regional Australia, submitted to *Telematics and Informatics* and is under review.

6. Salahuddin, M. & Alam, K., (2016), Information and communication technology, electricity consumption and economic growth in OECD countries: A panel data analysis, *Electrical Power and Energy Systems*, 76: 185–193.

7. Salahuddin, M., & Alam, K. (2015). Internet usage, electricity consumption and economic growth in Australia: A time series evidence, *Telematics and Informatics*, 32, 862–878.

8. Salahuddin, M., Alam, K., & Ozturk, I. (2016). The effects of Internet usage and economic growth on $CO_2$ emissions in OECD countries: A panel investigation, Renewable *and Sustainable Energy Reviews 62*, 1226-1235.

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# Abstract

Spectacular growth in the use of the Internet has revolutionised many aspects of nations and human lives, including the key pillars of sustainable development such as economic, social and environmental aspects, among others. However, such phenomenal growth in the use of this enabling technology has also led to different forms of social inequalities, popularly known as ‘digital divide’. However, it is not merely the access divide that haunts the digital landscapes of the world today. With the rapid diffusion of the Internet technology, other forms of divide resulting from various factors such as age, education, speed and e-skills are emerging as potential threats to achieving the expected benefits from this general purpose technology. Empirical literature on the effects of the Internet support the view that digital divide potentially hampers the positive effects of the Internet. Currently, this is the central focus of the debate with regards to the potential economic, social and environmental effects of the Internet and the burning question is whether the Internet significantly impacts these three key parameters of sustainable development.

This thesis seeks to answer this question through economic growth, social capital and environmental effects of the Internet – in the context of Organization of Economic Cooperation and Development (OECD) countries and in Australia, in particular. To accomplish this aim, this study is guided by four research questions: i) Does Internet use affect economic growth in OECD countries, and in Australia, in particular? ii) Does Internet use affect social capital in OECD countries and in Australia and regional Australia, in particular? iii) Does Internet use have any effect on electricity consumption in OECD countries, and in Australia, in particular? and iv) Does Internet use have any effect on $CO_2$ emissions in OECD countries, and in Australia, in particular?

In order to addressing these research questions, this study uses panel macro data for OECD countries, annual time series macro data for Australia, and quantitative survey data from regional Australia. Secondary data are obtained from the World Development Indicators Database of the World Bank. Data on social capital are gathered from the World Values Survey. An advanced panel data econometric estimation technique – the Pooled Mean Group (PMG) regression technique – is applied for panel data analysis, while the Autoregressive Distributed Lag (ARDL) model is used for analysis of time series data. Summated scale method is applied to quantify the social capital variable and multivariate regression technique is employed to examine the Internet–social capital nexus at a regional level.

This PhD by publication thesis consists of seven chapters. The Introduction and Conclusions are presented in Chapter one and Chapter seven, respectively. A total of nine research outputs delivered by this research are presented in the remaining five chapters. Research question one is addressed in paper one and paper two. Research question two is addressed in papers three, four and five. Papers six and seven deal with research question three while research question four is addressed in papers eight and nine.

Paper one and paper two examine economic growth effects of the Internet for OECD countries and for Australia respectively. In addition to enriching the existing literature on Internet-growth association, these two papers make a contribution by identifying the weaknesses of previous studies. Findings suggest that the Internet stimulates economic growth both for the panel of OECD countries and for Australia as well. Internet use data is analysed for the first time for Australia in paper two.

To address research question two, the potential of the Internet in generating social capital is examined in papers three, four and five. Findings from both OECD panel and Australian time series investigations indicate that the Internet reduces social capital in the long run, while it slightly enhances social capital in the short run. Paper five analyses survey data to explore the relationship between the Internet and social capital in regional Australia.

The survey data was collected from the Western Downs Region of Queensland. The social capital variable was constructed from five theoretically supported and statistically tested dimensions of social capital concept using summated scale method. These dimensions are; bonding social capital, bridging social capital, trust, neighbourhood effects and community engagement. This is believed to be a novel contribution to the existing literature on social capital measurement which suffers from intense debate on the topic. This paper also provides a conceptual framework on Internet-social capital relationship that may be a useful guideline for similar studies in future in regional context. The key finding indicates a positive relationship between Internet use and social capital implying that Internet-enabled network connectivity stimulates social capital in regional Australia.

Research questions three and four deal with the environmental effects of the Internet. Research question three is addressed in papers six and seven – these papers investigate the effect of Internet use on electricity consumption for a panel of OECD countries and for Australia, respectively. In both studies, the Internet is found to cause an increase in electricity consumption. Such findings enforced the development of research question four, which investigates the $CO_2$ emissions effect of the Internet. This is addressed in papers eight and nine. Both investigations found that Internet use does not have any significant effect on $CO_2$ emissions. In other words, the growth in Internet use is still environmentally sustainable for these countries. All of papers six, seven, eight and nine are believed to make important empirical contributions to the literature on the environmental effects of the Internet. The findings from these studies are expected to provide stimuli for future researchers to examine such effects for other regions and countries. The conceptual framework of this study is believed to be a contribution by itself as it studies the effects of the Internet in all three key aspects of sustainable development (economic, social and environmental). Also, the massive literature review of all the three areas will enable future researchers identify research gaps in a relatively easier way for further investigations.

This study offers a number of policy recommendations. To ensure expected economic benefits from Internet use, it is recommended in paper one and paper two that demand-side issues – such as education and skills – need more attention from policymakers responsible for framing and revising digital divide policies. Despite mixed findings on the Internet-social capital relationship from papers three, four and five, the inclusion of the social capital issue in digital divide policy should not be ruled out in the process of ensuring long-run success in addressing the digital divide. To achieve energy efficiency gains from the Internet and to exploit its emissions abatement potential, 'green Internet' and 'Internet for green' are strongly recommended in papers six, seven, eight and nine in order to combat future negative environmental effects of this technology. Finally, the overall findings from the investigations undertaken by this thesis confirm that the growth in the use of the Internet contributes towards sustainable development for the OECD countries as well as for Australia in particular.

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# List of Abbreviations

| | |
|---|---|
| ABS | Australian Bureau of Statistics |
| ADF | Augmented Dickey Fuller |
| AIC | Akaike Information Criterion |
| AIHW | Australian Institute of Health and Welfare |
| ARDL | Autoregressive Distributed Lag Model |
| ASEAN | Association of South East Asian Countries |
| AVE | Average Variance Extracted |
| BREE | Bureau of Resources and Energy Economics |
| BRICS | Brazil, Russia, India, China and South Africa |
| CADF | Cross Sectionally Augmented Dickey Fuller |
| CCS | Carbon Capture and Storage |
| CD | Cross Sectional Dependence |
| CIPS | Cross Sectionally Augmented Im Pesaran Shin |
| CIS | Combined Independent States |
| CRN | Collaborative Research Network |
| CUSUM | Cumulative Sum |
| CUSUMS | Cumulative Sum of Squares |
| DF-GLS | Dickey-Fuller Generalized Least Squares |
| DH | Dumetriscu Hurlin |
| DIN | Digital Infrastructure Network |
| DOLS | Dynamic Ordinary Least Squares |
| DPD | Dynamic Panel Data |
| ECM | Error Correction Mechanism |
| ECT | Error Correction Term |
| EKC | Environmental Kuznet's Curve |
| ETF | Exchange Traded Funds |
| ETS | Emissions Trading Scheme |
| FD | Financial Development |
| FDI | Foreign Direct Investment |
| FMOLS | Fully Modified Ordinary Least Squares |
| GCC | Gulf Cooperation and Council |
| GDP | Gross Domestic Product |
| GDPPC | Gross Domestic Product Per Capita |
| GDPCG | Gross Domestic Product Per Capita Growth |
| GPT | General Purpose Technology |
| GM-FMOLS | Group Mean Fully Modified Ordinary Least Squares |
| GMM | Generalized Method of Moments |
| IAA | Innovation Accounting Approach |
| ICCE | International Conference on Clean Energy |
| ICT | Information and Communication Technology |
| IEA | International Energy Agency |
| IRF | Impulse Response Function |

| | |
|---|---|
| IRSD | Index of Relative Socioeconomic Disadvantage |
| IT | Information Technology |
| ITU | International Telecommunications Union |
| KMO | Kaiser Meyer Olkin |
| KPSS | Kwiatkowski Phillips Schmidt Shin |
| LM | Lagrange Multiplier |
| LMDI | Log Mean Divisia Index |
| LTE | Long Term Evolution |
| MENA | Middle Eastern and North African |
| MG | Mean Group |
| NBN | National Broadband Network |
| OECD | Organization of Economic Cooperation and Development |
| OLS | Ordinary Least Squares |
| OLS-AG | Ordinary Least Squares- Augmented Group |
| OPEC | Organization of Petroleum Exporting Countries |
| PAA | Principal Component Analysis |
| PCR | Principal Component Regression |
| PMG | Pooled Mean Group |
| PP | Phillips Perron |
| R&D | Research and Development |
| RESET | Regression Equation Specific Error Test |
| RETS | Renewable Energy Target Scheme |
| RRMA | Rural, Remote and Metropolitan Areas |
| SBC | Swartz Bayesian Croterion |
| SC | Social Capital |
| SLA | Statistical Local Areas |
| SNS | Social Networking Sites |
| TO | Trade Openness |
| UECM | Unrestricted Error Correction Mechanism |
| UN | United Nations |
| UNDP | United Nations Development Program |
| USA | United States of America |
| VAR | Vector Auto Regression |
| VECM | Vector Error Correction Mechanism |
| VIF | Variance Inflation Factor |
| VoLTE | Voice Over Long Term Evolution |
| WDI | World Development Indicators |
| WDR | Western Downs Region |
| WDRC | Western Downs Regional Council |
| WVS | World Values Survey |
| ZA | Zivots Andrews |

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# CHAPTER ONE
# INTRODUCTION

## 1.1 INTRODUCTION AND BACKGROUND OF THE STUDY

The Internet is changing the dynamics of our lives, and it is shaping the economic, social, cultural, political and environmental aspects of nations around the world. Recognised as an enabling technology, the Internet is one of the basic human rights of contemporary society (The United Nations, 2009). It is a leading indicator of Information and Communication Technology (ICT), and it has changed the course of human history from an industrial age to an information age (Jin & Cho, 2015). The world has witnessed a quantum leap in the growth of Internet usage over the past decade in both developed and developing countries (Elgin, 2013; Zhang, 2013). Internet penetration on a global level has increased from 18% in 2006 to around 35% in 2011 (ITU, 2012) and 46% in 2014 (ITU, 2015). The Internet is recognised as a General Purpose Technology (GPT) (Ceccobelli et al., 2012) which can potentially have an effect across all sectors of an economy and on a range of human activities (Pradhan et al., 2015).

As well as having a positive impact, the Internet may also produce negative effects (Kim et al., 2011). One of the detrimental impacts of the Internet is that its massive growth over the past two decades has resulted in various forms of social inequalities – the concept of 'digital divide' was developed to describe this phenomenon. Originally, digital divide was defined as a gap between those who have access to the Internet and those who do not (OECD, 2001); however, with rapid growth in Internet use, the concept of digital divide has been reconceptualised.

Different forms of digital divide such as education divide, age divide, skill divide, group-specific fragmentation or group divide and generation divide are framing the digital landscapes of countries (Alam & Salahuddin, 2015; Whatacre et al. 2014; Rennie et al. 2013; Zhang, 2013; Doong & Ho, 2012; Bowles, 2012; Lee, 2011; Kyriakidou et al., 2011). Digital divide is currently the central focus of the debate on the multidimensional effects of this technology. It is believed that digital divide undermines the positive effects of the Internet.

The Internet also gives rise to other issues that may overshadow the benefits of this technology (Kim et al., 2011). These include spam, malware, privacy breaches, hacking of valuable and sensitive information, violation of digital property rights, defamation, addiction to social network sites and various other forms of cybercrimes (Kim et al., 2011). Governments of the OECD countries are spending billions of dollars to build and expand Internet infrastructure (Zhang, 2013). Therefore, it is important to assess the contribution of the Internet towards sustainable development.

One view-point in the economic literature is that if sustainable development is to be achieved, developmental changes must be economic, environmentally/ecologically sustainable and socially acceptable (Barbier, 1987; Tisdell, 2005, Ch. 11; 2014, Ch.9). Therefore, from a sustainable development point of view, it would be desirable for the use of the Internet to have positive economic consequences (such as by raising economic growth), not be a major contributor to environmental deterioration (such as by not increasing electricity consumption and $CO_2$ levels significantly) and to have effects on the community and individuals that are socially acceptable. Also, economic, social and environmental effects are the three key pillars of sustainable development (Elkington, 1998). This thesis explores the effect of the Internet on sustainable development by exploring each of these aspects in the context of Organization of Economic Cooperation and Development

(OECD) countries, with a particular focus on Australia. This has not been given much attention in the past.

In order to achieve this goal, this publication-based PhD thesis deals with one central aim, three objectives, four research questions (RQs). To address four research questions, a total of nine research outputs (papers) are produced. Paper one and paper two, each addresses economic growth effects of the Internet (RQ1), while papers three, four and five each examines the Internet's social capital effect (RQ2). Objective three is achieved by analysing the effects of the Internet on electricity consumption (RQ3) and $CO_2$ emissions (RQ4); this research is presented in papers six, seven, eight and nine. Papers one, three, six and eight each deal with OECD panel data, while papers two, four, seven and nine deal with Australian annual time series data. Paper five deals with survey data obtained from the Western Downs Region of Queensland, Australia.

## 1.2 STATEMENT OF THE PROBLEM

The Internet has engendered a paradigm shift from the industrial age to an information age (Castells, 2000). It potentially affects all key areas, economic, social and environmental aspects of sustainable development and these effects have drawn special attention from researchers around the world (Firth & Mellor, 2005).

The Internet can affect economic growth positively by increasing total output (Choi & Yi, 2009; Holt & Jamison, 2009; Koutrompis, 2009; Kumar et al., 2015). It can also affect economic growth in various other ways, such as through an increase in foreign direct investment (Choi, 2003), a reduction in inflation rate (Yi & Choi, 2005), an increase in bilateral and international trade (Choi, 2010; Frehund & Weinhold, 2004), an improvement in allocative efficiency of resources (Rapson & Schiraldi, 2013), increases in labour productivity (Najarjadeh et al. 2014), a reduction in the unemployment rate (Czernich, 2014), and an increase in industry competition (Wang & Zhang, 2015).

Despite a growing amount of literature on the economic impacts of the Internet, such associations have scarcely been examined for OECD countries. Only a handful of attempts (Czernich et al., 2011; Koutrompis, 2009), using data for very short periods, have been made to investigate the Internet–growth association for this region. Notwithstanding the recent claim (Deloitte Access Economics, 2015) that the Internet has been transforming the Australian economy for about a decade now, very few studies have focused on this significant role of the Internet. Two studies (Shahiduzzaman & Alam, 2014a; 2014b) recently investigated the growth and productivity effects of ICT in an Australian context. However, neither of the studies used Internet use data for such analysis.

The Internet is also able to generate social capital which is defined as the resources accumulated through relationships among people (Coleman, 1998). The social capital-building ability of the Internet has been analysed in several recent empirical studies, especially from a micro perspective (Kyujin, 2013; Antoci et al. 2012; Lippert & Spagnolo, 2011; Notely & Foth, 2008; Foth & Podkolicka, 2007; Fernback, 2005; Hopkins, 2005; Meredyth et al., 2004). Many of these studies, especially the most recent ones (Kyujin, 2013; Antoci et al., 2012; Lippert & Spagnolo, 2011; Notely & Foth, 2008) argue that Internet generated social capital may potentially reduce digital divide and recommend the inclusion of social capital issue into the digital divide policy of a country.

It is evident that digital divide resulting from geographic location – such as urban/rural – education, and inequity in the use of the Internet exists in OECD countries including Australia, and it has not diminished (Zhang, 2013; Broadbent &

Papadopoulos, 2013; Ewing & Thomas, 2013; Bowles, 2012; Vicente & Lopez, 2013). Recent evidence indicates that the most significant factors contributing to digital divide in Australia are income, age, tertiary education and ethnicity (Atkinson et al., 2008; Bowles, 2012; Broadbent & Papadopoulos, 2013; Charleson, 2013). Currently, this divide is even in the danger of widening in Australia, particularly outside metropolitan areas (Alam & Imran, 2015; Bowles, 2012). Kyriakidou et al., (2011) found support in favour of the existence of digital divide in 27 European countries, many of which are OECD countries. Since social capital potentially reduces digital divide through social inclusion (Notley and Foth, 1998), studying the effect of the Internet on social capital building will contribute to our knowledge and fill a gap in the literature.

The rapid growth of the Internet has environmental consequences as well. The increasing use of the Internet and consequently the exponential growth in the number of data centres and other Internet-related services, causes an increase in electricity demand. The vast majority of electricity is still produced from fossil fuels, which are responsible for $CO_2$ emissions (Heddeghem, et al., 2014; Coroama & Hilty, 2012; Sadorsky, 2012). However, the Internet may potentially contribute towards enhancing energy efficiency (Walker, 2005). As such, the effects of the Internet on electricity consumption and subsequently on $CO_2$ emissions may not be anticipated *a priori* without further investigation. Although OECD countries are home to the highest number of data centres in the world and 80% of electricity in these countries is generated from fossil fuels (Garimella et al., 2013; Hamdi et al., 2014), no empirical investigations into the effect of the Internet on electricity consumption and $CO_2$ emissions for these countries have been undertaken before this study.

Based on the above discussion, the following key issues with respect to the Internet's effects on sustainable development through its economic growth, social capital and environmental effects have been identified in the context of OECD countries and Australia, in particular:

1) The Internet plays an extremely important role in OECD economies, including Australia.
2) The Internet–growth literature is relatively scarce despite the Internet's significant role in transforming economies.
3) Digital divide exists in OECD countries. In Australia, it is even in the danger of widening.
4) Addressing digital divide is a policy priority of OECD countries.
5) Internet-generated social capital has the potential to reduce digital divide.
6) Empirical causal association between Internet use and social capital has not yet been examined for OECD as a panel, nor for Australia as a country-specific study.
7) Rapid growth in Internet use has environmental implications for OECD countries, however, an in-depth investigation of such effects is absent for the OECD countries as well as for Australia.

## 1.3. AIM AND OBJECTIVES OF THE STUDY

The central aim of this research is to assess the effect of Internet use on sustainable development through its economic growth, social capital and environmental effects in OECD countries with an emphasis on Australia. In light of the above goal, the following three objectives are set:

1) To analyse the effects of the Internet on economic growth for a panel of OECD countries and for Australia.

2) To analyse the effects of the Internet on social capital for a panel of OECD countries, for Australia and for regional Australia
3) To analyse the environmental effects of the Internet through energy use and $CO_2$ emissions for a panel of OECD countries and in Australia.

## 1.4 CONCEPTUAL FRAMEWORK

The rapid growth in Internet use and the spending of billions of dollars by governments across the world for the expansion of this technology make it imperative to know how this enabling technology is impacting the sustainable development of countries. Therefore, this study conducts an investigation into how Internet use is affecting sustainable development through economic growth, social capital and environmental effects which are the three key pillars of sustainable development. This conceptual framework of the study explains the sequential flow of how Internet use affects these three pillars and how these effects are linked altogether.

According to the 'network society thesis' (Barney, 2004; Castells, 2000), contemporary social, political and economic institutions and relations are organised through and around network structures. The Internet, in the first place, is a useful networking tool that generates a network of networks. The arrival of the Internet has revolutionised network connectivity (Wellman, 2001), and it is recognised as the most powerful information channel that has changed the way information is shared and acquired today (Liang & Guo, 2015).

Internet usage allows the generation and distribution of decentralised information and ideas in markets increasingly relying on information as an input. In light of modern theories of endogenous growth (e.g. Lucas, 1988; Romer, 1986, 1990; Aghion & Howitt, 1998; Barro, 1998), the Internet should accelerate economic growth by facilitating the development and adoption of innovation processes. Internet usage may accelerate the distribution of ideas and information, fostering competition for and development of new products, processes and business models, thereby facilitating macroeconomic growth further. By disseminating information, the Internet improves efficiency in resource allocation and boosts financial development, eventually promoting economic growth (Levine, 1991, 1993; Liang & Guo, 2015).

Romer's (1986, 1990) endogenous growth model explained that endogenous growth theories model the generation and distribution of ideas and information as key drivers of economic growth (Lucas, 1988; Romer, 1990; Aghion & Howitt, 1998). As such, massive growth in Internet usage may affect the innovative capacities of the economy through the creation of information and knowledge spill-over. In endogenous growth models (Lucas, 1988; Romer, 1986), innovation (Aghion & Howitt, 1992) and knowledge spill-over (Grossman & Helpman, 1991; Romer, 1990) contribute towards an increase in economies of scale that promotes economic growth.

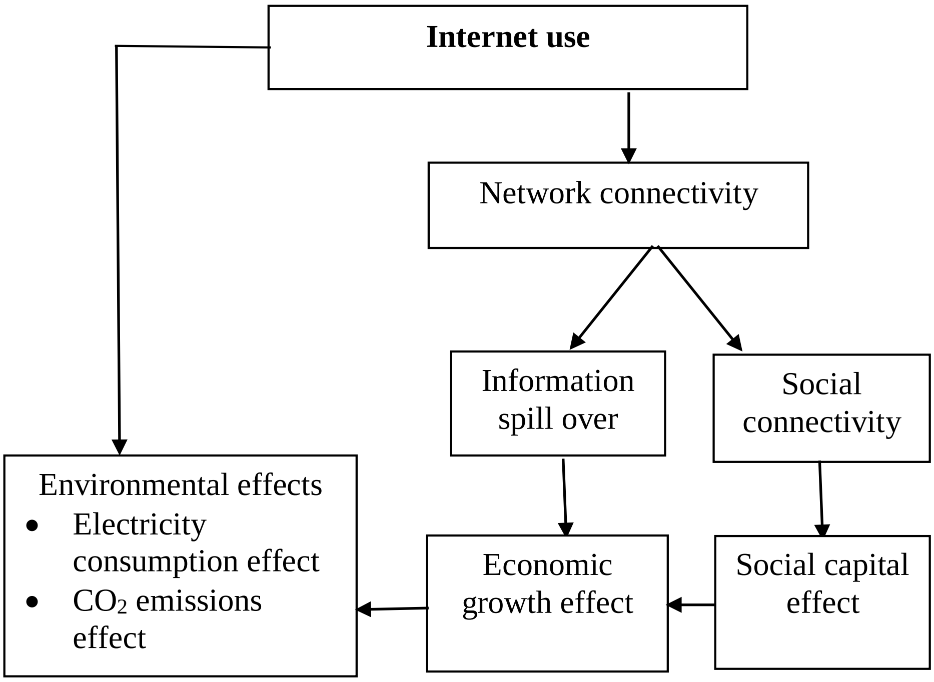
Information dissemination at an affordable cost can also facilitate the adoption of new technologies devised by others – a process which again promotes economic growth (Benhabib & Spiegel, 2005). This phenomenon also suggests that spill-over of codified knowledge across firms and regions may constitute another channel by which information technology in general, and Internet usage in particular, affects the economic growth of a nation. Extensive use of the Internet has fundamentally changed and improved the processing of information, resulting in significant productivity growth among IT-using firms (Stiroh, 2002; Jorgensen et al., 2008) and boosting economic growth at a macro level.

The Internet, through its networking capability, not only helps people connect in the virtual world but also facilitates social interaction in the real world. Further, it provides a set of useful tools for the proliferation of online social engagement (Zhong, 2014). Thus, it enables new forms of social interaction increasing digital inclusion in society (Vosner et al., 2016).

Internet usage generates social capital through networks of relations between people and different communities (Lippert & Spagnolo, 2011). Through the networking potential, the Internet allows people to be part of large networks of interest, to interact with people within their group or from outside their group, develop ties and friendships with them and strengthen existing ties (Neves & Fonseca, 2015). This interaction through network connectivity affects all the core dimensions of social capital such as: bonding social capital, bridging social capital, trust, neighbourhood effect and community engagement (through email, instant messaging, social networking sites, Skype etc.) and thus generate social capital. Social capital may also boost economic growth (Salahuddin et al. 2015).

Apart from the fact that, economic growth may have environmental effects by potentially causing electricity consumption and $CO_2$ emissions to rise, the massive growth in Internet-enabled network connectivity also leads to the phenomenal growth of data centres which consume electricity (Faucheux & Nicolai, 2011; Heddeghem et al., 2014; IEA, 2009; Sadorsky, 2012). This rise in electricity consumption is likely to cause an increase in $CO_2$ emissions.

**Figure 1: Conceptual model of the study**




Based on the conceptual model presented in Figure 1, first, this research examines the economic growth effect of the Internet. This follows the investigation into the effect of the Internet on social capital. Finally, the environmental effects of the Internet are analysed through its effects on electricity consumption and $CO_2$ emissions. Thus, the effects of the Internet on sustainable development are examined through its effects on three key dimensions of sustainable development.

## 1.5 RESEARCH QUESTIONS (RQs)

To accomplish the central aim and achieve the associated objectives, this study is guided by four research questions (RQs):

1) Does Internet use affect economic growth in OECD countries and in Australia, in particular?
1) Does Internet use affect social capital in OECD countries and in Australia and regional Australia, in particular?

2) Does Internet use have any effect on electricity consumption in OECD countries and in Australia, in particular?
3) Does Internet use have any effect on $CO_2$ emissions in OECD countries and in Australia, in particular?

## 1.6 METHODOLOGIES

This thesis analyses panel data for OECD countries, annual time series macro data for Australia and survey data from the Western Downs Region in Queensland (see Table 1). Over the years, panel data has gained extraordinary popularity for its unique feature of combining cross-sectional units (N) with time periods (T). It is argued that if the pooling of cross-sections is free from a significant level of heterogeneity, panel data has certain advantages over time series data (Asterio & Hall, 2009). First, the sample size in a panel data exercise can be extended, which is likely to provide better estimates. Second, the likelihood of the problem of omission bias is less in panel data than in time series data. Third, panel data overcomes the problem of failing to obtain significant t-ratios and F-statistics, unlike time series data which faces such problems if there are only few observations.

However, the applications of panel data and time series data are also context-dependent. When a researcher is interested in dealing with a situation that involves changes in only one cross-sectional unit over a certain period of time, they have to opt for time series data. Table 1 below presents an overview of methodologies used in this research. It briefly shows the types of data, sources of data and the various econometric and statistical tests and methods applied for addressing each research question.

This thesis deals mainly with macroeconomic panel and time series data, and this type of data are likely to be characterised by a unit root process (Nelson & Plosser, 1982); in other words, such data are likely to be non-stationary. Without converting non-stationary data into stationary data, all estimation results would be spurious. Nevertheless, there is high possibility of the presence of structural break in macroeconomic series when the sample period is large. This structural break is due to fluctuations in business cycles as a consequence of external and internal shocks.

**Table 1: An overview of methodologies**

| **Research Questions (RQs)** | **Region/Country of study and type of data** | **Sources of data** | **Tests and estimation techniques applied** |
|---|---|---|---|
| RQ1. Does Internet use affect economic growth in OECD countries in general and in Australia in particular? | OECD panel data, Australian annual time series data | World Development Indicators Database, The World Bank | Cross-sectional dependence test, CIPS unit root test, Pooled Mean Group Regression Technique, Structural break unit root test, Cointegration method and ARDL technique |
| RQ2: Does Internet use affect social capital in OECD countries, in Australia and in regional Australia? | OECD panel data, Australian annual time series data and social capital data generated through linear interpolation of WVS data, survey data | World Development Indicators Database, The World Bank and World Values Survey (WVS), Western Downs Region, Queensland | Cross-sectional dependence test, CIPS unit root test, Pooled Mean Group Regression Technique, Structural break unit root test, ARDL, summated scale method and regression analysis |
| RQ3: Does rapid growth in Internet use have any effect on electricity consumption in OECD countries and in Australia? | OECD panel data, Australian annual time series data | World Development Indicators Database, The World Bank and International Energy Agency | Cross-sectional dependence test, CIPS unit root test, Pooled Mean Group Regression Technique. Structural break unit root test, ARDL, summated scale method and regression analysis |
| RQ4: Does rapid growth in Internet use have any effect on $CO_2$ emissions in OECD countries and in Australia? | OECD panel data, Australian time series data | World Development Indicators Database, The World Bank and International Energy Agency | Cross-sectional dependence test, CIPS unit root test, Pooled Mean Group Regression Technique. Structural break unit root test, ARDL, summated scale method and regression analysis |

Prior to performing any data estimation, this research first converts both panel and time series data into first difference stationary series by conducting state-of-the-art panel and time series structural break unit root tests. Since panel data may suffer from the threat of cross-sectional dependence for obvious reasons, a cross-sectional dependence test is performed and then an appropriate unit root test that takes into account such dependence is conducted.

Finally, for estimation purposes, one of the most advanced econometric panel data techniques The Pooled Mean Group (PMG) regression – is applied for estimation of panel data, while the Autoregressive Distributed Lag (ARDL) model is applied for the analysis of time series data. A battery of diagnostic tests and other estimation methods are also used to test the robustness of findings. STATA 13 is used for panel data analysis while MICROFIT 5 is used for time series analysis and SPSS 16 is used for survey data analysis.

For survey data analysis, a structured questionnaire is used to conduct a quantitative survey. The questionnaire is finalised after a series of pilot tests, obtaining expert opinion, and an extensive literature survey. The social capital variable is quantified with the application of summated scale method using five core dimensions of social capital drawn from social capital theory. Intensity of the use of the Internet is derived from the weekly average number of hours of Internet use of each respondent who is an Internet user. Finally, Internet use is regressed on the social capital variable to estimate the magnitude of the association between Internet use and social capital.

## 1.7 CASE STUDY RESEARCH

To address research question two, this study uses a case-study approach. This section briefly explains the rationale for choosing the Western Downs Region (WDR) of Queensland as a potential case for examining whether Internet use generates social capital in regional Australia. This study was conducted with the ethics approval from the University of Southern Queensland (USQ H13REA150).

It is argued that the benefits of new technology – including IT – have been concentrated in major urban areas in Australia (Giesecke, 2006). As a consequence, digital divide is intensifying and even in the danger of widening (Bowles, 2012), particularly in rural and regional Australia (Alam and Salahuddin, 2015) and among disadvantaged communities (Alam and Imran, 2015). Therefore, one of the key objectives of the NBN is to narrow the digital divide in regional Australia (Lee, 2011). Similarly, digital divide in various forms haunt the regional landscape of other OECD countries (Doong and Ho, 2012; Zhang, 2013) and one of the priority goals of the digital divide policies of these countries is to reduce it especially in rural and remote areas (Doong and Ho, 2012).

Since, the Internet has the potential to generate social capital and social capital may potentially contribute towards reduction in digital divide (Charleson, 2013; Notely and Foth, 2008; Zhao and Lu, 2012), this case study aims to examine the potential link between Internet use and social capital in the context of regional Australia. Such a study is not expected to be useful for Australia only, it is expected to give further direction to all other OECD countries in deciding whether social capital issue needs to be included in framing their digital divide policies.

The WDR is believed to be representative of other regions in Australia as it has a similar socioeconomic profile to other regions to Australia. Baum et al. (1999) analysed Census data for all urban areas in Australia to develop measures for Statistical Local Areas (SLAs). Each of the SLAs was assigned a score, and each community was ranked based on these scores reflecting its socioeconomic status relative to those of the other communities in the study. Tara, Dalby and Chinchilla – the three major towns in the WDR – were identified as SLAs in this study, having Index of Relative Socioeconomic Disadvantage (IRSD) scores of 918.43, 989.52 and

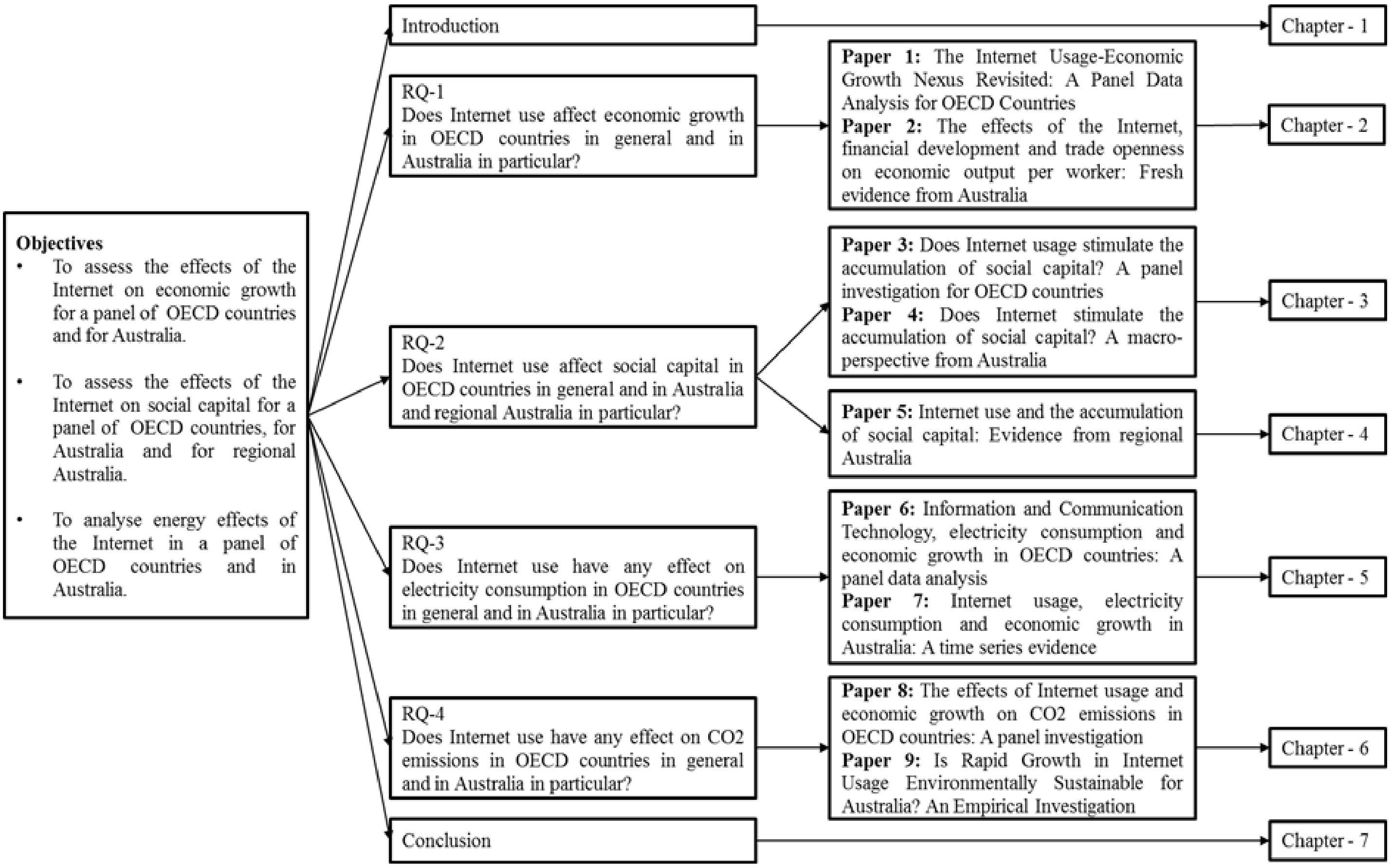
980.14, respectively. These scores are neither at the bottom of the disadvantaged group of regions in Australia nor in the top quintile of disadvantaged groups. According to the Rural, Remote and Metropolitan Areas (RRMA) classification criteria, WDR is recognised as a typical Australian region that consists of both rural urban centres and remote urban centres (AIHW, 2004).

**Figure 2: Map of WDR**


## 1.8 STRUCTURE OF THE THESIS

The structure of the thesis is presented in Figure 2. This thesis starts with an introduction section which is in chapter one. Papers one and two addressing research question one are accommodated in chapter two. Research question two is addressed in chapters three and four. Chapter five consists of papers six and seven addressing research question three while chapter six includes papers eight and nine which address research question four. Chapter seven draws the conclusions of the study. Figure 2 below presents the structure of the thesis in a more succinct way.

**Figure 3: Structure of the thesis**



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# CHAPTER TWO

# PAPER 1 AND PAPER 2

## PAPER 1: THE INTERNET USAGE-ECONOMIC GROWTH NEXUS REVISITED: A PANEL DATA ANALYSIS FOR OECD COUNTRIES

## PAPER 2: THE EFFECTS OF THE INTERNET, FINANCIAL DEVELOPMENT AND TRADE OPENNESS ON ECONOMIC GROWTH: FRESH EVIDENCE FROM AUSTRALIA

## PAPER 1: THE INTERNET USAGE-ECONOMIC GROWTH NEXUS REVISITED: A PANEL DATA ANALYSIS FOR OECD COUNTRIES

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## Statement of Contributions of Authorship

To whom it may concern

I, Mohammad Salahuddin contributed 70% to the paper entitled above.

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Signature of Candidate: [signature] Date: January 24, 2016

I, as a coauthor recognize and accept that the contribution of the candidate indicated above for the above mentioned paper is appropriate.

Khorshed Alam Signature: [signature] Date: 24/01/2016

Ilhan Ozturk Signature: Ilhan Ozturk Date: 24/01/2016

**This paper is one of two papers included in Chapter two in the candidate's PhD thesis**

**The Internet Usage-Economic Growth Nexus Revisited: A Panel Data Analysis for OECD Countries**

**Abstract**

This study addresses the major methodological weaknesses, namely, the endogeneity, cross country heterogeneity and cross-sectional dependence issues in previous panel studies on the Internet-growth relationship. It applies the Pooled Mean Group regression technique that accounts for endogeneity and cross country heterogeneity. The cross sectional dependence issue is also accounted for. A dynamic panel data are used for the period 1990-2012 in an endogenous growth model framework for Organization of Economic Cooperation and Development (OECD) countries. The current study further boasts the first-ever application of variance decomposition analysis in the Internet usage-economic growth literature to forecast their relationship beyond the sample period. The findings suggest significant positive short-run and long-run relationship between Internet usage and economic growth. The Internet is also found to Granger cause economic growth in the region. However, other variables show mixed results. Findings from variance decomposition analysis indicate that the Internet will continue to have an increasing impact on economic growth in OECD countries. The forecasted variance in economic growth explained by Internet usage would rise from 0.20% in 2013 to 3.27% in 2035. The study recommends that to expect the benefits of the Internet's positive effects on economic growth to continue, these countries need to focus on the demand side issues of the Internet such as education and e-skills, more than the supply side issues, such as expansion of network coverage.

*Keywords:* Economic growth; Internet usage; OECD countries; Pooled Mean Group Regression; Variance Decomposition

## 1. Introduction

The penetration of the Internet usage as a part of the Information and Communication Technology (ICT) revolution is believed to be a significant contributor towards social and economic development. Quite expectedly, there has been spectacular growth in Internet usage especially in the past two decades in Organization of Economic Cooperation and Development (OECD) countries (OECD Internet Outlook, 2013). Such phenomenal growth in Internet usage is attributed to the enormnous investment in the rolling out of fixed and wireless Internet infrastructures expanding the bandwidth available for all types of communication services in the region. ICT offers a wide spectrum of services ranging from the long-term evolution (LTE) standard for mobile networks based on Internet Protocol (IP)-only architecture using Voice over LTE (VoLTE) to the cloud-based and "over the top" providers (OECD Communications Outlook, 2013). All these services of the Internet are believed to have been transforming OECD economies with regards to productivity, growth and other macroeconomic effects (Zhang, 2013; OECD Internet Outlook, 2013).

Although several studies have been undertaken to investigate the effects of ICT on macroeconomic variables such as economic growth, productivity, international trade, inflation, financial development, stock market development and unemployment, the direct impact of Internet usage on growth and other macroeconomic variables is still an under-investigated field of research (Elgin, 2013).

Methodologically, most of the studies on the relationship between Internet usage and economic growth and other macro variables to date (Najarzadeh et al. 2014; Lio et al. 2011; Choi, 2010; Koutroumpis, 2009; Choi and Yee, 2009; Noh and Yoo, 2008; Yi and Choi, 2005) have made use of homogeneous panel data approaches, such as the traditional fixed and random effects estimators. They also often applied the instrumental variable (IV) technique proposed by Anderson and Hsiao (1981, 1982) and the generalized methods of moments (GMM) estimators of Arellano and Bond (1991) and Arellano and Bover (1995). The small time dimension of the data used in these studies restricted them to using these methodologies. The major weakness of these methodologies is that these methods allow certain degree of homogeneity allowing only the intercepts to vary across countries while restricting other parameters to remain cionstant.

When such techniques are employed to investigate the growth effects of different macro variables, they can potentially produce inconsistent, misleading and biased estimates since growth models are typically characterized by substantial cross-sectional heterogeneity (Pesaran and Smith, 1995; Cavalcanti et al., 2012). Nevertheless, none of these empirical exercises considered cross sectional dependence (CD) issue across the panel data although its presence due to common unobserved factors or shocks can yield biased and misleading results (Cavalcanti et al., 2012).

To overcome these limitations and in the light of the view that application of new methodologies to ICT and Internet-related studies has the potential to offer more reliable findings (Cardona et al., 2013), this study reexamines the Internet-growth relationship for OECD countries. Therefore, this empirical exercise addresses the following research questions: (i). Is the Internet growth relationship still positive for OECD countries when a longer sample period and a new methodology namely, Pooled Mean Group Regression

(PMG) technique that accounts for endogeneity and heterogeneity, is applied? (ii). Are the PMG results valid even when cross sectional dependence is accounted for? (iii). Does any causality exist between Internet usage and economic growth? and (iv). Is Internet usage expected to continue to boost economic growth in the future in the region?

This paper is expected to make a number of contributions to the study of the Internet-growth nexus both from methodological and policy-making perspectives. First, it makes a significant methodological contribution by overcoming the potential risk of producing biased and inconsistent results with the help of the application of a powerful heterogeneous dynamic panel data technique PMG. Second, the current study also considers the presence of cross-sectional dependence across the panel of OECD countries while testing for the stationarity of data. Third, this study performs variance decomposition analysis (Pesaran and Shin, 1998) to forecast the Internet-growth relationship in the region for a time horizon beyond the sample period. Such application is also believed to be new in both ICT-growth and Internet-growth literatures. Findings from such forecasting analysis are expected to be very useful for policy-makers not only to assess the current telecommunications and digital divide policies in the region but also to appropriately formulate such policies for the future.

The remainder of the paper is structured as follows; Section 2 presents a literature review and Section 3 outlines the data and methodological framework of this research. Section 4 presents the estimation results and Section 5 offers conclusions and policy implications.

## 2. Literature Review

Internet usage enables dissemination of information and ideas in markets. Modern theories of endogenous growth (e.g., Lucas 1988; Romer 1986, 1990; Aghion and Howitt 1998; Barro, 1998) state that the Internet should boost economic growth by facilitating the development and adoption of innovation processes. Internet usage may accelerate the diseemination of ideas and information and intensify competition through development and diversification of new products, processes, and business models which eventually propell macroeconomic growth.

Romer's (1986, 1990) endogenous growth model argued that endogenous growth theories model the generation and distribution of ideas and information as the catalysts of economic growth (Lucas, 1988; Romer, 1990; Aghion and Howitt, 1998). As such, the massive growth in Internet usage may enhance the innovative capacities of the economy through knowledge spillover, development of new products and processes, and business models to promote growth. Moreover, cheaper information dissemination encourages the adoption of new technologies which help stimulate economic growth (Nelson and Phelps, 1966; Benhabib and

Spiegel, 2005). This also suggests that information technology can affect economic growth through other channels such as codified knowledge across firms and regions. The Internet further enables the exchange of data across multiple locations and facilitates the decentralization of information processing. It also potentially contributes towards the emergence of new business and firm-cooperation models that rely on the spatial exchange of large batches of information resulting in intensified competition and innovation processes. The Internet may increase market transparency and thus additionally intensify competition. Extensive use of the Internet fundamentally changed and improved the processing of information, resulting in significant productivity growth of IT-using firms (Stiroh, 2002; Jorgensen et al., 2008).

There are also plenty of empirical evidences that suggest that the Internet potentially increases total output and affects economic growth positively (Zhang, 2013; Koutroumpis, 2009; Choi and Yi, 2009; Holt and Jamison, 2009; Cette et al., 2005; Kim and Oh, 2004; Klein, 2003). The Internet stimulates foreign direct investment (Choi, 2003). It also contributes towards lowering the inflation rate by reducing transaction cost and improving efficiency in the economy (Meijers, 2006; Yi and Choi, 2005). It enhances bilateral and international trade by reducing communication and transportation costs (Choi, 2010; Freund and Weinhold, 2004) and potentially reduces unemployment (Najarzadeh et al., 2014). The Internet also promotes exchange traded funds (ETF) and thus boosts investment in the economy (Lechman and Marszk, 2015).

At a micro level, the Internet has been able to enhance labor productivity and has led to major revenue increases and cost savings in developed countries (Litan and Rilvin, 2001; Varian et al., 2002). By reducing information asymmetry in the market, identifying customers and production standards, the Internet also helps boost exports at the firm level (Clarke,2008).

Empirical literature separately investigating the direct effects of the Internet on economic growth and other macro variables started evolving during the past decade and most of these studies have used panel data. Frehund and Weinhold (2002) investigated the effect of the Internet on service trade and found a positive significant relationship between them.

Choi (2003) studied the effect of the Internet on inward foreign direct investment (FDI) using data for a panel of 14 source countries and 53 host countries. The study applied cross-country regression on a gravity FDI equation and findings indicated that a 10% increase in the number of Internet users in a host country raised FDI inflows by 2%. Frehund and Weinhold in another study (2004) that ran both time series and cross-section regressions on a sample of 53 countries, found that the Internet stimulated trade. The study further observed that the Internet reduced market-specific fixed costs which contribute towards export growth.

Yi and Choi (2005) employed pooled OLS and random effects models for a panel of 207 countries. Their results showed that a 1% increase in the number of the Internet users led to a 0.42% drop in inflation. Noh and Yoo (2008) tested the empirical relationship among Internet adoption, income inequality and economic growth using a panel of 60 countries for the period 1995-2002. They found that the Internet's effect on economic growth is negative for countries with high income inequality. The findings were attributed to the presence of a digital divide in these countries.

Choi and Yee (2009) used data for a panel of 207 countries for the period 1991-2000 to examine the impact of the Internet on economic growth while controlling for some macro variables. They used a number of panel econometric techniques to control for endogeneity among the explanatory variables. Their findings supported the significant positive role of the Internet in spurring economic growth.

Holt and Jamison (2009) analysed the association between ICT and economic growth as well as the connection between broadband Internet and economic growth. The study supported the positive impact of broadband deployment and adoption on economic growth in the USA. Choi (2010) estimated the effect of the Internet on service trade and found a significant positive relationship between the number of the Internet users and total service trade. It was concluded that a 10% increase in the number of Internet users prompted an increase in service trade of between 0.23% and 0.42%.

Lio et al. (2011) estimated the effects of the Internet adoption on reducing corruption in a panel of 70 countries for the period 1998-2005. Using the Granger causality test to find the causal link, they further applied dynamic panel data models (DPD) to estimate the relationship between variables while addressing the endogeneity problem. The empirical results indicated significant role of the Internet in reducing corruption. Goel et al. (2012) obtained similar results in their cross-sectional empirical analysis.

Zhang (2013) developed the Internet consumption model and conducted a cross-country empirical research examining the relationship between income, the Gini index and the pattern of the internet diffusion curve. His findings indicated that the developed countries had steeper Internet diffusion curves and shorter time lags than developing countries. The Gross Domestic Product (GDP) per capita had positive correlation with the slope of the Internet diffusion curve while the Gini index had negative correlation.

Elgin (2013) used a panel data of 152 countries for the period 1999-2007 to investigate the effects of the Internet on the size of the shadow economy. The study used cross-country regressions and found that the association between the Internet usage and the shadow economy strongly interacts with GDP per capita. The study further highlighted two opposing effects of Internet usage-the increasing productivity effect reducing the size of the shadow economy and the increasing tax evasion effect increasing the size of the shadow economy. Mack and Rey (2014) showed that in 49 out of 54 metropolitan areas in the USA, the Internet enhanced productivity in knowledge intensive firms. Maria et al. (2013) demonstrated that deployment of mobile communication and greater use of Internet technologies were associated with a higher level of technical efficiency in high and low-income countries.

Choi et al. (2014) investigated the determinants of international financial transactions using cross country panel data on bilateral portfolio flow between the USA and 38 other countries for the period 1990-2008. The study estimated the effect of the Internet on the cross-border portfolio flows into the USA from other countries in the panel. It employed the gravity model and found that the Internet reduces information asymmetry and thus increases cross-border portfolio flows. The results were robust across different empirical models.

Najarzadeh et al. (2014) investigated the effect of the Internet on labor productivity using data for a panel of 108 countries for the period 1995-2010. Employing the pooled OLS, fixed effect, and one-step and two-step GMM methods to estimate the relationship. The empirical exercise suggested a positive and strong significant relationship between Internet use and labor productivity. Gruber et al. (2014) estimated the returns from broadband infrastructure for the period 2005-2011 and also assessed the cost of broadband roll out under different assumptions of technical performance. Their findings contrasted with the forecasted benefits from the expansion of broadband coverage. However, the study also found that the future benefits to be reaped from a broadband roll out project outweigh the investment involved therein for the highest performance technologies. The study recommended public subsidies to promote building high- speed broadband infrastructure.

Czernich (2014) examined the relationship between broadband Internet and unemployment rate using data of various municipalities of Germany. Simple OLS regression indicated a negative relationship between broadband Internet and unemployment while such an association between these variables could not be confirmed with the introduction of an instrument variable in the same study. Lechman and Marszk (2015) examined the relationship between ICT penetration and exchange traded funds (ETF) for Japan, Mexico, South Korea and the United States over the period 2002-2012 using two core indicators of ICT, 'number of

Internet users per 100 people' and 'Fixed Broadband Internet subscriptions per 100 people'. Using logistic growth models to analyse the data, the study found a positive, strong and significant relationship between ICT penetration and ETF.

Literature studying the Internet-growth relationship in the context of OECD countries is very scarce. Only a handful of studies (Czernich et al., 2011; Koutroumpis, 2009) to date could be identified. In one of the most recent studies, Czernich et al. (2011) examined the effect of broadband infrastructure on economic growth using an annual panel of 25 OECD countries for the period 1996-2007. Although this study addressed the endogeneity problem by introducing an instrumental variable, the time lag for drawing a definitive conclusion from the findings is still not sufficient (Holt and Jamison, 2009). Another study (Koutroumpis, 2009) used OECD data only for the period 2002-2007 and thus had limited ability to draw causal inference on the relationship between Internet usage and economic growth (Tsai et al., 2012).

It is evident from the above review that studies dealing with panel data involving both OECD and other contexts suffer from methodological shortcomings. This study aims to address these shortcomings with the application of relatively recent econometric techniques that were not used much before in such studies in addition to using the most recent data set.

## 3. Data and Methodological framework

### *3.1 Data*

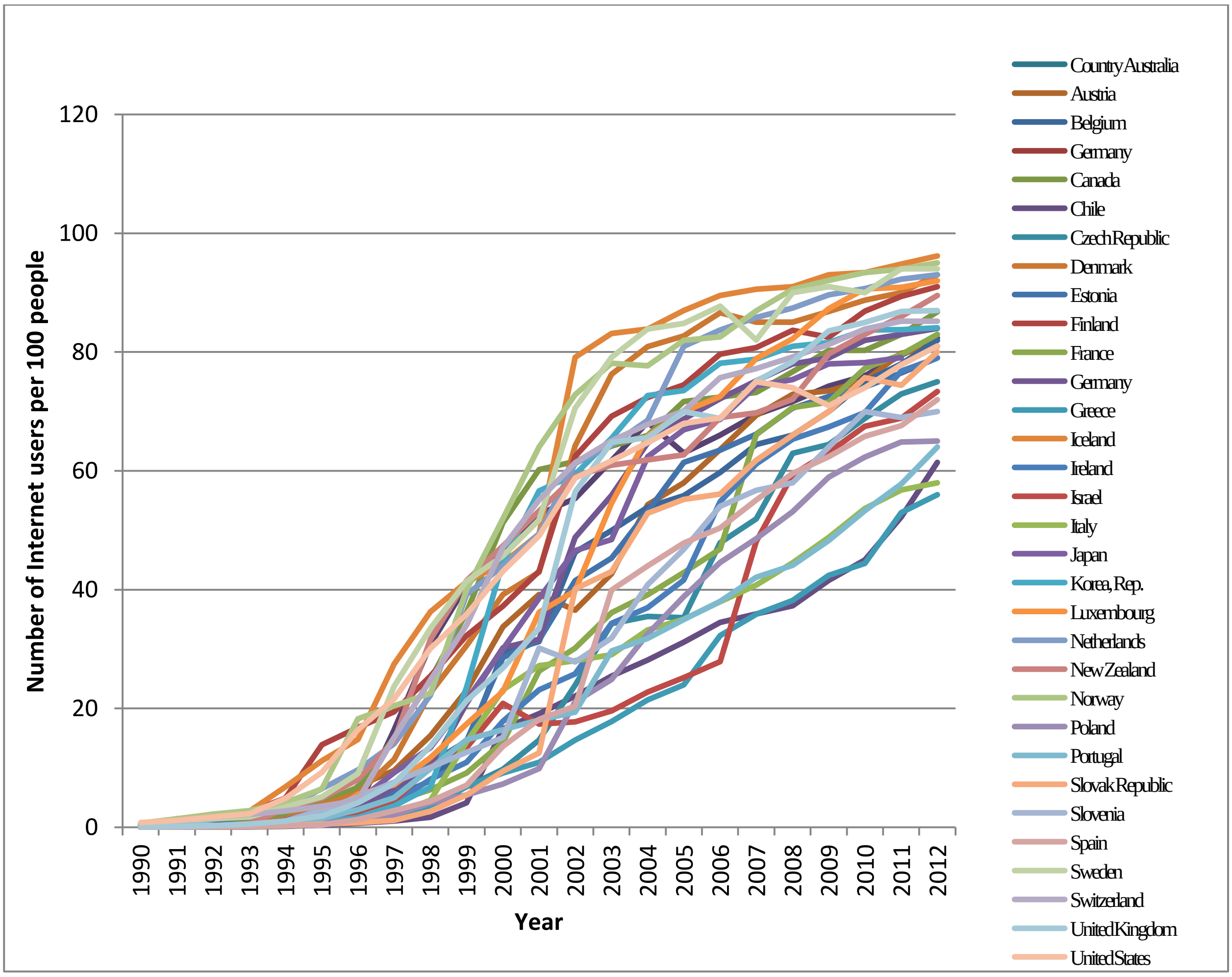
This study used a dynamic panel dataset for 31 out of 34 OECD countries for the period 1991-2012[1]. Three countries, Hungary, Mexico and Turkey were dropped from the study due to non-availability of adequate data. The core variables used in the study were real GDP per capita growth rate measured at a constant US$2000 price and the number of Internet users per 100 people, i.e., individuals who have worldwide access to and used the Internet from any location in the last three months from the time of data collection.

Data on Internet usage revealed that the OECD countries experienced phenomenal growth in Internet usage rates during the sample period of this study (Figure 1). At the start of the sample period in 1991, less than 1% of the population were Internet users in all OECD countries. Iceland, Norway, Sweden, Netherland, Denmark, Luxemburg and Finland were among the OECD countries that have more than 90% of their population using Internet in 2012. Portugal, Poland, Slovenia, Spain, Italy and Czech Republic have relatively low usage rates (between 60% and 72%) while Greece had the lowest Internet usage rate of 56% among

[1] Australia, Austria, Belgium, Canada, Chile, Czech Republic, Denmark, Estonia, Finland, France, Germany, Greece, Iceland, Ireland, Israel, Italy, Japan, South Korea, Luxembourg, Netherland, New Zealand, Norway, Poland, Portugal, Slovac Republic, Slovenia, Spain, Sweden, United Kingdom and United States of America.

OECD countries in 2012 followed by Chile with the second lowest rate of 61%. Although, the growth in Internet usage was phenomenal, it was not uniform across the region. This disparity in the percentage of Internet users between countries is a clear indication that digital divide exists between the OECD countries.

**Figure 1: Trends in the Internet usage in OECD countries during 1990-2012**




Source: The World Development Indicators Database, The World Bank, 2013.

It is also evident from Figure 1 that although the growth in the Internet usage rate was quite slow in the 1990s, it picked up and experienced a spectacular growth during the 2000s.

As bivariate models are likely to suffer from variable omission bias (Lean and Smyth, 2010), this study includes a number of potential growth drivers - financial development (FD) measured by private sector credit as a share of GDP, trade openness (TO) measured by the total exports and imports as a share of GDP and government expenditure (GOV) measured as a share of GDP in order to overcome this limitation. Data for all these variables were obtained from the World Data Bank, 2013 (previously, World Development Indicators (WDI) database).

3.2 Methodology

*3.2.1. The model*

Based on the endogenous growth models (e.g., Lucas 1988; Romer 1986, 1990; Aghion and Howitt 1998; Barro, 1998) and following the growth equation used in Choi and Yi (2009), we construct an econometric model with per capita GDP growth rate as a function of Initial GDP per capita (IGDPPC) Internet users per 100 people, financial development (FD), trade openness (TO) and government expenditure (GOV). All data were obtained from World Development Indicators Database (WDI, 2014). Initial GDP per capita was estimated by taking five year averages of real GDP per capita measured at US$2005. Therefore, the growth equation used in the study was:

$$Growth_{it}=\beta_0+ \beta_1 IGDPPC_{it} +\beta_1 NET_{it} + \beta_2 FD_{it}+\beta_3 TO_{it} + \beta_4 GOV_{it} +\varepsilon_{it} \qquad (1)$$

where $\varepsilon_{it} = \mu_i + \nu_{it}$ while $\mu_i \approx (0, \sigma^2 \mu)$ and $\nu_{it} \approx (0, \sigma^2 \nu)$ are independent of each other and among themselves. $\mu_i$ and $\nu_{it}$ denote country-specific fixed effects and time variant effects respectively. The subscripts *i*, *t* represent country (i= 1....31) and time period (1991-2012) respectively.

*3.2.2 Estimation procedures*

The study performs the following estimations:

i. A CD test is conducted to verify its presence in the data.

ii. As cross sectional dependence (if any) is detected, an appropriate panel unit root test (CIPS) is conducted to examine the stationarity of data.

iii. This follows Pedroni cointegration test to verify the presence of long-run relationship among the variables.

iv. PMG estimation is then performed to estimate the short - and the long-run relationship and the speed of error correction.

v. A panel VECM Granger causality test is applied to assess causality and

vi. Finally, variance decomposition analysis is performed to forecast the relationship for a 22-year time horizon.

*3.2.3. Tests for Unit Roots*

To avoid the risk of non-stationarity in a long dataset like ours, it was necessary to check the presence of unit root in the data. But before an appropriate test is conducted, it was important to verify whether there was any cross-sectional dependence in the panel. Therefore, we apply CD test developed by Pesaran (2004). The CD statistic is defined as:

$$\text{CD} = \left[\frac{TN(N-1)}{2}\right]^{1/2} \bar{\hat{\rho}}, \qquad (2)$$

where

$$\bar{\hat{\rho}} = \left(\frac{2}{N(N-1)}\right)\sum_{i=1}^{N-1}\sum_{j=i+1}^{N}\hat{\rho}_{ij}$$

in which $\hat{\rho}_{ij}$ is the pair-wise cross-sectional correlation coefficients of residuals from the conventional ADF regression, T and N are sample and panel sizes respectively.

As cross-sectional dependence is detected across the panel, next, we consider the following cross-sectionally augmented Dickey-Fuller (CADF) regression:

$$\Delta y_{it} = \alpha_i + \kappa_i t + \beta_i y_{it-1} + \gamma_i \bar{y}_{t-1} + \phi_i \Delta \bar{y}_t + \varepsilon_{it}, \text{ t= 1.............T and i=1................N,} \quad (3)$$

where

$$\bar{y}_t = N^{-1}\sum_{i=1}^{N} y_{it}$$

is the cross-sectional mean of $y_{it}$. It is a modified version of the t-bar test proposed by Im, Pesaran and Shin (IPS) referred to as the cross-sectionally augmented IPS unit root (CIPS) test (Pesaran, 2007). This test was conducted to make sure that the data were stationary after first differencing which would allow the regression technique to be applied to and render the estimation results valid and statistically significant. The null hypothesis of the test can be expressed as $H_0$: $\beta_1$=0 for all i against the alternative hypothesis $H_0$: β <0 for some i. The relevant test statistic is:

$$\text{CIPS}(N,T) = N^{-1}\sum_{i=1}^{N} t_i(N,T) \qquad (4)$$

where $t_i$ (N, T) is the t statistic of $\beta_i$ in equation (2). The critical values of CIPS (N, T) are provided in Table II(c) of Pesaran (2007).

*3.2.4. Panel Cointegration Test*

Since results from the CIPS unit root test confirm that the data are stationary at first difference [I(1)], indicating a long-run cointegrating relationship between the variables, we conducted several panel cointegration tests suggested by Pedroni (1997, 1999 and 2000) to examine whether such a relationship between the variables really exists. Pedroni test is appropriate in the present circumstance as it allows multiple regressors. Pedroni (1997) provides seven panel cointegration statistics for seven tests. Four of those are based on the within-dimension tests while the other three are based on the between-dimension or group statistics approach.

The starting point of the residual-based panel cointegration test statistics of Pedroni (1999) is the computation of the residuals of the hypothesized cointegrating regression as follows:

$$y_{i,t} = \alpha_i + \beta_{1i,}x_{1i,t} + \beta_{2i}x_{2i,t} + \cdots + \beta_{Mi}x_{Mi,t} + \varepsilon_{i,t} \qquad (5)$$

$$t = 1, \dots\dots, T; i = 1, \dots., N; m = 1, \dots\dots, M$$

where *T* is the number of observations over time, *N* denotes the number of individual members

in the panel, and *M* is the number of independent variables. It was assumed here that the slope coefficients $\beta_{1i}, \dots \beta_{Mi}$, and the member-specific intercept $\alpha_i$ can vary across each cross-section. To compute the relevant panel cointegration test statistics, the panel cointegration regression in equation (1) should be estimated first. For the computation of the panel $\rho$ and panel-*t* statistics, we took the first difference of the original series and estimate the residuals of the following regression:

$$y_{i,t} = b_{1i,}\Delta x_{1i,t} + b_{2i}\Delta x_{2i,t} + \cdots + b_{Mi}\Delta x_{Mi,t} + \pi_{i,t} \qquad (6)$$

Using the residuals from the differenced regression, with a Newey-West (1987) estimator, we calculated the long run variance of $\hat{\pi}_{i,t}^2$ which is symbolized as $\hat{L}_{11i}^2$

$$\hat{L}_{11i}^2 = \frac{1}{T}\sum_{t=1}^{T}\hat{\pi}_{i,t}^2 + \frac{2}{T}\sum_{s=1}^{k_i}(1 - \frac{s}{k_i+1})\sum_{t=s+1}^{T}\hat{\pi}_{i,t}\hat{\pi}_{i,t-s} \quad (7)$$

For panel ρ and group ρ statistics, we estimated the regression using the $\hat{e}_{i,t} = \hat{\gamma}_i \hat{e}_{i,t-1} + \hat{u}_{i,t}$ using the residuals $\hat{e}_{i,t}$ from the cointegration regression (2). Then compute the long-run variance ($\hat{\sigma}_i^2$) and the contemporaneous variance ($\hat{s}_i^2$) of $\hat{u}_{it}$ where, $\hat{s}_i^2 = \frac{1}{T}\sum_{t=1}^{T}\hat{u}_{i,t}$

$$\hat{\sigma}_i^2 = \frac{1}{T}\sum_{t=1}^{T}\hat{u}_{it} + \frac{2}{T}\sum_{s=1}^{k_i}(1 - \frac{s}{k_i+1})\sum_{t=s+1}^{T}\hat{u}_{i,t}\hat{u}_{i,t-s} \qquad (8)$$

where $k_i$ is the lag length. In addition to this, we also calculated the term, where, $\lambda_i = \frac{1}{2}(\hat{\sigma}_i^2 - \hat{s}_i^2)$ On the other side for panel-*t* and group-*t* statistics using again the residuals of $\hat{e}_{i,t}$ of cointegration regression (1), we estimate $\hat{e}_{i,t} = \hat{\gamma}_i \hat{e}_{i,t-1} + \sum_{t=1}^{k}\hat{\gamma}_{ik}\Delta\hat{e}_{i,t-1} + \hat{u} *_{i,t}$

In this study to determine the lag truncation order of the ADF *t*-statistics, the step-down procedure and the Schwarz lag order selection criterion were used where

$$\hat{s}_i^{*2} = \frac{1}{T}\sum_{t=1}^{T}\hat{u}_{i,t}^{*2} \qquad , \qquad \tilde{s}_{i,t}^{*2} \equiv \frac{1}{N}\sum_{i=1}^{N}\hat{s}_i^{*2}$$

The next step is the calculation of the relevant panel cointegration statistics using the following expressions.

Panel $-\rho$ statistic

$$T\sqrt{N}Z_{\hat{\rho}N,T-1} \equiv T\sqrt{N}\left(\sum_{i=1}^{N}\sum_{t=1}^{T}\hat{L}_{11i}^{-2}\hat{e}_{i,t-1}^{2}\right)^{-1}\sum_{i}^{N}\sum_{t=1}^{T}\hat{L}_{11i}^{-2}(\hat{e}_{i,t-1}\Delta\hat{e}_{i,t}-\hat{\lambda}_{i} \quad (9)$$

Panel $-t$ statistic

$$Z_{tN,T}^{*} \equiv \left(\tilde{s}_{N,T}^{*2}\sum_{i=1}^{N}\sum_{t=1}^{T}\hat{L}_{11i}^{-2}\hat{e}_{i,t-1}^{2}\right)^{-1/2}\sum_{i}^{N}\sum_{t=1}^{T}\hat{L}_{11i}^{-2}(\hat{e}_{i,t-1}\Delta\hat{e}_{i,t} \quad (10)$$

Group $-\rho$ statistic

$$TN^{-1/2}\tilde{Z}_{\hat{\rho}N,T-1} \equiv TN^{-1/2}\sum_{i=1}^{N}\left(\sum_{t=1}^{T}\hat{e}_{i,t-1}^{2}\right)^{-1}\sum_{t=1}^{T}(\hat{e}_{i,t-1}\Delta\hat{e}_{i,t}-\hat{\lambda}_{i}) \quad (11)$$

Group $-t$ statistic

$$N^{-1/2}\hat{Z}_{tN,T}^{*} \equiv TN^{-1/2}\sum_{i=1}^{N}\left(\sum_{t=1}^{T}\hat{s}_{i}^{*2}\hat{e}_{i,t-1}^{2}\right)^{-1/2}\sum_{t=1}^{T}\hat{e}_{i,t-1}\Delta\hat{e}_{i,t} \quad (12)$$

Lastly, we apply the appropriate mean and variance adjustment terms to each panel cointegration test statistic so that the test statistics were standard normally distributed.

$$\frac{\chi_{N,T}-\mu\sqrt{N}}{\sqrt{v}} => N(0,1)$$

where $\chi_{N,T}$ is the appropriately standardized form of the test statistic, and are the functions of moments of the underlying Brownian motion functionals. Different panel cointegration test statistics are provided in Table 2 in Pedroni (1999).

The null hypothesis of no cointegration for the panel cointegration test was the same for each statistic, $H_0 : \gamma_i = 1$ for all $i$ whereas the alternative hypothesis for the between-dimension-based and within-dimension-based panel cointegration tests differed. The alternative hypothesis for the between-dimension-based statistics was $H_1 : \gamma_i < 1$ for all $i$; where a common value for $\gamma_i = \gamma$ was not required. For within-dimension-based statistics, the alternative hypothesis was $H1 : \gamma = \gamma_i < 1$ for all $i$ and it assumed a common value for $\gamma_i = \gamma$. Under the alternative hypothesis, all the panel cointegration test statistics considered in this paper diverged to negative infinity. Thus, the left tail of the standard normal distribution was used to reject the null hypothesis.

*3.2.5 Pooled Mean Group Regression (PMG)*

One major shortcoming of Pedroni tests is that they do not estimate for the short-run relationship and the adjustment term of the short-run disequilibrium towards the long run equilibrium relationship (Murthy, 2007). Therefore, we applied the PMG technique allows short-term adjustments and convergence speeds to vary across countries, thus allowing cross-country heterogeneity. It imposes cross-country homogeneity restrictions only on the long-run coefficients. The justification for common long-run coefficients across OECD countries was that they have access to common technologies and have intensive intra-trade and foreign direct investment.

As the short-run adjustment depends on country-specific characteristics such as vulnerability to domestic and external shocks (for example, recent debt crisis in Greece and financial mismanagement, different types of adjustment to the recent global financial crisis), monetary and fiscal adjustment mechanisms. financial-market imperfections, lack of sufficient time for implementation of different Internet and digital divide policies and change in political regime etc., allowing the speed of covergence to vary is justified.

Pesaran and Smith (1995), Pesaran (1997) and Pesaran et al. (1999) showed that PMG can render consistent and efficient estimates even in case of mixed order of integration. In order to comply with the requirements for standard estimation and inference, the long-run growth regression equation (equation 1) was embedded into an ARDL (*p, q*) model. In error correction form, this can be written as follows:

$$\Delta(y_i)_t = \sum_{j=1}^{p-1} \gamma^i_j \, \Delta(y_i)_{t-j} + \sum_{j=0}^{q-1} \delta^i_j \, \Delta(x_i)_{t-j} + \varphi^i \, [(y_i)_{t-1} - \beta^i_1 (X_i)_{t-1}\}] + \varepsilon_{it} \qquad (13)$$

where $\gamma^i_j$ and $\delta^i_j$ are short run coefficients, $\varphi^i$ is the error correction adjustment speed, $\beta^i_1$ are the long- run coefficients and $\varepsilon_{it} = \mu_i + \nu_{it}$ where $\mu_i$ and $\nu_{it}$ denote country-specific fixed effects and time variant effects respectively.

*3.2.6 Panel VECM Granger Causality*

If and once the variables are found to be first difference stationary [I(1)], assessing the causal direction of the relationship between them is important (Granger, 1969). Information about the exact direction of the causal link enables a more pragmatic and relevant discussion of the policy implications of the findings (Shahbaz et al., 2012).

*3.2.7 Variance decomposition analysis*

Despite its importance for policy implications, one of the weaknesses of the causality analysis is that it can not predict the strength of the causal relationship beyond the sample period. To overcome this limitation and to forecast the Internet-growth relationship beyond the sample period, this study employs variance decomposition analysis. The variance decomposition (Pesaran and Shin, 1998) measures the percentage contribution of each innovation to h-step ahead of the forecast error variance of the dependent variable and provides a means to determine the relative importance of shocks in independent variables to explain the variation in the dependent variable beyond the selected time period. Engle and Granger (1987) and

Ibrahim (2005) argued that the variance decomposition approach produces more reliable results as compared to those from other traditional approaches.

## 4. Empirical Results

Table 1 presents descriptive statistics of all the variables. It reveals that the data were fairly dispersed around the mean. The maximum number of Internet users per 100 people was above 96 while the minimum is 0.005. The mean of the Internet users per 100 people in the OECD panel was above 36% for the whole sample period. The main reason for this low mean percentage is that throughout the 1990s, growth in the number of Internet users was quite slow. However, although it picked up during the 2000s, the percentage growth in the usage rate was very skewed throughout the region. Some countries experienced very high growth in Internet usage while others lagged behind. The mean GDP growth rate was close to 2% which implies that the OECD countries were somewhat successful in outweighing the negative effect of the global financial crisis that shook the world economy during 2008-2010. The average inflation rate was below 5% indicating overall macroeconomic stability in the region during the period.

**Table 1: Descriptive Statistics**

| Variable | Observation | Mean | Std. Dev. | Min | Max |
|---|---|---|---|---|---|
| GDP per capita Growth | 713 | 1.834 | 3.187 | -14.639 | 13.018 |
| Internet uses | 713 | 36.387 | 32.108 | 0 | 96.21 |
| Financial development | 713 | 100.228 | 50.814 | 13.105 | 319.460 |
| Trade Openness | 713 | 85.308 | 49.171 | 15.923 | 333.532 |
| Government Expense | 713 | 19.584 | 4.109 | 9.951 | 29.995 |

Table 2 presents correlation matrix which rules out the threat of any multicollinearity problem in the data. This is further corroborated by the Variance Inflation Factor (VIF) results reported in Table 3, which clearly demonstrates that all VIF values were less than 5 implying no multicollinearity issue in the study.

**Table 2: Correlation matrix**

| | FD | GDPCG | GOV | NET | TRD |
|---|---|---|---|---|---|
| FD | 1.000000 | -0.283505 | -0.048507 | 0.053486 | -0.056993 |
| GDPCG | -0.283505 | 1.000000 | -0.218563 | 0.161069 | 0.108047 |
| GOV | -0.048507 | -0.218563 | 1.000000 | 0.133690 | 0.050578 |
| NET | 0.053486 | 0.161069 | 0.133690 | 1.000000 | 0.196912 |
| TRD | -0.056993 | 0.108047 | 0.050578 | 0.196912 | 1.000000 |

**Table 3: Variance Inflation Factors (VIF) results**

| | Coefficient | Uncentered |
|---|---|---|
| Variable | Variance | VIF |
| LGOV | 2.197889 | 1.073548 |
| LFD | 0.138802 | 1.704621 |
| LNET | 0.008191 | 2.899833 |
| LTRD | 0.983410 | 2.242251 |

The unit root results are reported in Table 4. The results show that all but the Internet (NET) the series were first-difference stationary in the presence of cross-sectional dependence. The variable NET is stationary at levels [I(0)]. This implies a cointegrating relationship among the variables.

**Table 4: Panel unit root test results**

| Variables | $\hat{\rho}$ | CD | Levels | First differences |
|---|---|---|---|---|
| | | | CIPS | CIPS |
| GDPCG | 0.468 | 47.01 | -1.844 | -2.501*** |
| NET | 0.964 | 99.71 | -2.395*** | -3.121*** |
| FD | 0.702 | 52.23 | -1.894 | -2.238*** |
| TO | 0.627 | 63.09 | -1.847 | -2.893*** |
| GS | 0.421 | 23.90 | -1.477 | -2.928*** |

Table 5 presents results from the Pedroni cointegration test. All Pedroni test statistics except the v statistic have a critical value of -1.64.The v statistic has a critical value of 1.64. It is evident from Table 5 that the statistical values of five out of seven tests were greater than the critical values which indicates the rejection of the null hypothesis of no cointegration. Nevertheless, among the seven test statistics, the group rho statistic has the best power (Gutierrez, 2003) which was also greater than the critical value. Thus, it can be concluded that there is a long run cointegrating relationship among the variables.

**Table 5: Pedroni Residual Cointegration Test**

| | | | | |
|---|---|---|---|---|
| Newey-West bandwidth selection with Bartlett kernel | | | | |
| Alternative hypothesis: common AR coefs. (within-dimension) | | | | |
| | Statistic | Prob. | Weighted Statistic | Prob. |
| Panel v-Statistic | -2.836950 | 0.9977 | -5.525383 | 1.0000 |
| Panel rho-Statistic | 2.716936 | 0.9967 | 3.406301 | 0.9997 |
| Panel PP-Statistic | -4.968551 | 0.8723 | -7.803080 | 0.0000 |
| Panel ADF-Statistic | -4.010019 | 0.0000 | -7.249487 | 0.0000 |
| Alternative hypothesis: individual AR coefs. (between-dimension) | | | | |
| | Statistic | Prob. | | |
| Group rho-Statistic | 5.005760 | 1.0000 | | |
| Group PP-Statistic | -9.379687 | 0.6745 | | |
| Group ADF-Statistic | -5.569025 | 0.0000 | | |

Table 6 presents results from the PMG estimations. The findings indicate that there is a positive significant relationship between Internet usage and economic growth in OECD countries both in the short- and long-run. A negative significant relationship was observed between economic growth and government expenditure in both the short-run and long-run.

The long-run relationship between economic growth and financial development and trade openness was found negative at 1% and 5% levels of significance respectively. However, the short-run relationship between trade openness and economic growth was positive and highly significant at the 1% level of significance. Financial development has positive but insignificant association with economic growth in the short-run.

The error correction coefficient of $ECT_{t-1}$ was −0.750 which was statistically significant at the 1% level of significance. From these results, it can be concluded that changes in economic growth are corrected by 75% in each year in the long-run. It further suggests that a full convergence process will take only 1.25 years to reach the stable path of equilibrium.

**Table 6 : Results from PMG estimation**

| Dependent variable: GDP per capita growth rate | Pooled Mean Group | |
|---|---|---|
| Variable | Coefficient | Standard. Error |
| *Long-run coefficients* | | |
| IGDPPC | *.0000431* | *.0000196* |
| NET | .0067855** | .002819 |
| FD | -.011771*** | .0022987 |
| TO | - .0080459** | .0067794 |
| GOV | -.2625549* | .0597684 |
| *Error correction Coefficient* | -.755571** | .048604 |
| *Short-run coefficients* | | |
| ΔIGDPPC | 6.38007 | .0000529 |
| Δ NET | .0278098* | .0173965 |
| Δ FD | .0170441 | .0168957 |
| Δ TO | .1084861*** | .0267527 |
| Δ GOV | -1.949751* | .254179 |
| Intercept | 5.743522* | .4018659 |

Notes. ***, ** and * indicate 1%, 5% and 10% levels of significance, respectively.

Table 7 reports Granger causality results. It shows that the Internet usage Granger causes economic growth in the OECD countries. Economic growth has no causal link with financial development, government expenditure and trade openness. A unidirectional causal link running from Internet usage to financial development and government expenditure was also observed.

**Table 7: Pairwise Granger Causality Test**

| Null Hypothesis: | Obs | F-Statistic | Prob. |
|---|---|---|---|
| FD does not Granger Cause GDPCG | 651 | 48.0181 | 1.E-11 |
| GDPCG does not Granger Cause FD | | 13.7464 | 0.0002 |
| GOV does not Granger Cause GDPCG | 651 | 0.00878 | 0.9254 |
| GDPCG does not Granger Cause GOV | | 6.43241 | 0.0114 |
| INITIAL_GDP_PER_CAPITA does not Granger Cause GDPCG | 651 | 19.2058 | 1.E-05 |
| GDPCG does not Granger Cause INITIAL_GDP_PER_CAPITA | | 3.19428 | 0.0744 |
| NET does not Granger Cause GDPCG | 651 | 28.6674 | 0.0439 |
| GDPCG does not Granger Cause NET | | 6.91762 | 0.0087 |
| TRD does not Granger Cause GDPCG | 651 | 0.00147 | 0.9695 |
| GDPCG does not Granger Cause TRD | | 5.64753 | 0.0178 |
| GOV does not Granger Cause FD | 651 | 1.76984 | 0.1839 |
| FD does not Granger Cause GOV | | 7.53485 | 0.0062 |
| INITIAL_GDP_PER_CAPITA does not Granger Cause FD | 651 | 6.10059 | 0.0138 |
| FD does not Granger Cause INITIAL_GDP_PER_CAPITA | | 0.00064 | 0.9799 |
| NET does not Granger Cause FD | 651 | 3.66909 | 0.0559 |
| FD does not Granger Cause NET | | 0.00784 | 0.9295 |
| TRD does not Granger Cause FD | 651 | 0.16033 | 0.6890 |
| FD does not Granger Cause TRD | | 0.24085 | 0.6238 |
| INITIAL_GDP_PER_CAPITA does not Granger Cause GOV | 651 | 4.12899 | 0.0426 |
| GOV does not Granger Cause INITIAL_GDP_PER_CAPITA | | 0.17516 | 0.6757 |
| NET does not Granger Cause GOV | 651 | 11.6507 | 0.0007 |
| GOV does not Granger Cause NET | | 0.33811 | 0.5611 |
| TRD does not Granger Cause GOV | 651 | 0.79016 | 0.3744 |
| GOV does not Granger Cause TRD | | 1.08427 | 0.2981 |
| NET does not Granger Cause INITIAL_GDP_PER_CAPITA | 651 | 0.10123 | 0.7505 |
| INITIAL_GDP_PER_CAPITA does not Granger Cause NET | | 4.07829 | 0.0438 |
| TRD does not Granger Cause INITIAL_GDP_PER_CAPITA | 651 | 0.03121 | 0.8598 |
| INITIAL_GDP_PER_CAPITA does not Granger Cause TRD | | 0.23330 | 0.6292 |
| TRD does not Granger Cause NET | 651 | 2.49767 | 0.1145 |
| NET does not Granger Cause TRD | | 0.00955 | 0.9222 |

Variance decomposition analysis results are presented in Table 8. The results forecast that the Internet usage will have an increasing effect on economic growth in the region in future also during the period 2013-2034. In the first 5-year time horizon (up to 2017), 0.21% of the variation in the growth rate is expected to be explained by Internet usage followed by 1.32% in the 10th year (2022). In the third 5-year time horizon (up to 2027), Internet usage is forecasted to explain 2.23% of the variation in per capita GDP growth rate. In the fourth time horizon (up to 2032), the forecasted variance in the growth rate to be explained by Internet usage stands at 2.74% which is expected to rise further to 2.92% in the 22nd year (2034). Other variables are also forecasted to continue to affect growth rate during the period. In the 22nd year, 3.18%, 6.74%, 2.40% and 0.22% of the variations in growth rate are explained by initial GDP per capita, financial development, trade openness and government expenditure, respectively.

**Table 8: Variance Decomposition test**

| Period | S.E. | GDPCG | FD | GOV | INITIAL_GDP_ PER_CAPITA | NET | TRD |
|---|---|---|---|---|---|---|---|
| 1 | 2.415070 | 100.0000 | 0.000000 | 0.000000 | 0.000000 | 0.000000 | 0.000000 |
| 2 | 2.644182 | 97.31041 | 0.440258 | 0.020080 | 0.059048 | 0.037861 | 2.132342 |
| 3 | 2.648575 | 97.13448 | 0.439998 | 0.041090 | 0.066284 | 0.041575 | 2.276576 |
| 4 | 2.656878 | 96.52833 | 0.962597 | 0.042193 | 0.117872 | 0.081336 | 2.267676 |
| 5 | 2.671734 | 95.46028 | 1.809895 | 0.054597 | 0.209281 | 0.215624 | 2.250327 |
| 6 | 2.687805 | 94.32530 | 2.632008 | 0.068534 | 0.332789 | 0.411529 | 2.229835 |
| 7 | 2.704068 | 93.21900 | 3.368098 | 0.081731 | 0.481098 | 0.635930 | 2.214139 |
| 8 | 2.719932 | 92.17273 | 4.010957 | 0.094602 | 0.647167 | 0.869724 | 2.204819 |
| 9 | 2.734861 | 91.20925 | 4.555958 | 0.106973 | 0.825842 | 1.101351 | 2.200624 |
| 10 | 2.748658 | 90.33468 | 5.008201 | 0.118633 | 1.013662 | 1.324111 | 2.200718 |
| 11 | 2.761335 | 89.54341 | 5.379452 | 0.129616 | 1.208092 | 1.534678 | 2.204750 |
| 12 | 2.772973 | 88.82634 | 5.682437 | 0.140061 | 1.407102 | 1.731681 | 2.212380 |
| 13 | 2.783669 | 88.17433 | 5.928573 | 0.150110 | 1.608996 | 1.914737 | 2.223254 |
| 14 | 2.793522 | 87.57909 | 6.127650 | 0.159891 | 1.812324 | 2.083970 | 2.237076 |
| 15 | 2.802627 | 87.03335 | 6.287927 | 0.169517 | 2.015820 | 2.239781 | 2.253608 |
| 16 | 2.811065 | 86.53087 | 6.416290 | 0.179088 | 2.218371 | 2.382720 | 2.272661 |
| 17 | 2.818909 | 86.06638 | 6.518431 | 0.188693 | 2.418999 | 2.513420 | 2.294080 |
| 18 | 2.826223 | 85.63541 | 6.599046 | 0.198407 | 2.616846 | 2.632555 | 2.317738 |
| 19 | 2.833061 | 85.23419 | 6.662002 | 0.208297 | 2.811164 | 2.740815 | 2.343533 |
| 20 | 2.839470 | 84.85951 | 6.710483 | 0.218420 | 3.001310 | 2.838895 | 2.371386 |
| 21 | 2.845493 | 84.50862 | 6.747112 | 0.228828 | 3.186734 | 2.927480 | 2.401230 |

## 5. Conclusions and Policy Implications

This study revisits the relationship between Internet usage and economic growth for OECD countries with a longer sample period (1991-2012) and new methodology namely, the PMG technique that accounts for endogeneity and heterogeneity issues. Application of such a technique is relatively new in the area of the Internet-growth relationship which potentially removes the threat of producing biased and misleading results.

Also, a forecasting analysis of this relationship was performed with the application of variance decomposition method to assess how the Internet is going to impact economic growth in the region in the future. The study also addressed the issue of cross-sectional dependence while testing for the stationarity of data. This study also utilizes one of the longest panel datasets. An appropriate unit root test namely, the CIPS test was conducted which reported that all the series were stationary at first difference [I(1)]. This was followed by the Pedroni (1999) cointegration test which confirmed a cointegrating relationship among the variables. The PMG technique was applied to estimate the short- and the long-run relationship among the variables. To assess the causal link between the variables, the Granger causality test was conducted. Finally, variance decomposition analysis was performed to forecast the future potential impact of the Internet on economic growth.

Findings from PMG estimates indicated that there is a positive significant relationship between Internet usage and economic growth in OECD countries both in the short- and long-run. There is a negative significant relationship between economic growth and government expenditure in both the short - and long-run. The long-run relationship of economic growth with financial development and trade openness is negative and significant. However, the short-run relationship between trade openness and economic growth is significant and positive. There is no significant relationship between financial development and economic growth in the short-run.

Also Internet usage was found to Granger cause economic growth. Economic growth has no causal link with financial development, government expenditure and trade openness. A unidirectional causal link running from Internet usage to financial development and government expenditure was also observed. Results from the variance decomposition analysis forecast that  Internet usage will have an increasing effect on economic growth in the region in the future also during the period 2013-2034. Other variables, financial development, trade openness and government expenditure will also continue to affect economic growth in the region.

The findings of this study have very important policy implications. First, they imply that Internet usage not only affects economic growth during the sample period of the study (1990-2012) but would also continue to stimulate it in the future. Therefore, the ongoing efforts of OECD countries to pursue and implement various ICT policies (such as, National Broadband Plan in the USA and National Broadband Network in Australia) with emphasis on developing wireless infrastructure for greater network coverage seem to be worthy. But this is not enough. Although, the findings of this empirical exercise may be encouraging for the policymakers of these countries, policymakers can not afford to be complacent for some valid reasons. First, Internet technology is a General Purpose Technology (GPT) (Ceccobelli et al., 2012), so expanding network coverage may be enough in the short-run but not in the long-run. It is argued that without substantial investment in complementary assets, the expected positive effects of the Internet on economic growth may not be accomplished in the long-run (Shahiduzzaman and Alam, 2014; Ceccobelli et al., 2012). Second, with the rapid growth in Internet usage, digital divide in different forms- such as equity divide (inequity in the use), skill divide (some people may not have enough skills to use the Internet effectively while others have), group divide (so called "cyber balkanization" which refers to the creation of new groups or cohorts through Internet contacts who segregate themselves from other groups), speed divide (disparity in speed of Internet connection) and rural-urban divide may potentially hamper its growth effects. Finally, digital divide policies in OECD countries have so far been singularly focused on supply-side issues (Notley and Foth, 2008; Belloc et al., 2012). An effective policy goal should combine both the elements of demand and supply-side stimulus. Also it should not be forgotten that different policies will have different levels of effectiveness in different countries with diverse initial conditions.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# PAPER 2: THE EFFECTS OF THE INTERNET, FINANCIAL DEVELOPMENT AND TRADE OPENNESS ON ECONOMIC GROWTH: FRESH EVIDENCE FROM AUSTRALIA

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## Statement of Contributions of Authorship

To whom it may concern

I, Mohammad Salahuddin contributed 75% to the paper entitled above.

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**This paper is one of two papers included in Chapter two of the candidate's PhD thesis**

# The effects of the Internet, financial development and trade openness on economic growth: Fresh evidence from Australia


## Abstract

This study explores the short- and long-term effects of Internet usage, financial development and trade openness on economic growth in Australia using annual data for the period 1985–2012. The ARDL bounds test for cointegration and Granger causality test for causal links are applied. The results indicate that Internet usage and financial development spur economic growth in the long run. Trade openness has a positive but insignificant long-run effect on growth; however, the short-term effects of all of the variables on growth are insignificant. Dynamic OLS estimation confirms the robustness of findings involving long-term effects on growth. The Granger causality test reveals that both Internet usage and financial development Granger-cause economic growth in Australia; Internet usage also Granger-causes financial development. The robustness of the causality link is checked by the Innovation Accounting Approach. Findings are supportive of the claim that the Internet is transforming the Australian economy at a rapid pace. However, in order to ensure the continuous stream of economic benefits from the Internet, this study recommends that Australia follows South Korea's example of boosting its investment to promote ICT education among its relatively disadvantaged and underprivileged people to enhance their ability to use the Internet more effectively. Also, there should be emphasis on transliteracy to make ICT education more productive. The ongoing National Broadband Network (NBN) roll out should target these goals on priority basis.



**Keywords:** Australia, Economic growth, Financial development, Granger causality, Internet usage, Trade openness.

JEL Classifications: C23, L86, O40

## 1. Introduction

The enormous expansion in Internet usage over the past 20 years has drawn keen interest from researchers due to its numerous economic consequences. The Internet has a wide range of effects on the economy, including on technological productivity; foreign direct investment; inflation; political economy issues; corruption; democratic freedom issues; and the shadow economy (Elgin, 2013; Sassi and Goaied, 2013).

Australia is one of the very few countries that survived the two global financial crises – one in the 1990s and the other in the late 2000s. Rapid expansion of ICT usage was identified as a major contributor towards robust growth performance during this period (Parham, 2005; Parham et al., 2001). Australian economic growth performance, however, fell short of expectations during the 2000s, and the role of IT capital in spurring growth and productivity remains questionable. Growth rates in multifactor productivity plummeted on average from 1.7% during the 1990s to 0.4% in the 2000s and 1.3% in 2012 (ABS, 2013). This slowdown in growth rates and productivity performance of the Australian economy during the 2000s may be because growth and productivity achievements have not been without opportunity costs. The rapid expansion of Internet usage has resulted in the creation of a type of social inequality popularly known as digital divide, a phenomenon that is believed to have the potential to undermine both growth and productivity achievements (Lee, 2011).

Despite the recent ICT productivity decline, the Internet as part of the ICT revolution continues to transform the Australian economy, not only by impacting its GDP growth rate but also through other channels such as investment, e-commerce and SMEs (Bowles, 2012; Deloitte Access Economics, 2011; Lee and Valadkhani, 2014). Since the mid-1990s, Internet usage in Australia has been increasing rapidly (Figure 1), and an overwhelming majority of Australians are using the Internet. In 2011, 87% of Australians had used the Internet, up from

81% in 2009 and 73% in 2007. The vast majority of household connections are now through broadband (96%), while the proportion of Australians accessing the Internet through a mobile device more than doubled between 2009 and 2011 from 15% to 37% (Ewing and Julian, 2012). It is claimed that the Internet has been transforming the Australian economy for the last 10 years (Bowles, 2012; Deloitte Access Economics, 2011), and it is anticipated to play an even more significant role in the future as the nation prepares to become a leading digital economy. In 2010, the direct contribution of the Internet to the Australian economy was AU$50 billion, or 3.6% of its Gross Domestic Product (GDP). The contribution of the Internet to the economy will further increase and is thus projected to be around AU$70 billion by 2015 (Deloitte Access Economics, 2011). The widespread adoption of broadband (i.e. a form of high speed Internet) has been linked to economic growth and social wellbeing (Dwivedi et al., 2009; Reede, 2011). The availability of high speed broadband for businesses and households is a well-understood factor in many modern nations' efforts to stimulate growth (Bowles and Wilson, 2010).

Nevertheless, in its bid to become a leading digital economy, Australia has invested significantly in IT and has emerged as a leading user of the Internet (Karunaratne, 2002). It is argued that the benefits of new technology – including IT – have been concentrated in major urban areas (Giesecke, 2006). Since 2009, the Australian Government has been overseeing the construction of the largest ever broadband rollout project, the National Broadband Network (NBN), with a view to expanding high speed internet (broadband) to regional and remote areas of the country. The rapid expansion of Internet usage has resulted in a type of social inequality popularly known as digital divide – a phenomenon that is believed to have the potential to undermine growth and productivity achievements (Lee, 2011). One of the key objectives of the NBN is to narrow the digital divide in regional areas (Lee, 2011), which are believed to be in danger of widening (Bowles, 2012), particularly in rural and regional

Australia (Alam and Salahuddin, 2015) and among disadvantaged communities (Alam and Imran, 2015).

Despite the increasingly important role of the Internet, no study has thus far empirically investigated its direct effect on the Australian economy. Two recent studies (Shahiduzzaman and Alam, 2014a; 2014b) examined the role of ICT investment in the growth and productivity of Australia. One of the studies (Shahiduzzaman and Alam, 2014a) showed that the contribution of IT capital to output and labour productivity in Australia has decreased since the 1990s; the second study (Shahiduzzaman and Alam, 2014b) confirmed the long-term relationship between IT capital, output and multifactor productivity. In both of these studies, the effects of investment in IT on output and productivity of Australia were examined which was a monetary approach (Ishida, 2015). Since the Internet is a leading and very important indicator of a nation's ICT demand and capacity (Jin and Hyum, 2010; Jin and Cho, 2015), this study adopts a non-monetary approach by examining the specific role of the Internet in the Australian economy which, to the best of the authors' knowledge, was not considered in any previous study for Australia.

Therefore, it is believed that this current study – which aims to assess the direct effect of the Internet on economic growth in the Australian context – is a modest contribution to filling this void. In order to offset omission bias potentially arising from a bivariate approach, this study further includes two key growth variables in the model: financial development and trade openness. The empirical exercise is expected to make a number of other contributions as well. It uses recent data (1985–2012) to analyse a multivariate model and, based on the results of this analysis, initiates a discussion of policy implications more suited to current Australian policy perspectives, especially in the light of the ongoing National Broadband Network (NBN) rollout. It employs an econometric technique that offsets the shortcomings of small sample biases arising from data limitations. The econometric technique applied in this study also resolves an endogeneity problem, as well as issues resulting from the spillover and externality effects of Internet usage (Lin, 2013; Zhao and Lu, 2012; Levendis and Lee, 2013).

This paper is structured as follows: Section 2 presents a theoretical and empirical review of the economic impacts of Internet usage. Section 3 is devoted to data and methodology, while Section 4 presents empirical results. The study concludes in Section 5 with conclusions, policy implications and limitations.

## 2. Literature review

### *2.1 The Internet and the economy: a theoretical perspective*

Internet usage allows the generation and distribution of decentralised information and ideas in markets increasingly relying on information as an input. In light of modern theories of endogenous growth (e.g. Lucas 1988; Romer 1986, 1990; Aghion and Howitt 1998; Barro, 1998), the Internet should accelerate economic growth by facilitating the development and adoption of innovation processes. New growth theories suggest that the growth effects of modern communication networks that have emerged since the arrival of Internet technology may have a different quality. Internet usage may accelerate the distribution of ideas and information, fostering competition for and development of new products, processes and business models, thereby further facilitating macroeconomic growth.

Romer's (1986, 1990) endogenous growth model explained that endogenous growth theories model the generation and distribution of ideas and information as key drivers of economic growth (Lucas, 1988; Romer 1990; Aghion and Howitt 1998). As such, massive growth in Internet usage may affect the innovative capacities of the economy through the creation of knowledge spillover and the development of new products, processes and business models to promote growth. Moreover, information dissemination at an affordable cost can facilitate the adoption of new technologies devised by others – a process which again promotes economic growth (Benhabib and Spiegel, 2005). This phenomenon also suggests that spillover of codified knowledge across firms and regions may constitute another channel by which information technology in general, and Internet usage in particular, affects economic growth.

The Internet enables the exchange of data across multiple locations and aids decentralised information processing. It also potentially contributes to the emergence of new business and firm cooperation models that rely on the spatial exchange of large batches of information, thereby boosting competition and innovation processes. The Internet may increase market transparency and thus additionally intensify competition. Extensive use of the Internet has fundamentally changed and improved the processing of information, resulting in significant productivity growth among IT-using firms (Stiroh 2002; Jorgensen et al., 2008).

*2.2 The effects of ICT and the Internet on the economy: empirical evidence*

Literature on the ICT–growth nexus began to emerge in the 1960s. Until the middle of the 1980s, most of the studies used static data (Jipp, 1963; Gilling, 1975; Hardy, 1980; Saunders et al., 1983), and the findings of these studies supported the positive role of ICT in stimulating economic growth. However, these studies have little policy relevance, as their findings do not provide any information about the long-run equilibrium relationship among the variables included. Thus, it was difficult to draw a conclusion on the actual contribution of ICT to economic growth.

Since the arrival of several advanced time series and panel econometric techniques, especially following the seminal work of Engle and Granger (1987) on cointegration analysis, the use of time series data and the application of cointegration analysis for examining the long-run association between variables have become widely popular. The 1990s marked the beginning of the application of such techniques to time series studies investigating the ICT–growth nexus. Scholars also started to use panel data in ICT–growth studies from the beginning of the 2000s. Overall, panel data dominates recent ICT–growth nexus literature.

Despite the economic potentials of ICT, empirical studies on the effects of ICT on growth have produced mixed results. Kraemer (2000) used a sample of 36 countries over the period 1985–1993 and found evidence of a positive relationship between ICT and economic growth, but only for developed countries. Nour (2002) investigated the impact of ICT investment on growth in seven MENA countries and found evidence of the expected positive effect of ICT investment on economic growth. Hassan (2005) examined the positive effect of ICT infrastructure on growth for 95 countries but failed to do so for MENA countries. Seu et al. (2009) used data for 29 countries and also found that ICT has a positive effect on economic growth.

Koutrompis (2009) revealed a significant causal link between broadband penetration and economic growth for 22 OECD countries over the period 2002–2007. Jorgenson and Vu (2009) applied a methodological framework for the projection of growth rates of productivity, GDP and GDP per capita for the period 2006–2016 for a large sample of 122 countries; they divided the economy into IT and non-IT sectors. The results indicated that too much importance placed on investments in IT and non-IT assets as sources of global economic growth is the key reason for the underperformance of various economies. Gruber and Koutrompis (2010) found a positive association between mobile telecommunications diffusion, and growth and productivity for 192 countries for the period 1990–2007. Kumar (2011) analysed time series data for Nepal for the period 1975–2010, investigating the empirical association among ICT, remittances inflow and export liberalisation. The study found that ICT contributes towards the level of income both in the short and the long run. Vu (2011) tested the hypothesis that Internet penetration spurs economic growth, using a panel data set covering 102 countries. The study identified three potential channels – (i) fostering technology diffusion, so enhancing the quality of decision making at firm and household level, (ii) increasing demand, and (iii) reducing production costs – and found a strong association between ICT penetration and growth for the period 1996–2005, controlling for other potential growth drivers and country fixed effects.

Ceccobelli et al. (2012) used data for 14 OECD countries, and results confirmed the role of ICT as a general purpose technology (GPT). By applying a non-parametric test, the study showed that ICTs positively contribute to labour productivity. Kumar (2012) empirically estimated a growth equation for Fiji using time series data for the period 1980–2008. He found the long-run and short-run contributions of ICT to be 1.07% and 0.89%, respectively. Vu (2013) conducted a comprehensive investigation of the contribution of ICT towards Singapore's economic growth. The study found that the intensity of ICT use and the ICT manufacturing sector contribute positively to Singapore's economic growth; also, ICT investment led to around a 1 percentage point rise in Singapore's GDP during the sample period. Jorgenson and Vu (2013) suggested that the dynamics of the world economy will change by the year 2020, which they termed as 'new economic order'. They attributed the slowdown of the world economies to the over-emphasis on innovation, the role of which has been observed to be only modest in world economic growth. The authors further argued that the importance of the role of investment in human and non-human capital –which is more important for the growth of both advanced and emerging economies – is undermined. Sassi and Goaied (2013) found that ICT has a positive and significant direct effect on economic growth using panel data of Middle Eastern and North African (MENA) countries. They also revealed a positive interaction between ICT penetration and financial development. Maria (2013) showed that Internet usage enhances technical efficiency at a higher rate in high-income countries than in low-income countries due to higher Internet diffusion in high-income countries. Mack and Rey (2013) revealed that in 49 out of 54 metropolitan areas in the USA, the Internet enhances productivity in knowledge-intensive firms, emphasising its expansion in knowledge-based industries. Kumar (2013) found that remittances and remittances' interaction with ICT have positive effects on income. The findings were obtained from the analysis of time series data for the period 1976–2010 for the Philippines.

Kumar and Singh (2014) analysed the effects of ICT and health expenditure on the economic growth of Fiji. The findings of the study indicated that both ICT development and health expenditure contribute towards Fiji's economic growth. However, a weak causality was observed between ICT development and economic growth. Kumar and Vu (2014) explored the nexus between ICT remittances and economic growth using time series data for Vietnam for the period 1980–2012. The results demonstrated a positive and significant association between ICT and output per worker; however, the coefficient of association between ICT and remittances was insignificant – a unidirectional causality running from ICT to remittances was observed. Pradhan et al., (2014) examined the association between the development of ICT and economic growth for a panel of G20 countries for the period 1991-2012. The study also included four other explanatory variables: gross fixed capital formation, foreign direct investment inflows, urbanization and trade openness. The study finds long-run bidirectional causal link between the development of ICT and economic growth.

Kumar et al. (2015), in a study of Small Pacific Island States, investigated the effects of telecommunications on output per worker. They employed ARDL bounds testing procedures in an augmented Solow growth framework. The study found that the telecommunications sector produces a positive contribution to output per worker, both in the short run and the long run. In another study, Kumar et al. (2015) examined short- and long-run effects of ICT on the economic growth of China for the period 1980–2013. They used five indicators of ICT to assess its contribution towards economic growth, and the findings indicated a positive and significant association between all the indicators of ICT and economic growth. The study further claimed that apart from capital per worker, the dominant technology drivers are mobile cellular and telecommunications technology. Jin and Cho

(2015) conducted an empirical exercise to estimate the effects of ICT on economic development. The study considered a number of ICT factors such as IT infrastructure, IT competence, IT investment and IT trade, and investigated whether these factors contribute towards economic development for a panel of 128 countries. The study further used a number of intervening variables such as corruption, education and inflation. Results indicated that these intervening variables mediated ICT indicators' influences on economic growth in the selected countries .

Lechman and Marszk (2015) examined the relationship between ICT penetration and exchange-traded funds (ETF) for Japan, Mexico, South Korea and the United States over the period 2002–2012 using two core indicators of ICT – ‘number of Internet users per 100 people’ and ‘Fixed Broadband Internet subscriptions per 100 people’. Using logistic growth models to analyse the data, the study found a positive, strong and significant relationship between ICT penetration and ETF. Ishida (2015) analysed the effects of ICT development on economic growth and energy consumption using time series data for Japan for the period 1980–2010. The results revealed that ICT investment does not contribute towards an increase in the GDP of Japan. Pradhan et al. (2015) investigated the causal association between ICT infrastructure, economic growth and financial development for a panel of Asian countries for the period 2001–2012. All the variables were found to be cointegrated. Also, bidirectional causality was noted between ICT infrastructure and economic growth and between ICT infrastructure and financial development.

It is evident from the above discussion that although most of the ICT studies focused on various indicators of ICT, very few of them included Internet in their studies. As such, literature investigating the direct effects of the Internet on the economy is relatively scarce, despite the growing role of the Internet in every aspect of the economy. In one of the earliest studies of the economic effects of the Internet, Frehund and Weinhold (2002) investigated the effect of the Internet on service trade and found a positive significant relationship. Choi (2003) studied the effect of the Internet on inward foreign direct investment (FDI), using data for a panel of 14 source countries and 53 host countries. The study applied cross-country regression on a gravity FDI equation. The findings of the study indicated that a 10% increase in the number of Internet users in a host country raises FDI inflows by 2%. In another study, Frehund and Weinhold (2004) argued that the Internet has a positive effect on bilateral trade. Running both time series and cross-section regressions on a sample of 53 countries, they found that the Internet stimulates trade. The study further claimed that the Internet reduces those market-specific fixed costs which contribute to export growth.

Yi and Choi (2005) investigated the effects of the Internet on inflation. They employed pooled OLS and random effects models using data for the period 1991-2000 for a panel of 207 countries. Their results showed that a 1% increase in the number of Internet users leads to a 0.42% drop in inflation. Noh and Yoo (2008) tested the empirical relationship among Internet adoption, income inequality and economic growth. They used a panel of 60 countries for the period 1995–2002, finding that the Internet has a negative effect on economic growth for countries with high income inequality. These findings were attributed to the presence of the digital divide in these countries, as a digital divide hampers the economic growth effects of the Internet.

Choi and Yee (2009) used data for a panel of 207 countries for the period 1991–2000 to examine the impact of the Internet on economic growth while controlling for some macro variables – namely, investment ratio, government consumption ratio and inflation. They used a number of panel econometric techniques such as pooled OLS, individual random effects, individual fixed effects, time-fixed effects, individual random and time-fixed models and, finally, panel GMM, to control for endogeneity among the explanatory variables. Their findings supported the significant positive role of the Internet in spurring economic growth.

Choi (2010) estimated the effect of the Internet on service trade using panel data for 151 countries for the period 1990–2006. Pooled OLS, a fixed effects model and panel GMM were employed for data estimation. The study found a significant positive relationship between the number of Internet users and total service trade. It was concluded that a 10% increase in the number of Internet users prompts an increase in service trade from 0.23% to 0.42%.

Lio et al. (2011) estimated the effects of Internet adoption on corruption reduction using a panel of 70 countries for the period 1998–2005. They first conducted a Granger causality test to assess the causal direction of the relationship. Having found a causal link, they then applied dynamic panel data models (DPD) to estimate the relationship between variables while addressing the endogeneity problem. Empirical results indicated that the Internet plays a significant role in the reduction of corruption. Goel et al. (2012) used the Internet as an indicator of corruption awareness. They demonstrated that there is a negative relationship between Internet hits related to corruption awareness, and corruption perceptions and incidence. Elgin (2013) used the panel data of 152 countries for the period 1999–2007 to investigate the effects of the Internet on the size of the shadow economy. The study used cross-country regressions and found that the association between Internet usage and the shadow economy strongly interacts with GDP per capita. The study further highlighted two opposing effects of Internet usage: an increase in productivity corresponds to a reduction in the size of the shadow economy, while an increase in tax evasion corresponds to an increase in the size of the shadow economy. The results were robust across different econometric specifications.

Mack and Rey (2013) showed that in 49 out of 54 metropolitan areas in the USA, the Internet enhances productivity in knowledge-intensive firms. Maria et al. (2013) demonstrated that deployment of mobile communication and greater use of Internet technologies are associated with a higher level of technical efficiency in both high- and low-income countries.

Choi et al. (2014) investigated the determinants of international financial transactions using cross-country panel data on bilateral portfolio flows between the USA and 38 other countries for the period 1990–2008. The study estimated the effect of the Internet on cross-border portfolio flows into the USA from other countries in the panel. It employed a gravity model to demonstrate that the Internet reduces information asymmetry and thus increases cross-border portfolio flows. The results were robust across different empirical models.

Najarzadeh et al. (2014) investigated the effect of the Internet on labour productivity using data for a panel of 108 countries for the period 1995–2010. The study employed pooled OLS, fixed effect, and one- and two-step GMM methods to estimate the relationship. This empirical exercise suggested a strong, significant positive relationship between Internet use and labour productivity. Gruber et al. (2014) estimated returns from broadband infrastructure for the period 2005–2011 and also assessed the cost of a broadband rollout under different assumptions of technical performance. Their findings contrasted with forecasted benefits from the expansion of broadband coverage. However, the study also found that future benefits to be reaped from a broadband rollout project may outweigh the investment involved therein for the highest performance technologies. The study recommended public subsidies to promote building high speed broadband infrastructure.

Czernich (2014) examined the relationship between broadband Internet and unemployment rates using data from various municipalities in Germany. A simple OLS regression indicated a negative relationship between broadband Internet and unemployment, while such an association between these variables could not be confirmed with the introduction of an instrument variable in the same study. Lechman and Marszk (2015) examined the relationship between ICT penetration and exchange-traded funds (ETF) for

Japan, Mexico, South Korea and the United States over the period 2002–2012 using two core indicators of ICT: ‘number of Internet users per 100 people’ and ‘Fixed Broadband Internet subscriptions per 100 people’. Using logistic growth models to conduct this analysis, the study found a positive, strong and significant relationship between ICT penetration and ETF.

At a micro level, the Internet has enhanced labour productivity and led to major revenue increases and cost savings in developed countries (Litan and Rilvin, 2001; Varian et al., 2002). By reducing information asymmetry in the market, identifying customers and production standards, the Internet has also helped boost exports at the firm level (Clarke, 2008).

From the above discussion, it is evident that most of the empirical studies on the economic effects of the Internet have dealt with panel data. Time series country-specific studies assessing the specific role of the Internet are scanty, although a few time series studies used the Internet as one of the indicators of ICT. Hence, to the best of our knowledge, so far, there is no time series empirical exercise that has investigated the effect of the most important ICT indicator – the Internet – on the economic growth of Australia, despite it's vital role in transforming the Australian economy for more than a decade. Using similar methods applied to other country-specific studies, this current study makes a modest contribution to the existing Internet–growth literature, especially from an Australian perspective.

*2.3 Economic growth, financial development and trade openness: theory and evidence*

Empirical literature recognises that financial development and the degree of trade openness are among the most important endogenous variables that profoundly impact the economic growth of countries and regions. The relationship between financial development and economic growth has attracted increasing attention from researchers since the pioneering works of Goldsmith (1969), McKinnon (1973) and Shaw (1973) on the role of financial development in promoting economic growth. Early economic growth theories did not recognise financial intermediaries as variables to be explicitly modelled in regards to long-term growth effects. However, a growing contemporary theoretical and empirical body of literature shows how financial intermediation mobilises savings, allocates resources, diversifies risks and contributes to economic growth (Greenwood and Jovanovic, 1990; Jibili et al. 1997). Endogenous growth models argue that financial institutions and markets reduce information and transaction costs; influence decisions in favour of more productive activities; and evaluate prospective entrepreneurs for promising investments, thus eventually contributing to long-term economic growth.

Empirical literature dealing with the financial development–economic growth nexus mostly supports a positive relationship between the two; however, there is considerable disagreement over the direction of the causal link between them. Some authors support the direction from financial development to economic growth, while others argue that the link flows from economic growth to financial development. Still, others support a bidirectional link.

In the empirical literature, on the one hand, most of the panel and cross-country studies find support in favour of a positive relationship between financial development and economic growth while controlling for other growth determinants, variable omission bias, simultaneity and country-specific effects. These studies also support a causality running from financial development to economic growth. On the other hand, most of the time series studies find both unidirectional and bidirectional causal relationships between financial development and economic growth. In addition, a variety of results have emerged for the use of different proxy measures for financial development. Overall, however, the literature supports the conclusion that financial development has a positive effect on long-term growth. Examples of some recent studies that support the positive effect of financial development on economic growth include Hassan et al. (2013), Jedidia et al. (2014) and Uddin, G.S. et al. (2013).

Hsueh et al. (2013) reported that financial development stimulates economic growth in some Asian countries, including China. Zhang et al. (2013) suggested that traditional measures of financial development have positive effects on economic growth. Abu et al. (2013) argued that whether financial development affects economic growth positively or negatively depends on which proxy measure is being used in the study.

Bangake and Eggoh (2011) used panel data for 71 countries for the period 1960–2004. They classified the countries into low-income, middle-income and high-income groups. The study reported bidirectional long-term causality between financial development and economic growth for all countries involved, though no short-term causality for low-income and middle-income countries was found. A significant short-term causal link was observed between variables for high-income countries. Rousseau and Yilmazkuday (2009) showed that the relationship between financial development and economic growth is conditional on the presence of inflation rates. This study, which involved a panel of 84 countries, revealed that higher levels of financial development are associated with higher levels of growth when the inflation rate is below 4%. For countries with inflation rates between 4% and 19%, the effect of financial development on economic growth is overshadowed.

Recent theoretical literature on economic development and in particular, those studies involving endogenous growth theories – pay attention to the potential of trade openness to spur long-term economic growth. According to these theories, openness to international trade results in four distinct opportunities that stimulate economic growth. These opportunities are: the transmission of knowledge through communication with international counterparts, the invention of new ideas and technologies reducing duplication of R&D efforts, an increase in the size of accessible markets and the integration of other markets, and opportunities for specialisation. Rivera-Batiz and Romer (1991) and Barro and Sala-i-Martin (1997) argued that trade openness spurs economic growth both through the diffusion of technical knowledge by importing high-tech items and the presence of spillover effects. However, Redding (1999) documented that trade openness negatively affects economic growth through comparative disadvantages in productivity growth in special sectors of the economy.

Recent empirical studies also offer mixed findings on the relationship between economic growth and trade openness. A few examples include Trejos and Barboza (2015) who, for a panel of Asian countries, reported that trade openness accelerates per capita growth through gains in productivity associated with capital accumulation. A recent study by Musila and Yiheyis (2015) indicated there is a positive relationship between trade openness and economic growth in Kenya. Shahbaz and Lean (2012) argued, in a time series study on Pakistan, that trade openness promotes economic growth in the long term. Belloumi (2014) examined the association among foreign direct investment, trade openness and economic growth for Tunisia using time series data for the period 1970–2008. The study found a long-term relationship between trade openness and economic growth but failed to confirm any causal link between them in the short term. Menyah et al. (2014), in a panel study of 21 African countries, found no significant relationship between trade openness and economic growth. Eris and Ulasan (2013), in a cross-country analysis, found no evidence of any direct robust relationship between trade openness and economic growth.

## 3. Data and methodology

### *3.1 Method*

Romer's (1986, 1990) endogenous growth model explained that balanced growth is positively influenced by knowledge spillover. The Internet is hypothesised as playing a significant role in disseminating knowledge (Choi and Yi, 2009) and thus stimulating economic growth. Barro's (1998) endogenous growth model also highlighted the role of knowledge and innovation in promoting economic growth. Based on these models, and similar to the growth equation used in Barro (1997) and Choi and Yi (2009), we estimated the following growth equation where real GDP per capita growth rate (GDPCG) is assumed to be determined by the number of Internet users per 100 people (NET). To circumvent omission bias, our model included two theoretically and empirically supported key growth drivers – financial development (FD) and trade openness (TO). Therefore, the following econometric equation was considered for this study:

$$GDPCG_t=\beta_0+\beta_1 NET_t+\beta_2 FD_t+\beta_3 TO_t+\varepsilon_t \quad (1)$$

where $\beta_0$ and $\varepsilon_t$ are the constant and stochastic error term, respectively.

*3.2 Data*

In this study, we used annual data for 1985–2012 sourced from the World Development Indicators Database CD ROM (World Bank, 2013). The economic growth rate was defined as the real GDP per capita (GDPCG) growth rate. Internet usage was taken as the number of Internet users per 100 people. The variable financial development (FD) was estimated from the ratio of credit to private sector as a share of GDP, while trade openness (TO) was defined as the total exports and imports as a share of GDP (Sassi and Goaied, 2013; Yartley, 2008).

*3.3 Estimation procedures*

*3.3.1 Unit root tests*

Because the unit root test helps us with a robust causality assessment (Kumar, 2013), we first employed the conventional ADF (Dickey and Fuller, 1979), PP (Phillips and Peron, 1988) and KPSS (Kwiatkowski et al., 1992) unit root tests. However, these tests were followed by another test, the DF-GLS (Dickey Fuller-Generalized Least Squares) proposed by Eliott et al. (1996) — as it is more powerful than these conventional tests. Despite its superiority over other tests, however, it fails to identify the presence of structural breaks, if any, in the series (Baum, 2004). Therefore, we also conducted a Zivot and Andrews (1992) unit root test, which accommodates a single structural break point in the level. If we consider our series as X, the structural tests take the following form:

$$\Delta X_t = a + aX_{t-1} + \text{bT} + cD_t + \sum_{j=1}^{k} d_j \, \Delta X_{t-j} + \varepsilon_t \qquad (2)$$

$$\Delta X_t = \beta + \beta X_{t-1} + \text{ct} + bDT_t + \sum_{j=1}^{k} d_j \, \Delta X_{t-j} + \varepsilon_t \qquad (3)$$

$$\Delta X_t = \gamma + \gamma X_{t-1} + \text{ct} + dDT_t + \varepsilon_t \qquad (4)$$

$$\Delta X_t = \Omega + \Omega X_{t-1} + \text{ct} + dD_t + dDT_t + \sum_{j=1}^{k} d_j \, \Delta X_{t-j} + \varepsilon_t \qquad (5)$$

where D is a dummy variable and shows the mean shift at each point, and $DT_t$ is a trend shift variable. The null hypothesis in Zivot and Andrews (1992) is c=0, meaning the presence of a unit root in the absence of a structural break hypothesis against the alternative that the series is trend-stationary with an unknown time break. Then, this unit root test selects the time break which reduces the one-sided t-statistic to test c(=c-1)=1. In order to assess consistency in break periods, we also perform another structural unit root test, the Perron (1997) test which also considers a single structural break.

*3.3.2 ARDL bounds testing approach*

As conventional cointegration techniques have certain limitations with their findings in the presence of structural breaks in macroeconomic dynamics (Uddin, et al., 2014), we employed an Autoregressive Distributed Lag model (ARDL) bounds testing approach developed by Pesaran (1997) and Pesaran et al., (2001) to estimate the long-term relationship between variables. The ARDL technique has several advantages over other conventional cointegration techniques. First, this method can be applied to a small sample size study (Pesaran et al., 2001); therefore, conducting bounds testing is justified for the present study. Second, it can be applied even in cases involving the mixed order of variable integration [both for I(0) and I(1) variables]. Third, it simultaneously estimates the short-term dynamics and long-term equilibrium with a dynamic Unrestricted Error Correction Model (UCEM) through a simple linear transformation of variables. Fourth, it estimates short- and long-term components simultaneously, potentially removing the problems associated with omitted variables and autocorrelation. In addition, this technique generally provides unbiased estimates of the long-term model and valid t-statistic, even when the model suffers from the problem of endogeneity (Harris and Sollis, 2003). The empirical formulation of the ARDL equation for our study was specified as follows:

$$\Delta GDPCG_t = \beta_0 + \beta_1 T + \beta_2 D + \beta_3 GDPCG_{t-1} + \beta_4 FD_{t-1} + \beta_5 NET_{t-1} + \beta_6 TO_{t-1} + \sum_{i=1}^{p} \beta_7 \Delta GDPCG_{t-j} + \sum_{J=1}^{q} \beta_8 \Delta FD_{t-k} + \sum_{k=0}^{r} \beta_9 \Delta NET_{t-l} + \sum_{l=0}^{s} \beta_{10} \Delta TO_{t-m} + \varepsilon_t \quad (6)$$

$$\Delta NET_t = \beta_0 + \beta_1 T + \beta_2 D + \beta_3 NET_{t-1} + \beta_4 FD_{t-1} + \beta_5 GDPCG_{t-1} + \beta_6 TO_{t-1} + \sum_{i=1}^{p} \beta_7 \Delta NET_{t-j} + \sum_{J=1}^{q} \beta_8 \Delta FD_{t-k} + \sum_{k=0}^{r} \beta_9 \Delta GDPCG_{t-l} + \sum_{l=0}^{s} \beta_{10} \Delta TO_{t-m} + \varepsilon_t \quad (7)$$

$$\Delta FD_t = \beta_0 + \beta_1 T + \beta_2 D + \beta_3 FD_{t-1} + \beta_4 GDPCG_{t-1} + \beta_5 NET_{t-1} + \beta_6 TO_{t-1} + \sum_{i=1}^{p} \beta_7 \Delta FD_{t-j} + \sum_{J=1}^{q} \beta_8 \Delta GDPCG_{t-k} + \sum_{k=0}^{r} \beta_9 \Delta NET_{t-l} + \sum_{l=0}^{s} \beta_{10} \Delta TO_{t-m} + \varepsilon_t \quad (8)$$

$$\Delta TO_t = \beta_0 + \beta_1 T + \beta_2 D + \beta_3 TO_{t-1} + \beta_4 FD_{t-1} + \beta_5 NET_{t-1} + \beta_6 GDPCG_{t-1} + \sum_{i=1}^{p} \beta_7 \Delta TO_{t-j} + \sum_{J=1}^{q} \beta_8 \Delta FD_{t-k} + \sum_{k=0}^{r} \beta_9 \Delta NET_{t-l} + \sum_{l=0}^{s} \beta_{10} \Delta GDPCG_{t-m} + \varepsilon_t \quad (9)$$

where GDPCG, FD, NET and TO indicate values for the real GDP per capita growth rate, financial development, Internet users per 100 people and trade openness, respectively. $\Delta$ is the difference operator; T and D denote a time trend and dummy variable, respectively. The dummy variable was included in the equation to capture the structural break arising from the series. $\varepsilon_t$ is the disturbance term.

To examine the cointegrating relationship, the Wald Test or F-test for the joint significance of the coefficients of lagged variables was applied with the null hypothesis, $H_0: \beta_3=\beta_4=\beta_5=\beta_6$, indicating no cointegration against the alternative hypothesis of the existence of cointegration between variables. F statistics were computed to compare the upper and lower bounds critical values provided by Pesaran (2001).

*3.3.3 Dynamic Ordinary Least Squares*

Next, we applied the Dynamic Ordinary Least Squares (DOLS) method (Stock and Watson, 1993) and estimated the long-term coefficients between variables to check the robustness of the findings. The application of this robustness check method is appropriate in that this estimator is robust in regards to small sample bias and eliminates a simultaneity problem. Moreover, the cointegrating vectors obtained from DOLS estimators are asymptotically efficient.

*3.3.4 The VECM Granger causality test*

According to Granger (1969), once the variables are found integrated of the same order, the VECM Granger causality test is appropriate for estimating their causal link. Because all of the variables in our study were first difference stationary (I(1)), this study proceeded further to determine the causal direction between them. Information about the causal linkage provides some insight into the development of a better discussion on policy implications (Shahbaz, 2013). The potential causality pattern for our study was represented by the following VECM specification in a multivariate framework:

$$\Delta lnY_t = \beta_{0i}+\sum_{i=1}^{p}\beta_{1i}\,\Delta lnY_{t-i}+\sum_{i=0}^{p}\beta_{2i}\,\Delta NET_{t-i} + \sum_{i=0}^{p}\beta_{3i}\,\Delta FD_{t-i}+\sum_{i=0}^{p}\beta_{4i}\,\Delta TO_{t-i}+\varepsilon_t \quad (10)$$

*3.3.5 Impulse response and variance decomposition*

One major weakness of the VECM Granger causality test is that it is unable to provide reliable estimates of the causal strength of the relationship between variables beyond the selected sample period. Another limitation is that it provides only the direction of the relationship, not the corresponding sign. To overcome these limitations, this study applied an Innovation Accounting Approach (IAA), which consists of variance decomposition and generalised impulse response functions.

The generalised impulse response function is preferred over the simple Choleski fractionalisation impulse response analysis, as the generalised impulse response function is insensitive to the order of the VECM (Shahbaz et al., 2013). It also indicates whether the impacts of innovations are positive or negative, and whether they have short- or long-run effects. Consequently, a variance decomposition method was employed to examine this magnitude.

Variance decomposition (Pesaran and Shin, 1999) measures the percentage contribution of each innovation to the h-step forecasting error variance of the dependent variable and provides a means for determining the relative importance of shocks in explaining variation in the dependent variable. Engle and Granger (1987) and Ibrahim (2005) argued that the variance decomposition approach produces more reliable results than other traditional approaches.

## 4. Results and discussion

Table 1 reports summary statistics. The standard deviations in all series are quite low, thus implying that the data are evenly dispersed around the mean. Hence, it was convenient for us to proceed with the datasets for further estimation. Table 2 presents results from the Variance Inflation Factor (VIF). Since all the VIF values are less than 5, it may be assumed that the data this study deals with are free from the threat of multicollinearity.

Table 1: Descriptive Statistics

| Variable | Observation | Mean | Std. Dev. | Min | Max |
|---|---|---|---|---|---|
| GDPCG | 28 | 2.3450 | 1.6761 | -1.6129 | 5.9167 |
| FD | 28 | 83.963 | 28.607 | 37.031 | 126.36 |
| NET | 28 | 34.355 | 32.095 | 0.530 | 82.349 |
| TO | 28 | 37.783 | 3.938 | 32.128 | 44.778 |

Table 2: Variance Inflation Factor (VIF) results

| Variable | Coefficient Variance | Centered VIF |
|---|---|---|
| FD | 0.001565 | 4.30849 |
| NET | 0.001245 | 3.16509 |
| TO | 0.022178 | 3.436467 |
| C | 28.01029 | NA |

The ADF, PP and KPSS unit root tests results are presented in Table 3. The DF-GLS unit root results are reported in Table 4, which shows that all the series in our study are first difference stationary, i.e. I(1).

Table 3: ADF, PP and KPSS unit root test results

| | ADF | KPSS | PP |
|---|---|---|---|
| | Trend &intercept | Trend &intercept | Trend &intercept |
| **FD** | | | |
| Level | -1.068 | 0.6637**,*** | -1.068 |
| 1st Diff: | -4.051*,**,*** | 0.9472*,**,*** | -4.019*,**,*** |
| **NET** | | | |
| Level | -2.819 | 0.6261**,*** | 0.108 |
| 1st Diff: | -4.140**,*** | 1.585*,**,*** | -3.711**, *** |
| **TO** | | | |
| Level | -2.693 | -1.758 | -2.868*** |
| 1st Diff: | -5.615*,**,*** | -4.738*,**,*** | -4.949*,**,*** |
| **GDPCG** | | | |
| Level | -4.955*, **,*** | -1.755**,*** | -1.567*** |
| 1st Diff: | -4.547*,**,*** | -4.438*,**,*** | -3.895*,**,*** |

**Notes**
* indicates statistical significance at the 1% level
** indicates statistical significance at the 5% level
*** indicates statistical significance at the 10% level

Table 4: DF-GLS unit root test results

| Log Levels ( $Z_t$ ) | | Log 1st Difference ( $Z_t$ ) | | |
|---|---|---|---|---|
| Variable | DFGLS stat | Variable | DFGLS stat | I(d) |
| GPDCG | 0.239 | ΔLGDPC | -3.601[a] | I(1) |
| NET | 1.644 | ΔNET | -2.140[b] | I(1) |
| FD | -0.475 | ΔFD | -4.131[a] | I(1) |
| TO | -1.016 | ΔTO | -5.802[a] | I(1) |

Note: a, b, & c indicate 1 %, 5%, & 10 % significance level respectively

However, since these tests do not consider the presence of structural breaks (Baum, 2004), which may be due to different types of internal and external shocks in an economy, we performed two other unit root tests that take into account structural break: the Perron (1997) single structural break unit root test and the Zivot and Andrews (1992) unit root structural break test. The results from these tests are reported in Table 5 and Table 6 respectively. As evident from Table 5, the Perron structural break test identifies the break periods for the respective series as: 1991 (GDPPCG), 2002 (FD), 1996 (NET), 2003 (TO), 1991 (ΔGDPCG), 1989 (ΔFD), 1996 (ΔNET) and 2001 (ΔTO). In Table 6, the Zivot-Andrews break test locates the break points as 2008 (GDPPCG), 1994 (FD), 1997 (NET), 2001 (TO), 1993 (ΔGDPCG), 2008 (ΔFD), 1997 (ΔNET) and 1994 (ΔTO). Although the break periods detected by the two tests are not identical, they are not significantly different or inconsistent either. Overall results from these tests imply that early and late 1990s and 2000s are dominated by the break periods. This is not unexpected, as Australia went through a number of policy reforms during this period, especially in terms of boosting its investment in Internet expansion. The results further confirm that all the series are first difference stationary, i.e. I(1) even in the presence of these structural breaks. Therefore, the maximum order of integration of the variables is 1.

Table 5: Perron Unit root Test under structural break

| Variable | Perron test for level | | | Perron test for 1st difference | | |
|---|---|---|---|---|---|---|
| | T-Statistic | TB | Outcome | T-Statistic | TB | Outcome |
| LGDPCG | -4.156 | 1991 | Unit Root | -6.571*** | 1991 | Stationary |
| FD | -2.891 | 2002 | Unit Root | -4.943* | 1989 | Stationary |
| NET | -7.181 | 1996 | Stationary | -4.204* | 1996 | Stationary |
| TO | -3.959 | 2003 | Unit Root | -6.505*** | 2001 | Stationary |

Note *, **, *** indicate 1 %, 5%, & 10% significance level respectively.

Table 6: Zivot–Andrews structural break unit root test

| Variable | Z&A test for level | | | Z&A test for 1st difference | | |
|---|---|---|---|---|---|---|
| | T-Statistic | TB | Outcome | T-Statistic | TB | Outcome |
| GDPCG | -2.795 | 2008 | Unit Root | -6.039[a] | 1993 | Stationary |
| FD | -1.588 | 1994 | Unit Root | -5.026[a] | 2008 | Stationary |
| NET | -8.979[a] | 1997 | Unit Root | -5.553[a] | 1997 | Stationary |
| TO | -3.466 | 2001 | Unit Root | -5.768[a] | 1994 | Stationary |

Note a, b, & c indicate 1 %, 5%, & 10% significance level respectively

Because ARDL is sensitive to lag order, to calculate the F statistic, we first needed to identify the optimum lag order. Based on the results demonstrated in Table 7, this study selected the optimum lag order to be 1 according to the Schwarz Information Criterion (SC). Table 8 reports the results of the calculated F statistics when each variable in our model is normalised as a dependent variable. To conserve space, we focused on our variable of interest – GDP per capita growth rate, which is normalised as the dependent variable. The null hypothesis of no cointegration was rejected as the calculated F statistic of 4.689 is higher than the upper bound critical value (4.37) of Pesaran et al. (2001) and the upper bound critical value (4.229) of Narayan (2005) at the 1% and 5% levels of significance, respectively. Therefore, there is a highly significant cointegrating relationship between economic growth and the predicted variables (i.e. Internet usage, financial development and trade openness).

Table 7: Result from Bounds Test

| Dep. Var. | SB | AIC Lag | F-stat. | Probability | Outcome |
|---|---|---|---|---|---|
| $F_{LGDPC}$(GDPCG\|FD,NET, TO) | 1991 | 2 | 4.689*** | 0.019 | Cointegration |
| $F_{FD}$(FD\|GDPCG, NET, TO) | 1989 | 2 | 6.471*** | 0.006 | Cointegration |
| $F_{NET}$(NET\|GDPCG, FD, TO) | 1996 | 2 | 2.390 | 0.114 | No Cointegration |
| $F_{TO}$(TO\|GDPCG, FD,NET) | 2001 | 2 | 1.963 | 0.170 | No Cointegration |
| | | I(0) | I(1) | I(0) | I(1) |
| Critical value (Pesaran et al., 2001) (Narayan 2005) | | | | | |
| 1% level of significance | | 3.29 | 4.37 | 4.280 | 5.840 |
| 5% level of significance | | 2.56 | 3.49 | 3.058 | 4.223 |
| 10% level of significance | | 2.20 | 3.09 | 2.525 | 3.560 |

Note: *** denote 1% level of significance.

Table 8: VAR Lag Order Selection Criteria

| Lag | LogL | LR | FPE | AIC | SC | HQ |
|---|---|---|---|---|---|---|
| 0 | -290.1456 | NA | 519604.0 | 24.51214 | 24.70848 | 24.56423 |
| 1 | -203.8412 | 136.6487 | 1520.338 | 18.65344 | 19.63515* | 18.91388 |
| 2 | -180.9984 | 28.55348* | 978.0147 | 18.08320 | 19.85028 | 18.55201 |
| 3 | -171.9153 | 8.326231 | 2507.034 | 18.65961 | 21.21206 | 19.33677 |
| 4 | -130.4590 | 24.18285 | 728.3047* | 16.53825* | 19.87607 | 17.42377* |

* indicates lag order selected by the criterion
LR: sequential modified LR test statistic (each test at 5% level)
FPE: Final prediction error
AIC: Akaike information criterion
SC: Schwarz information
HQ: Hannan-Quinn information criterion

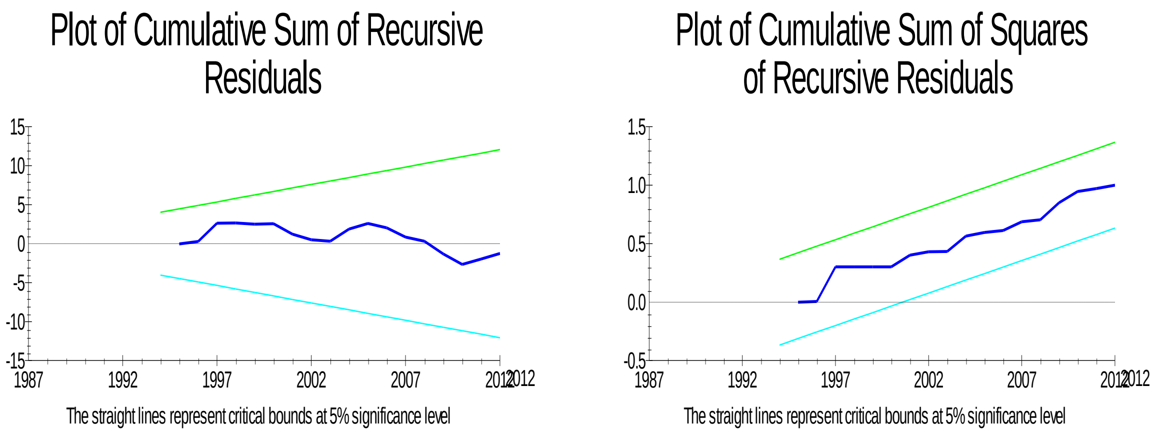
Once the presence of a cointegrating relationship between the variables was confirmed, the next step was to estimate the short- and the long-run coefficients of the respective variables. But prior to these estimations, conducting a battery of diagnostic tests was imperative. These tests included the Lagrange multiplier test of residual serial correlation ($\chi^2_{sc}$); Ramsey's RESET test using the square of the fitted values for correct functional form ($\chi^2_{ff}$); a normality test based on skewness and kurtosis of residuals ($\chi^2_{n}$); and a heteroscedasticity test ($\chi^2_{hc}$) based on the regression of squared residuals on squared fitted values. The results in Table 9 show that the model passes all of these diagnostic tests at least at the 5% level of significance. The parameters of the model are also dynamically stable as reflected through the graphical plots of CUSUM and CUSUM of Squares (Figure 1, Panel A and Panel B respectively).

Table 9: Diagnostic Test

| Test Statistics | LM Version | | |
|---|---|---|---|
| R Square 0.99 | | | Adjusted R Square 0.99 |
| Serial Correlation | $\chi^2(1)$= 0.004[0.944] | Normality | $\chi^2(2)$= 1.461[0.482] |
| Functional Form | $\chi^2(1)$= 2.921[0.087] | Heteroscedasticity | $\chi^2(1)$= 1.516[0.218] |

Figure 1: Plot of Cumulative Sum of Recursive Residuals (Panel A) and Plot of Cumulative Sum of Squares of Recursive Residuals (Panel B)

Panel A Panel B




Results in Table 10 reveal that the long-run contribution of Internet usage to Australia's economic growth is positive and statistically significant. The elasticity coefficient of Internet usage indicates that a 1% increase in Internet usage is expected to lead to a 0.1% rise in economic growth. Financial development also stimulates Australia's economic growth in the long run. The elasticity coefficient of financial development is 0.007, which implies that a 1% increase in credit availability to the private sector (proxy for financial development) causes a 0.7% increase in economic growth. The long-run association between trade openness and economic growth is positive but insignificant.

Table 10: Estimated Long Run Coefficients using the ARDL Approach, (2,0,0,1) selected based on AIC, dependent variable is GDPCG

| Regressor | Coefficient | Standard Error | T-Ratio[Prob] |
|---|---|---|---|
| LFD | 0.003[a] | 0.827 | 4.059[.001] |
| LNET | 0.001[b] | 0.727 | 2.018[.058] |
| LTO | 0.007[c] | 0.003 | 1.841[.081] |
| C | 9.693[a] | 0.122 | 79.136[.000] |

Note: a, b, & c indicate 1 %, 5%, & 10 % levels of significance respectively

Table 11 reports the short-run effects of the independent variables on economic growth. The findings indicate that there are no significant growth effects of Internet usage, financial development and trade openness in the short run. The coefficient of the error correction term $ECT_{t-1}$ is -0.438 and has the expected sign. It also implies a relatively speedy convergence (the short-term deviations being corrected at the speed of 43% towards the long-run equilibrium each year).

Table 11: Error Correction Representation for the Selected ARDL Model(2,0,0,1) selected based AIC, dependent variable is dGDPCG

| Regressor | Coefficient | Standard Error | T-Ratio[Prob] |
|---|---|---|---|
| dGDPC1 | 0.352 | 0.207 | 1.696[0.105] |
| dFD | 0.001 | 0.940 | 1.565[0.133] |
| dNET | 0.644 | 0.499 | 1.289[0.212] |
| dTO | 0.820 | 0.001 | 0.509[0.616] |
| dC | 4.250[c] | 2.291 | 1.855[0.078] |
| ecm(-1) | -0.438[c] | 0.234 | -1.869[0.076] |

Note: a, b, & c indicate 1 %, 5%, & 10 % levels of significance respectively

The results from the DOLS are reported in Table 12. The DOLS estimation results are consistent with the ARDL estimates according to the sign and significance. Therefore, the long-run ARDL coefficients are robust across a different econometric specification.

Table 12: Results from Dynamic OLS (Dependent variable, GDPCG)

| | Coefficient | Robust Std. Err. | P- Value |
|---|---|---|---|
| TO | 0.0078[a] | 0.0009 | 0.000 |
| NET | 0.0009[a] | 0.0002 | 0.000 |
| FD | 0.0038[a] | 0.0001 | 0.000 |
| C | 9.6090 | 0.0429 | 0.000 |

Note: a, b, & c indicate 1 %, 5%, & 10 % significance level respectively

The Granger causality results are presented in Table 13, and indicate that there is a unidirectional causal link running from Internet usage to the variables, real GDP per capita growth rate and financial development. Variable trade openness has no causal link with both Internet usage and financial development. A unidirectional causal association running from financial development to real GDP per capita growth rate is also observed. The unidirectional causal link between Internet usage and financial development is also a promising finding. Internet usage promotes information dissemination and thus potentially contributes towards a financially more developed market by reducing information asymmetry in the credit market.

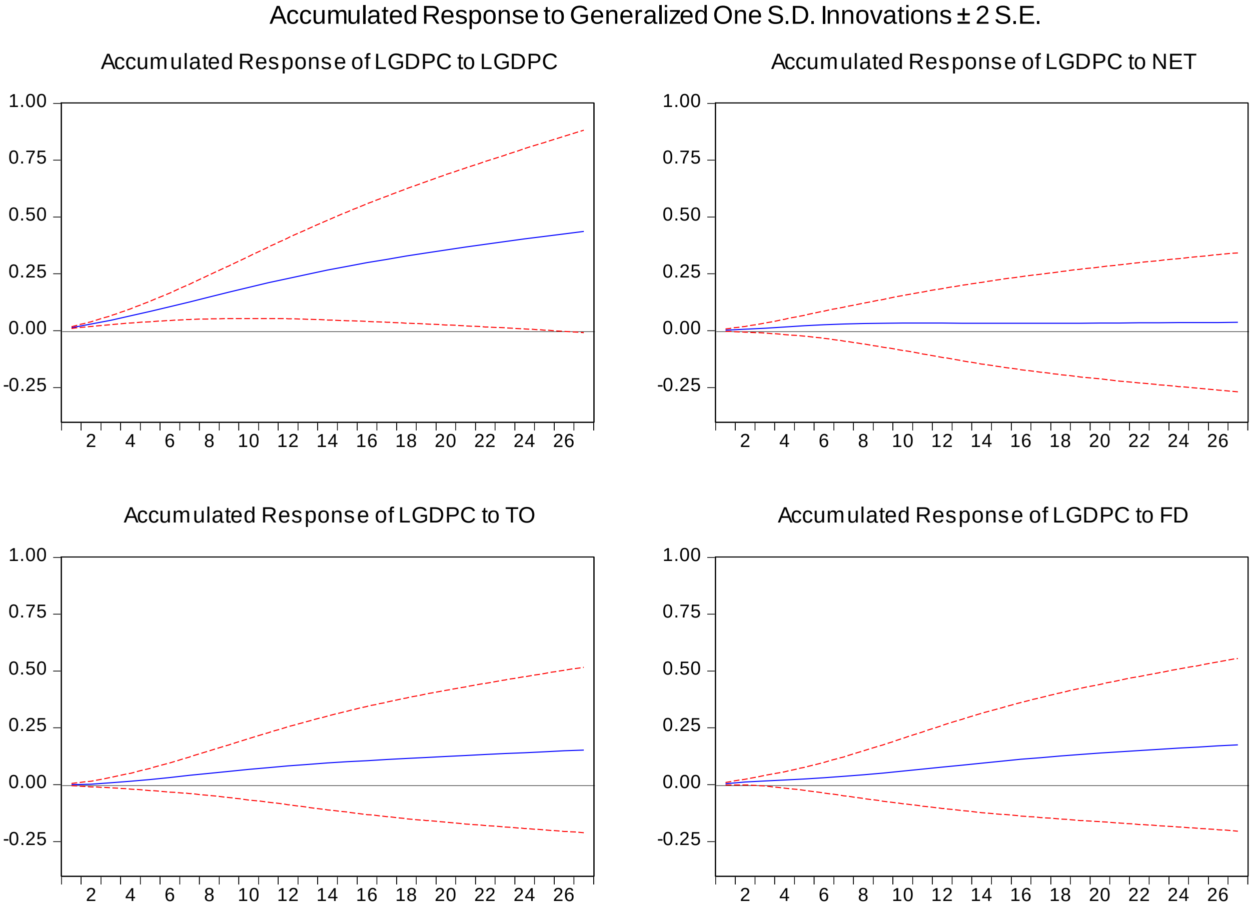
Table 13: Results from Granger Causality Test

| Equation | $\chi^2$ Test | P-value |
|---|---|---|
| $GDPCG \rightarrow Trade\ Openness$ | 2.917 | 0.233 |
| $GDPCG \rightarrow Internet\ Use$ | 0.851 | 0.653 |
| $GDPCG \rightarrow Financial\ Development$ | 2.060 | 0.357 |
| $GDPCG \rightarrow All$ | 7.070 | 0.314 |
| $Trade\ Openness \rightarrow GDPCG$ | 4.059 | 0.131 |
| $Trade\ Openness \rightarrow Internet\ Use$ | 5.141[c] | 0.076 |
| $Trade\ Openness \rightarrow Financial\ Development$ | 2.247 | 0.325 |
| $Trade\ Openness \rightarrow All$ | 17.444[a] | 0.008 |
| $Internet\ Use \rightarrow$ GDPCG | 11.772[a] | 0.003 |
| $Internet\ Use \rightarrow Trade\ Openness$ | 0.647 | 0.724 |
| $Internet\ Use \rightarrow Fnancial\ Development$ | 5.642[c] | 0.060 |
| $Internet\ Use \rightarrow ALL$ | 24.588[a] | 0.000 |
| $Fnancial\ Development \rightarrow GDPCG$ | 7.460[b] | 0.024 |
| $Fnancial\ Development \rightarrow Trade\ Openness$ | 1.565 | 0.457 |
| $Fnancial\ Development \rightarrow Internet\ Use$ | 0.529 | 0.767 |
| $Fnancial\ Development \rightarrow All$ | 13.839[b] | 0.031 |

The impulse response graphs in Figure 2 indicate that the standard deviation of real GDP per capita growth leads to a positive increase in future real GDP per capita in Australia. The response of real GDP per capita growth to the shocks in Internet users per 100 people and financial development, demonstrates expected signs but with different magnitudes. The accumulated response of the real GDP per capita growth rate to a shock in Internet users per

100 people is positive and significant. The accumulated response of real GDP per capita growth to future shocks in financial development is also positive and significant. Thus, the findings are supportive of the earlier ARDL estimates of this study.

Figure 2: Impulse response function (IRF)




The results from the variance decomposition analysis are reported in Table 14. The study allows a 27-year forecasting horizon. Interestingly, at the 5-year forecasting horizon, approximately 91.2% of the one-step forecast variance in real GDP per capita growth is accounted for by its own innovations, and altogether, 8.8% is accounted for by Internet users per 100 people, financial development and trade openness. In the long run, after a period of 27 years, the response to innovative shocks declines to approximately 85%, while the response of the real GDP per capita growth rate to shocks in Internet users per 100 people, financial development and trade openness rises to 15% from the first 5-year forecast horizon of 8.8.%. Of the 15% variance, approximately 2% is due to shocks in the variable of Internet users per 100 people, approximately 9.5% is attributable to trade openness, while approximately 3.5% is attributable to financial development. The findings indicate that while trade openness has a strong forecasted impact on real GDP per capita growth rate, the forecasted impacts of Internet usage and financial development are also evident in the future. This leads to justification in favour of the argument that the positive growth impact of Internet expansion will be felt by Australia even after a long period of time. Therefore, the ongoing construction of the NBN rollout is assumed to be a worthy investment for Australia, given that its political dynamics are not altered frequently.

Table 14: Results from variance decomposition analysis

| Period | S.E. | GDPCG | NET | TO | FD |
|---|---|---|---|---|---|
| 1 | 0.013533 | 100.0000 | 0.000000 | 0.000000 | 0.000000 |
| 2 | 0.020877 | 96.84526 | 0.160309 | 0.562898 | 2.431532 |
| 3 | 0.027619 | 93.89085 | 0.501806 | 3.802269 | 1.805079 |
| 4 | 0.034035 | 92.33858 | 0.758077 | 5.649495 | 1.253846 |
| 5 | 0.039969 | 91.24577 | 0.700895 | 7.077390 | 0.975948 |
| 6 | 0.045687 | 90.18835 | 0.544596 | 8.437059 | 0.829995 |
| 7 | 0.051156 | 89.26639 | 0.454776 | 9.469237 | 0.809596 |
| 8 | 0.056263 | 88.44331 | 0.472669 | 10.16641 | 0.917616 |
| 9 | 0.060941 | 87.72548 | 0.580333 | 10.56927 | 1.124918 |
| 10 | 0.065148 | 87.12515 | 0.743754 | 10.73197 | 1.399126 |
| 11 | 0.068880 | 86.62958 | 0.930882 | 10.73268 | 1.706852 |
| 12 | 0.072155 | 86.22854 | 1.115174 | 10.63953 | 2.016755 |
| 13 | 0.075010 | 85.91498 | 1.278131 | 10.50107 | 2.305816 |
| 14 | 0.077489 | 85.68077 | 1.410285 | 10.34934 | 2.559606 |
| 15 | 0.079641 | 85.51563 | 1.509790 | 10.20321 | 2.771363 |
| 16 | 0.081517 | 85.40704 | 1.579863 | 10.07243 | 2.940664 |
| 17 | 0.083164 | 85.34148 | 1.626146 | 9.961032 | 3.071344 |
| 18 | 0.084625 | 85.30616 | 1.654730 | 9.869622 | 3.169484 |
| 19 | 0.085936 | 85.29022 | 1.671051 | 9.796872 | 3.241854 |
| 20 | 0.087125 | 85.28522 | 1.679468 | 9.740445 | 3.294867 |
| 21 | 0.088213 | 85.28517 | 1.683231 | 9.697565 | 3.334035 |
| 22 | 0.089216 | 85.28620 | 1.684638 | 9.665376 | 3.363784 |
| 23 | 0.090145 | 85.28612 | 1.685225 | 9.641180 | 3.387472 |
| 24 | 0.091009 | 85.28393 | 1.685951 | 9.622604 | 3.407517 |
| 25 | 0.091814 | 85.27941 | 1.687337 | 9.607702 | 3.425549 |
| 26 | 0.092562 | 85.27285 | 1.689580 | 9.594994 | 3.442573 |
| 27 | 0.093257 | 85.26478 | 1.692654 | 9.583453 | 3.459113 |

## 5. Conclusions, policy implications and limitations

This study investigated the economic growth effects of Internet usage, financial development and trade openness using the most recent Australian annual time series macro data for the period 1985–2012. An ARDL bounds testing approach was employed to estimate the short- and long-term relationship among the variables, and the Granger causality test was performed to determine the causal link. The findings from the ARDL estimates suggest that Internet usage and financial development have long-run significant positive effects on growth, while the short-run effects are insignificant.

The multivariate Granger causality test confirms that Internet usage Granger-causes economic growth and financial development. The long-run coefficients are robust, as supported by an alternative DOLS method. The robustness of the causal direction of the relationship was checked by impulse response functions and variance decomposition analysis. The econometric model estimated in this study succeeded all conventional diagnostic tests.

The results of this study have a number of policy implications. The findings suggest that despite the recent claim that there was a slowdown in the productivity contribution of IT investment to the Australian economy (Shahiduzzaman and Alam, 2014a), the Internet continues to stimulate growth. Additionally, the use of the Internet is found to positively contribute to the fostering of a financially more developed market, which is also likely to boost economic growth performance (Thangavelu et al., 2004). However, there is a need for caution in the implementation of the ongoing NBN rollout, as the presence of new forms of digital divide resulting from factors such as, inequality in the ability to use the Internet, disparity in the speed of connectivity across urban and regional areas etc. may hamper the growth potential of the Internet in Australia. Therefore, this study recommends that Australia boosts its efforts to promote ICT education especially among the disadvantaged and underprivileged people to enhance their ability to use the Internet more effectively and also improve the quality of Internet services especially in regional and rural areas in terms of connectivity and speed and other issues related to the services. Introducing transliteracy approach in ICT education (Bobish, 2011) may be a potential mean to achieve higher growth and productivity effects of the Internet. Previously these demand side issues were largely ignored which was identified as a major weakness of the Australian digital divide policies (Notley and Foth, 2008; Lee, 2012). Overcoming this weakness by achieving these goals might be important parameters for NBN's success.

Finally, the Internet can affect a nation's economic growth and productivity in a number of indirect ways also as evident from the literature review. Among the various enabling capacities, it also has the potential to generate social capital through its network effects which might eventually affect economic growth. Also, the widespread use of the Internet can affect a nation's energy demand by causing a rise in electricity consumption and subsequently affect the level of emissions. In contrast, it may also potentially contribute towards achieving efficiency in the energy sector of Australia and elsewhere. This leading ICT indicator may even contribute towards combating the emissions caused by a nation. Exploring these social capital and energy effects of the Internet for Australia and other countries might be good recipe for future research.

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# CHAPTER THREE

# PAPER 3 AND PAPER 4

## PAPER 3: DOES INTERNET USAGE STIMULATE THE ACCUMULATION OF SOCIAL CAPITAL? A PANEL INVESTIGATION FOR ORGANIZATION OF ECONOMIC COOPERATION AND DEVELOPMENT COUNTRIES

## PAPER 4: DOES INTERNET STIMULATE THE ACCUMULATION OF SOCIAL CAPITAL? A MACRO-PERSPECTIVE FROM AUSTRALIA

## PAPER 3: DOES INTERNET USAGE STIMULATE THE ACCUMULATION OF SOCIAL CAPITAL? A PANEL INVESTIGATION FOR ORGANIZATION OF ECONOMIC COOPERATION AND DEVELOPMENT COUNTRIES

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**Statement of Contributions of Authorship**

To whom it may concern

I, Mohammad Salahuddin contributed 70% to the paper entitled above.

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# Does Internet Usage Stimulate the Accumulation of Social Capital? A Panel Investigation for Organization of Economic Cooperation and Development Countries

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**ABSTRACT**

This study estimates the effects of the Internet and economic growth on the accumulation of social capital (measured by trust) using panel data for 19 Organization of Economic Cooperation and Development (OECD) countries for the period 1985-2012. A cross sectional dependence (CD) test is performed. Having found the cross sectional dependence, a cross-sectionally augmented IPS (CIPS) unit root test is conducted to check for stationarity of data. All the variables were found first-difference stationary. Pedroni cointegration test confirms the presence of long-run relationship among the variables. This follows the application of pooled mean group regression technique to estimate the short- and long-run association between the variables. The findings suggest a highly significant negative long-run relationship between Internet usage and social capital and a positive relationship between them in the short-run. However, both long-run and short-run coefficients are small in magnitude. Economic growth stimulates social capital both in the short- and the long-run. That the Internet reduces social capital in the long-run implies that the gains in trust obtained from online connectivity were perhaps offset by the loss in the same due to decline in frequency of offline interaction caused by increasing online engagement. Economic growth stimulates activities in markets that engage into more frequent transactions between businesses that may result in increased trust. Finally, the findings of this study do not rule out the potential of including social capital issue into the digital divide policies of these countries.

**Keywords:** Economic Growth, Internet Usage, Organization of Economic Cooperation and Development, Panel Data, Social Capital
**JEL Classifications:** C23, F43, O

## 1. INTRODUCTION

Internet use grew at a phenomenal speed in the Organization of Economic Cooperation and Development (OECD) countries over the last two decades (Zhang, 2013). As a general purpose technology (Cardona et al., 2013), the internet has been able to affect every sector of the economy and as such, played a significant role in transforming economies of this region (The OECD Economic Outlook, 2013). Almost all the OECD countries have invested billions of dollars for the roll out of this amazing technology (OECD Internet Outlook, 2013). But such massive expansion also resulted in various forms of social inequalities - a phenomenon commonly referred to as digital divide. Initially the concept of digital divide was meant to understand the difference between those who have access to the Internet and those who don't (OECD, 2001). With the passage of time, various forms of other divides such as education divide, skill divide, speed divide, net generation divide and group divide (so called cyber balkanization) have been emerging.

While access divide is declining within OECD countries (OECD, 2013), it still persists between countries in the region. Nevertheless, with rapid expansion of Internet infrastructure, other forms of divide have been emerging and haunting the digital landscapes of this region. The presence of these various forms of digital divide undermines the economy-stimulating potential of the Internet (Vicente and Lopez, 2011). However, the Internet itself may be able to reduce digital divide through its potential to generate social capital (Bauernschuster et al., 2014). Charlson (2013) suggests that enhancing empowerment and social capital through Internet network for those already burdened with disadvantage and marginalization could be a potential mean to narrow digital divide.

The World Bank (2005) defined social capital as 'the norms and networks that enable collective action. It referred to the institutions, relationships and norms that shape the quality and quantity of a society's social interactions'. Recognizing the potential of the internet to generate social capital, recent studies (Kyujin, 2013; Antoci et al., 2012; Ferreira-Lopes et al., 2012; Lippert and Spagnolo, 2011; Notley and Foth, 2008; Foth and Podkolicka, 2007; Fernback, 2005; Hopkins, 2005; Meredyth et al., 2004) on digital divide have recommended the inclusion of social capital issue into the digital divide policy of a country. Whether or not the social capital issue should be included into the digital divide policies of the OECD countries, it is important to investigate first of all, if the Internet really generates social capital in the region at macro level. While there is presence of digital divide in OECD region (Zhang, 2013) and that the Internet has the potential to generate social capital -these two factors underlie the key motivation for this investigation. This study makes a novel contribution by undertaking this investigation as it is believed that such important empirical exercise is the first of its kind for OECD region.

The rest of the paper is structured as follows: Section 2 gives a brief presentation on the concept and measurement of social capital. Section 3 provides a relevant literature review, and the methodology used in this empirical analysis is presented in Section 4. Section 5 reports the empirical results and the conclusions and policy implications of the research are given and discussed in Section 6.

## 2. AN OVERVIEW OF THE CONCEPT AND MEASUREMENT OF SOCIAL CAPITAL

The term "social capital" was first coined by Hanifan (Putnam 2000, p. 443) who highlighted the importance of the social structure of the people within the spheres of business and economics. The concept was later popularized by Bourdieu (1980; 1986), Coleman (1988, 1990) and Putnam (1993; 1995; 2000). Coleman (1990) defined social capital as ". social organization that constitutes social capital, facilitating the achievement of goals that could not be achieved in its absence or could be achieved only at a higher cost".

In their seminal work, Making Democracy Work, Putnam et al. (1993) defined social capital "as the collective values of all social networks and the inclinations that arise from these networks to do things for each other." Also he viewed social capital as encompassing features such as trust, social norms and networks that can improve the efficiency of the organization of society by facilitating coordinated actions. Given this point of view, Putnam et al. (1993) used indices of civil society and political participation to measure the stock of social capital.

However, the nature of the empirical literature on the measurement of social capital is very broad. One of the most recent studies (Righi, 2013) recommended that social capital should be measured by three main attributes: Generalized trust, the intensity of the associative links, and civic and political participation expressed in various ways. A recent meta-analysis (Westlund and Adam, 2010) covered 65 studies on social capital and social capital related issues and insisted that more than 90% of the studies used trust as the proxy variable for social capital. It is expected that higher levels of Internet use would lead to denser social networks resulting in the increased level of trust. Until the multidimensionality of the concept of social capital is resolved, trust appears to be the most ideal indicator of social capital. This is so far a major weakness of most of the social capital studies.

## 3. LITERATURE REVIEW

### 3.1. Internet Use and Social Capital: Theoretical and Empirical Perspectives

The arrival of the Internet technology resulted in a significant expansion of network communication (Wellman, 2001; Castells, 2000). Internet usage is potentially able to generate social capital through facilitating networks of relations between different people and different communities (Lippert and Spagnolo, 2011). It is recommended that through digital inclusion of the disadvantaged people in rural and regional areas, a successful digital divide policy should include social capital framework in its agenda (Notley and Foth, 2008). There has been significant increase in the use of various social network sites (SNSs) since recent times which continue to affect our social, political and economic lives (Ferreira-Lopes et al., 2012). There are at least three reasons to suspect that web-mediated social participation generates social capital (Antoci et al., 2012). Online interactions contribute to the accumulation of Internet social capital. A salient feature of this capital is that it allows asynchronous social interactions; one can benefit from another's participation through the act of communication a message or posting a photo even when the person who did this is offline. Internet social capital also benefits internet non-users by the information spill-over. It was suggested (Kyujin, 2013) that online social network services supported by ICT policy relate to social capital.

Earlier studies also (Meredyth et al., 2004; Hopkins, 2005; Fernback 2005; Foth and Podkalicka, 2007) addressed the potential of the Internet to generate social capital These studies concluded that ICT use can have a positive impact on an individual's social inclusion and on a community's collective social capital. Selwyn and Facer (2007) argue that ICT lies at the heart of most of the activities that are seen to constitute "social inclusion" - from playing an active role in one's neighborhood and community to maintaining one's personal finances.

Simpson (2005) emphasizes the interplay between physical infrastructure, soft technologies and social capital for successful implementation, widespread uptake, greater social inclusion and the sustainability of ICT initiatives. Servon (2002) perceive technology as a tool of inclusion or exclusion. She notes that technology includes certain classes of people while excluding others. DiMaggio and Hargittai (2001) argue that Internet builds social capital by enhancing the effectiveness of community-level voluntary associations.

The possible relation between the Internet and social capital was also explained in what is known as "network society thesis" (Barney, 2004; Castells, 2000). The central idea of "network society thesis" is that contemporary social, political and economic practices, institutions and relationships are organized through and around network structures (Barney, 2004; Castells, 2000). The "network society thesis" is a useful tool to understand new forms of internet use.

It is within the "network society thesis" framework that social inclusion and social capital offer policy frameworks through which the current digital divide could be bridged addressing the online needs of specific disadvantaged groups and ensuring that all citizens with online opportunities lead to the formation of social, cultural and economic capital (Notley and Foth, 2008).

In summary, the above review reveals that despite importance of Internet-social capital association from the perspectives of massive growth in Internet use and the subsequent presence of different forms of digital divide, such an association was absolutely unexplored to date for OECD region. This study fills in this research gap.

## 4. METHODOLOGY

### 4.1. Data

Annual time series data on real GDP per capita growth rate and Internet users per 100 people for the period of 1981-2013 for 19 OECD countries[1] are obtained from the World Data Bank (previously, World Development Indicators database, The World Bank, 2014). Since trust is recognized as the most prominent dimension of social capital (Fukuyama, 1995a, b; Knack and Keefer, 1997; Glaeser et al., 2000; Zak and Knack, 2001; Ng et al., 2014), the current study uses trust as the indicator for social capital. Data on trust for OECD countries were gathered from the World Values Survey (WVS, 2014) conducted in multiple waves from 1981 to 2014. Missing values of trust variable were obtained through linear interpolation of data. Trust is measured as the percentage share of people who answer that "most people can be trusted" to the WVS survey question "Generally speaking, would you say that most people can be trusted or that you can't be too careful in dealing with people?" Trust data are available only for 19 out of 34 OECD countries. As such, 15 OECD countries are dropped from the study. The variable economic growth is taken from the growth rates in real GDP per capita (GDPC) which was measured at constant 2005 US$.

### 4.2. The Model

To test the hypothesis that the Internet generates trust (a proxy of social capital), we estimate an econometric model where social capital measured by trust (SC) is assumed to be a function of number of internet users per 100 people (NET) and real GDP growth rate (GDPCG). This model is based on the assumption that the Internet and economic growth stimulate trust. Higher economic growth is associated with higher level of transactions in an economy which may work to strengthen trust among the actors in the economy which is likely to enhance the overall level of trust. Therefore, the functional form of the estimated model in this study is:

$$SC_{it} = \beta_0 + \beta_1\ NET_{it} + \beta_2\ GDPCGC_{it} + \varepsilon_{it} \quad (1)$$

The subscripts *i* and *t* represent the country and time respectively.

### 4.3. Estimation Procedures

The estimation of our model proceeded as follows: (i) A cross-sectional dependence test was conducted to detect its presence, (ii) the stationarity of data was checked by an appropriate panel unit root test (CIPS), (iii) presence of unit root enforced the Pedroni cointegration test to verify long run relationship among the variables and (iv) pooled mean group (PMG) estimation technique was applied to examine the short-run and long-run relationship among the variables.

#### *4.3.1. Tests for unit roots*

Usually in panel data, there is likelihood of the threat of cross sectional dependence across the panel. To verify its presence and to consider it in the unit root test procedures, a cross-sectional dependence (CD) test developed by Pesaran (2004) was conducted. Pesaran (2004) defined CD statistic as:

$$CD = \left[\frac{TN(N-1)}{2}\right]^{1/2} \bar{\hat{\rho}}$$

Where:

$$\bar{\hat{\rho}} = \left(\frac{2}{N(N-1)}\right) \sum_{i=1}^{N-1} \sum_{j=i+1}^{N} \hat{\rho}ij$$

In which $\hat{\rho}ij$ is the pair-wise cross-sectional correlation coefficients of residuals from the conventional augmented Dickey–Fuller regression, T and N are sample and panel sizes respectively.

Having found the cross sectional dependence across the panel, next, a cross-sectionally augmented IPS (CIPS) unit root test is performed. The test statistic provided by Pesaran (2007) was given by:

$$CIPS(N,T) = N^{-1} \sum_{i=1}^{N} t_i\,(N,T)$$

Where $t_i$(N, T) is the t statistic of $\beta_i$ in Equation (2). The critical values of CIPS (N, T) are provided in Table 1 of Pesaran (2007).

#### *4.3.2. Panel cointegration test*

The presence of cointegrating relationship is an indication of the possibility of long-run relationship between variables as evident from the CIPS results (Table 1). This enforced conducting panel cointegration tests suggested by Pedroni (1999). The key advantage of Pedroni cointegration test over other similar tests was that it controls for country size and heterogeneity allowing for multiple regressors (as in our case). Pedroni (1997) provided

1 Australia, Canada, Chile, Finland, France, Germany, Israel, Italy, Japan, Korea, Netherlands, New Zealand, Norway, Portugal, Spain, Sweden, Switzerland, United Kingdom and USA.

seven panel cointegration statistics for seven tests. Four of those were based on the within-dimension tests while the other three were based on the between-dimension or group statistics approach. The critical values of panel cointegration test statistics are available in Table 1 in Pedroni (1999).

#### *4.3.3. PMG regression*

One shortcoming of Pedroni tests is that these tests do not estimate for the short-run relationship (Murthy, 2007) which also has significant policy relevance. A number of alternative methods are available that estimate both short-run and long-run association between variables. These methods also estimate the speed of short-run adjustment towards the long run equilibrium.

At one extreme, the fully heterogeneous-coefficient model imposes no cross-country parameter restrictions and can be estimated on a country by country basis. When both the time series and cross sections are large, the MG estimator (Pesaran and Shin, 1996) provides consistent estimates. At the other extreme, the fully homogeneous-coefficient model, the dynamic fixed effect model imposes the restrictions that all slope and intercept coefficients be equal across countries.

This study employs an intermediate approach between these extremes, the PMG estimator technique (Pesaran et al., 1999). The justification for employing this technique is based on the expectation that social capital (measured by trust) in OECD countries is likely to be affected by the long-run homogeneous conditions while the short-run conditions may be heterogeneous depending on various factors such as, country-specific characteristics like vulnerability to domestic and external shocks (for example, recent debt crisis in Greece and financial mismanagement, different types of adjustment to the recent global financial crisis), monetary and fiscal adjustment mechanisms. Financial-market imperfections, lack of sufficient time for implementation of different Internet and digital divide policies, change in political regime, etc.).

In order to comply with the requirements for standard estimation and inference, the regression equation (Equation 1) is embedded into an ARDL (p, q) model. In error correction form, this could be written as follows:

$$\Delta(y_i)_t = \sum_{j=1}^{p-1}\gamma_j^i\Delta(y_i)_{t-j} + \sum_{j=0}^{q-1}\delta_j^i\Delta(x_i)_{t-j} + \varphi^i[(y_i)_{t-1} - \beta_1^i(X_i)_{t-1}] + \beta_0^i + \varepsilon_{it} \quad (2)$$

Where, $Y_i$ and $X_i$ are the long run values of dependent (SC) and independent variables (NET and GDPCG) respectively. $y_i$ and $x_i$ represent short run values. $\gamma_j^i$ and $\delta_j^i$ are short run coefficients, $\varphi^i$ is the error correction adjustment speed, $\beta_1^i$ are homogeneous long- run coefficients, $\beta_0^i$ represents country-specific fixed effects and $\varepsilon_{it}$ is the error term.

## 5. ESTIMATION RESULTS

Table 2 presents descriptive statistics of all the variables. It reveals that the data were fairly dispersed around the mean. The maximum number of Internet users per 100 people is above 96 while the minimum is 0.005. The mean of the Internet users per 100 people in the OECD panel is above 36% for the whole sample period. The percentage growth in the usage rate is very skewed throughout the region. Some countries experienced very high growth in Internet usage while others lagged behind. The mean GDP growth rate was close to 2% which implies that the OECD countries were somewhat successful in outweighing the negative effect of the global financial crisis that shook the world economy during 2008-2010.

Table 1 presents the correlation matrix that shows that the correlation coefficient between all the variables is <0.5 which rules out the threat of any multicollinearity problem in the data.

The unit root results are reported in Table 3. The results show that all the series are first-difference stationary [I(1)] indicating the presence of unit root. This implies the possibility of a cointegrating relationship among the variables.

Table 4 presents results from the Pedroni cointegration test. It is evident from Table 4 that the statistical values of three out of seven tests were greater than the critical values which indicate the rejection of the null hypothesis of no cointegration at least 5% level of significance. Based on these results, it can be concluded that there is a long run cointegrating relationship among the variables.

Table 5 presents results from the PMG estimations. The findings indicate that there is a highly significant negative relationship between Internet usage and social capital in the OECD countries in the long-run. No significant association between Internet use and social capital is observed. Surprisingly but not unexpectedly, the interaction term of Internet use and social capital has highly

**Table 1: Correlation matrix**

| Variables | GDPCG | NET | SC |
|---|---|---|---|
| GDPCG | 1.0000 | | |
| NET | 0.2515 | 1.0000 | |
| SC | 0.0356 | −0.0594 | 1.0000 |

**Table 2: Descriptive statistics**

| Variable | Mean | SD | Min | Max |
|---|---|---|---|---|
| GDPCG | 1.952032 | 2.484641 | −8.97498 | 10.23 |
| Net use (per 100 people) | 31.31645 | 32.71986 | 0.00732 | 95 |
| Social capital | 0.379637 | 0.151378 | 0.0603 | 0.7417 |

SD: Standard deviation

**Table 3: Panel unit root test**

| Variables | P | CD | Levels | First differences |
|---|---|---|---|---|
| | | | CIPS[2] | CIPS |
| GDP (per capita) growth rate | 0.451 | 30.30*** | −1.990 | −2.962*** |
| Net use (per 100 people) | 0.969 | 67.05*** | −1.944 | −2.136** |
| Social capital | 0.971 | 69.20*** | 2.610 | −6.453** |

**and ***denote the level of significance at 5% and 1% level of significance

2 CIPS runs the t-test for unit roots in heterogeneous panels with cross-section dependence, proposed by Pesaran (2007)

**Table 4: Pedroni residual cointegration test**

| Alternative hypothesis: Common AR coefficients (within-dimension) | | | | |
|---|---|---|---|---|
| Tests | | | Weighted | |
| | Statistic | P | Statistic | P |
| Panel v-statistic | 3.232815 | 0.0006 | 3.163079 | 0.0008 |
| Panel rho-statistic | 1.086973 | 0.8615 | 1.109565 | 0.8664 |
| Panel PP-statistic | 2.090357 | 0.9817 | 2.103272 | 0.9823 |
| Panel ADF-statistic | −5.623627 | 0.0000 | −5.591478 | 0.0000 |
| **Alternative hypothesis: Individual AR coefficients (between-dimension)** | | | | |
| **Tests** | **Statistic** | **P** | | |
| Group rho-statistic | 3.240647 | 0.9994 | | |
| Group PP-statistic | 4.131497 | 1.0000 | | |
| Group ADF-statistic | −5.731875 | 0.0000 | | |

Null hypothesis: No cointegration. ADF: Augmented Dickey–Fuller

**Table 5: Results from PMG estimation**

| Dependent variable: Social capital (trust) | PMG | |
|---|---|---|
| Variable | Coefficient | Standard error |
| Long-run coefficients | | |
| NET | −0.000901*** | 0.0003781 |
| GDPCG | 0.0720542*** | 0.0183252 |
| Error correction coefficient | −0.1042585*** | 0.0070742 |
| Short-run coefficients | | |
| Δ NET | 0.0005369*** | 0.0002196 |
| Δ GDPCG | 0.0015184** | 0.0003751 |
| Intercept | 0.0254775*** | 0.0029357 |

Note: *, ** and *** indicate level of significance at 10%, 5% and 1% respectively

significant positive relationship with economic growth in both the short- and the long-run.

The short-run relationship between both Internet use and social capital with economic growth are insignificant. The error correction term i.e., $ECT_{t-1}$ is statistically highly significant with an expected negative sign. The value of $ECT_{t-1}$ was −0.104 which implies that the short-run deviations are corrected by around 10% in each year towards the long-run equilibrium. It further suggests that a full convergence process will take approximately 10 years to reach the stable path of equilibrium.

## 6. SUMMARY AND CONCLUSIONS

This study addresses the research question "Does Internet generate social capital in OECD countries?" using panel data for 19 OECD countries for the period 1985-2012. The model also includes another variable, economic growth rate in order to offset omission bias. A cross sectional dependence test (CD) is performed followed by an appropriate unit root test (CIPS) that takes into account cross sectional dependence. The unit root test reported that all the variables are first-difference stationary. Pedroni cointegration tests confirm long-run relationship between variables. PMG regression technique is employed to estimate the effects of Internet use and economic growth rate on social capital measured by trust.

The findings suggest a highly significant negative long-run relationship between Internet usage and social capital and a significant positive relationship between them in the short-run. In other words, Internet use reduces social capital in the long-run but slightly enhances it in the short-run. Economic growth is found to stimulate social capital both in the short- and the long-run.

These findings have important policy implications. The negative long-run association between Internet use and social capital does not necessarily rule out the potential of including social capital issue into the digital divide policy of these countries as there is evidence of a short-run linkage between these variables. The fact that Internet use reduces social capital is attributed to the failure of building new trust and strengthening existing trust through network connectivity facilitated by the Internet. Such failure may be due to unfavorable trade-off between online and offline connectivity. Benefits from online connectivity might have been outweighed by the loss in offline connectivity due to online engagement. Face to face interactions and transactions still seem to be more effective to build trust and strengthen existing trust. At least, this may be potentially reflected through the findings in this study especially with respect to the negative long-run association between Internet use and social capital. Also lot of cyber crimes take place through the Internet which may have negative influence on the moral and social values of a society especially in the long-run. This may also play a role to slacken the string of trust among people.

The finding of the positive significant effect of economic growth on social capital also sounds sensible and is in line with expectations. If and when an economy experiences high growth rates, it triggers the market to be more vibrant and robust. As a consequence, more investment pour into the market and it generates increasing number of transactions between businesses and between citizens of a country. Such growing numbers of transactions are likely to boost trust (social capital) among people.

Despite maximum possible efforts, this study suffers from certain limitations. First of all, a large number of OECD countries were dropped from this work due to the missing of significant amount of social capital data. Another issue is that the digital divide policies of different countries of this region differ although they are priority policies of almost all of these countries, one should not expect same policy implications of the findings of such research to each and every country of the region. Nevertheless, the heterogeneity in the structure and characteristics of the economies within the region (for example, if a comparison is made between the economy of France with that of Chile) limits the implications of such studies. It should also be noted that the estimation results are not expected to be invariant across different econometric specifications. Country specific studies and studies involving different regions within a country might perhaps be able to provide more reliable and better policy-oriented findings, since, the issue this study deals with looks more aligned to rural and regional areas within a country. Further such academic explorations are left for future.

## 7. ACKNOWLEDGMENT

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## PAPER 4: DOES INTERNET STIMULATE THE ACCUMULATION OF SOCIAL CAPITAL? A MACRO-PERSPECTIVE FROM AUSTRALIA

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**Statement of Contributions of Authorship**

To whom it may concern

I, Mohammad Salahuddin contributed 70% to the paper entitled above and cited below;

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I, as a coauthor recognize and accept that the contribution of the candidate indicated above for the above mentioned PhD output is appropriate.

Clem Tisdell Signature: Date: 28 January, 2016

Lorelle Burton Signature: Date: 01 February, 2016

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Full length article

# Does internet stimulate the accumulation of social capital? A macro-perspective from Australia

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ABSTRACT

Based on the premise that the Internet has the potential to generate trust, this study estimates the effects of the Internet and real GDP per capita on the creation of social capital (measured by trust) for Australia for the period 1985–2013. We use ARDL bounds testing approach (Pesaran et al., 2001) to estimate the short- and long-run relationship and Granger (1969) causality test to assess the causal linkages among the variables. Findings indicate that Internet use reduces social capital in the long-run but contributes slightly to its enhancement in the short-run. There is positive significant association between the level of real GDP per capita and the stock of social capital in the long-run while the relationship in the short-run is negative and significant. No causal link is found between Internet use and social capital while a unidirectional causality running from social capital to real GDP per capita is observed. The negative association between Internet use and the formation of social capital in the long-run may occur because the trust generated through greater online interaction is outweighed by the loss in trust arising from reduced face to face interaction.



## 1. Introduction

Most studies of determinants of economic growth focus on factors such as physical and/or human capital, technological capacity and innovation, managerial and leadership skills in business and state sectors, and trade liberalization of domestic and international markets. Less attention is paid to the important role of social factors such as culture, social norms and cohesion in promoting economic growth. This study addresses this issue by examining the effect of the use of the Internet on the stock of social capital and the consequences of this effect for economic growth. Therefore, the variables of interest in this study are social capital proxied by trust, the use of Internet and an interaction term between social capital and Internet usage.

The term 'social capital' was first coined by L. J. Hanifan (Putnam, 2000, p. 443) who highlighted the importance of the social relationships of people having business and economic interests. The concept was later popularized by Bourdieu (1980, 1986), Coleman (1988, 1990) and Putnam et al. (1993); Putnam (1995, 2000). Coleman (1990) defines social capital as '…social organization that constitutes social capital, facilitating the achievement of goals that could not be achieved in

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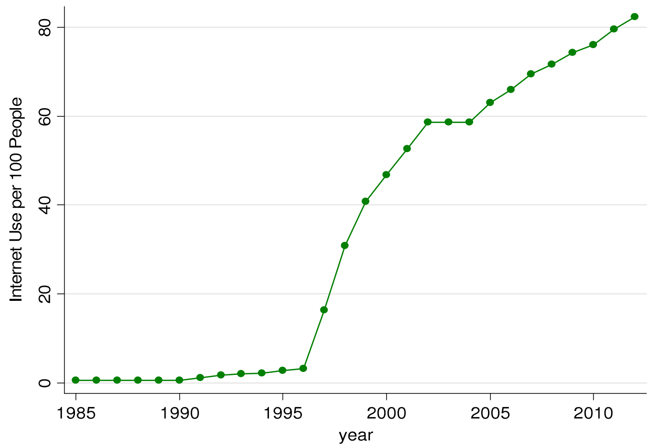


**Fig. 1.** Number of Internet users per hundred people (%) in Australia during 1985–2012.

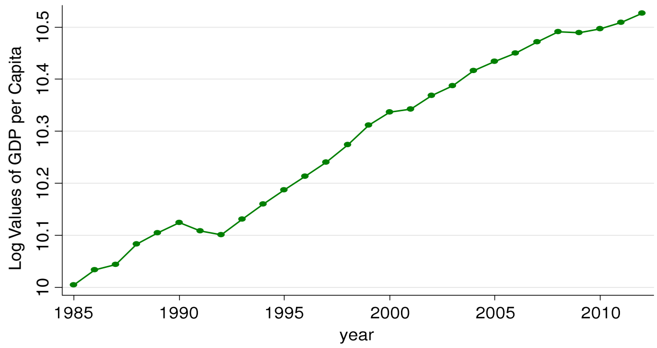


**Fig. 2.** Logarithmic trend in per capita real GDP of Australia during the period 1985–2012.
*Source:* The World Data Bank, World Development Indicators Database, The World Bank (2013).

its absence or could be achieved only at a higher cost'. In their seminal work, *Making Democracy Work*, Putnam et al. (1993) define social capital 'as the collective values of all social networks and the inclinations that arise from these networks to do things for each other'. Also he views social capital as encompassing features of social organization such as trust, social norms and networks that can improve the efficiency of society by facilitating coordinated actions. Given this point of view, Putnam et al. use indices of civil society and political participation to measure the stock of social capital. The World Bank offered another similar definition for social capital. It defines social capital as 'the norms and networks that enable collective action'.

However, the empirical literature on the measurement of social capital is very disparate. Existing studies vary substantially in their methods of measuring social capital and in the type of data collected for this measurement. One of the most recent studies (Righi, 2013) claims that the three main attributes of social capital which should be measured are generalized trust, the intensity of the associative links, and civic and political participation expressed in various ways. Nevertheless, so far, the most frequent indicators used in the literature on social capital are trust and associational activities. A recent meta-analysis study (Westlund and Adam, 2010) covering 65 studies on social capital conclude that trust is the most widely used measure of social capital.

Australia has experienced spectacular growth in Internet usage during the last two decades (Fig. 1), and this has significantly transformed the Australian economy (The Connected Continent, 2011).

Fig. 2 shows the logarithmic trend in real GDP per capita of Australia during the period 1985–2012. It shows a steady upward trend.

Recent literature suggests that Internet use may potentially add to social capital in Australia (Notley and Foth, 2008) but no research has been completed to measure that effect. The aim of this article is to address this shortcoming. It is expected that higher levels of Internet use would lead to denser social networks resulting in increased levels of social participation. Higher levels of social interaction and participation may lead to higher levels of trust (proxy of social capital) among people. This study also includes real GDP per capita as an independent variable. The inclusion of this variable is based on the assumption that higher levels of real GDP per capita boost economic transactions in an economy which in turn is expected to enhance trust and confidence in the business community eventually adding to the level of generalized trust. Thus, this study circumvents the omission bias in the model. The current study represents the first empirical investigation of this issue in Australian context. The findings of the study point to important policy implications for Australia, especially in relation to the digital divide policy. However, probably more significantly they highlight the possible limitations of the Internet in building social capital when this is measured by a trust variable.

The rest of the paper is structured as follows: Section 2 provides a relevant literature review, and the methodology used in this empirical analysis is presented in Section 3. Section 4 reports the results of the study and conclusions and policy implications of the research are given in Section 5.

## 2. Literature review

### *2.1. Internet and the stock of social capital in Australian context*

Recent literature demonstrates that the residents of rural and remote areas of Australia are socially disadvantaged compared to their urban counterparts (ABS, 2013). It has been argued that greater and improved access to the Internet could increase the social inclusion (through greater social interaction) and could reduce the social disadvantage of rural and remote communities (Broadbent and Papadopoulos, 2013).

It has also been argued that the Internet helps build citizen trust through online civic engagement (Warren et al., 2014). The ability to do so however, depends on the nature of the social obligations, connections, and network availability. Internet usage generates social capital by developing networks of relationships between different people and different communities (Lippert and Spagnolo, 2011). Thus, the Internet has emerged as the key facilitator of social networks in modern times.

Charleson (2013) suggests that enhancing empowerment and social capital by greater use of the Internet network for those already burdened with disadvantage and marginalization is a potential means to narrow the current digital divide in Australia.

In Australia, successful digital divide policy should include a social capital framework in its agenda to ensure the digital inclusion of disadvantaged people in rural and regional areas (Notley and Foth, 2008). Internet use has been reported to have positive impacts on areas such as the pursuit of hobbies and interests, shopping, work, employment and provision of health care information (Doong and Ho, 2012). Australia has witnessed a significant growth in the use of various social network sites (SNSs) that affect our social, political and economic lives (Ferreira-Lopes et al., 2012). It is also important (Kyujin, 2013) that online social network services supported by rural ICT policy should take into account social capital.

A few earlier studies addressed the potential of Internet to generate social capital in Australia but only to a limited extent. Such studies (Meredyth et al., 2004; Hopkins, 2005; Fernback, 2005; Foth and Podkalicka, 2007) concluded that ICT use can have a positive impact on an individual's social inclusion and the stock of a community's collective social capital. However, most of these studies are descriptive and are dated in their policy relevance.

Selwyn and Facer (2007) argue that ICT use involves a wide spectrum of activities that potentially constitute 'social inclusion'—from playing an active role in one's neighborhood and community to maintaining one's personal finances. Simpson (2005) emphasizes the interplay between physical infrastructure, soft technologies and social capital for successful implementation, widespread uptake, greater social inclusion and the sustainability of ICT initiatives. DiMaggio and Hargittai (2001) argue that Internet helps boost community-level voluntary associations and thus may generate social capital.

Servon (2002) perceives digital technology as being a tool of inclusion or exclusion. She notes that this technology is inclusive of certain classes of people while excluding others. The observation of Servon is important in relation to the digital divide between residents of rural and remote areas of Australia and their urban counterparts as well as to disadvantaged persons in urban areas. The elderly, less well educated and the physically or mentally handicapped are relatively lacking in skills or ability to utilize the internet. An associated problem is that it is easier and less costly to enhance the Internet skills of those residing in urban areas than in rural and remote areas. Therefore, even with high speed Internet access, the former may be disadvantaged in accumulating social capital and locked out of networking with those who are relatively skilled in using Internet.

These findings lead to consideration of what is known as 'network society thesis' (Barney, 2004; Castells, 2000). The central idea of 'network society thesis' is that contemporary social, political and economic practices, institutions and relationships are organized through and around network structures (Barney, 2004; Castells, 2000). The 'network society thesis' provides an understanding of how new forms of Internet use can facilitate an ever-expanding information society. The arrival of the Internet technology has resulted in a significant expansion of network communication (Wellman, 2001; Castells, 2000).

There are both positive and negative consequences of the network society (Barney, 2004). Nevertheless, the ICT-mediated network is transforming the social nature of developed nations like Australia (The Connected Continent, 2011). The 'network society thesis' provides the background framework in which the current digital divide can be addressed and consideration can be given to the online needs of specific disadvantaged groups thereby enabling their increased participation in the formation of social, cultural and economic capital.

A positive view is that web-mediated social participation has the potential to protect the relational aspect of individuals' lives from the stress of time-constraint (Antoci et al., 2012). First, it is less exposed to the deterioration of the social environment that physically surrounds individuals. Second, Internet interaction is less time-consuming than face-to-face interaction and thus encourages social participation. Third, online interactions contribute towards the accumulation of Internet social capital. A salient feature of social capital is that it allows asynchronous social interactions; one can benefit from another's participation through the act of communicating a message or posting a photo even when the person who did this, is offline. Increased internet social capital may also generate positive externalities from the information spill-over to Internet non-users.

However, the social capital effect of Internet may not always be positive. In fact, it may also crowd out social participation when it is massively used for entertainment rather than for social networking. It may even lead to so called 'cyber balkanization' by stimulating the separation of communication into separate groups with specific interests leading to group separation and community fragmentation (Van Alstyne and Brynjolfsson, 1996; Gentzkow and Shapiro, 2011; Bauernschuster et al., 2014).

In summary, the above review reveals that there is a significant gap in the literature about the association between Internet and the stock social capital in the Australian context although there are plenty of studies that investigate the effects of different factors on social capital. No recent study has been completed to investigate the link between Internet usage and social capital in Australia even though this link is very important (Charleson, 2012; Notley and Foth, 2008).

### 2.2. Digital divide policies in Australia: from Networking the Nation (NTN) to the National Broadband Network (NBN)

In order to reduce disparity in telecommunications access, services and facilities, the Australian government approved the Networking the Nation (NTN) initiative (a digital divide policy intervention) in 1996. However, this initiative failed to adequately address the digital divide in Australia (Van Vuuren, 2007). A co-ordinated communication infrastructure scheme was then put in place in 2004 in order to boost health, education and other sectors of public interest to generate opportunities for improved broadband access and services in rural, regional and remote Australia.

At the same time, a *Communications Fund* was established to future-proof telecommunications services in rural, regional and remote Australia and the *Connect Australia* initiative to roll out broadband to people living in regional, rural and remote areas was started. These projects involved extending mobile phone coverage, building new regional communications networks and setting up of telecommunications services for remote Indigenous communities (Coonan, 2005). Recognizing that the Indigenous communities in Australia were substantially deprived of telecommunications services, two more initiatives were undertaken to address the infrastructure needs of the Indigenous communities: The 2002 Telecommunications Action Plan for remote indigenous communities and the 2006 Backing Indigenous Ability to redress low level of telecommunications access and access quality in Indigenous communities.

A broadband future policy for Australia was first announced in 2007 with the objective of building an optical fiber network to target 98% Australian households and offer speeds over 40 times greater than the average at that time (Hoy, 2007). However, this policy only focused on the issue of technology access and it failed to show how this would address differences in abilities to use of Internet.

The National Broadband Network (NBN) project, the largest ever infrastructure project in the history of Australia—was announced in 2009. The construction of the $47 billion NBN is now underway and its roll out will continue until 2018. It provides an opportunity to address the digital divide and to empower people to effectively use new technologies as they become available. With the change in the Australian Government recently, the political dynamics of NBN has changed. The coalition policy (present government) on the NBN is designed to deploy FTTP (Fiber-To-The-Premises) to only twenty-two percent as against ninety-three percent targeted by the former government. Seventy-one percent is expected to be covered by the FTTN (Fiber-To-The-Node) technology where fiber is being extended to high nodes. The remainder of the distance will be covered by Telstra's copper network. Although coalition's target is to downsize the cost of the project, this may have negative cost implications for the NBN-users. Experts fear that this might even increase the digital divide especially in regional Australia where cost is still a vital factor in decisions about Internet use (Alam and Salahuddin, 2015). Politicization of NBN might negatively affect the expected benefits from this mega-project at the cost taxpayers' expense.

### 2.3. A review on the measurement of social capital

Despite its historical roots and its considerable contemporary use, there has been increasing debate on the development of tools for measuring social capital empirically. The appropriate measurement of social capital is one of the major challenges in social capital research today. There is not yet a consensus about the appropriate indicators for measurement of social capital (Fukuyama, 2001; Antoci et al., 2012). To date, researchers have failed to provide a unique comprehensive measure of social capital.

Although the failure to measure this concept in an entirely adequate way has been attributed to various factors, Antocy et al., (2012) have proposed three reasons for it. The first of these is the multidimensionality of the definitions of social capital. Furthermore, a range of concepts of social capital exist, several of which are vague. This can result in a situation described by Mohan and Mohan (2002, p. 199) as 'operational opportunism' and by Stone (2001, p. 5) as 'empirical mayhem'. Second, any attempt to measure the properties of inherently ambiguous concepts such as community networks and organization is correspondingly problematic Third, there is a lack of availability of survey data for contemporary researchers to compile indexes using a range of proxies such as measures of trust in government voting trends, membership in civic organizations, hours spent in volunteering and so on.

Also, there is a gap between the theoretical concept of social capital and the concepts applied in empirical researches to measure social capital to date. Such gap has resulted in empirical confusion about the meaning, measurement and outcomes

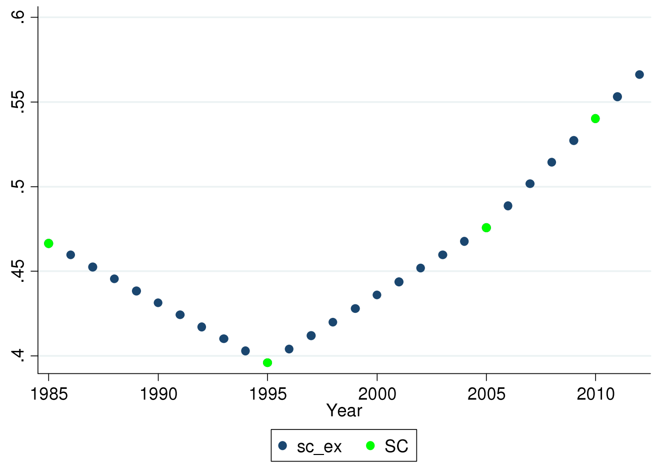


**Fig. 3.** WVS values and interpolated values of social capital.
*Source:* World Values Survey and author's own calculation through linear interpolation.

of social capital. Paxton (1999, 90) identified the same problem noting that previous studies provide little rationale for how measures of social capital relate to its theoretical definition.

The empirical literature on social capital is now very wide and studies differ in their degree of depth, methods and data collection. From the above review, it is evident that social capital is a complex multidimensional concept. Therefore, it still remains a challenge to satisfactorily represent it by a single measure or figure. This should be kept in mind when considering the following analysis.

## 3. Data and methodology

### 3.1. Data

Data on trust variable (SC) for Australia was gathered from the World Values Survey (WVS, 2014) conducted in multiple waves from 1981 to 2014. Trust is measured as the percentage share of people who answer that "most people can be trusted" to the WVS survey question "*Generally speaking, would you say that most people can be trusted or that you need to be very careful in dealing with people*?". Since estimating such periodic data is likely to provide unreliable findings, we generate annual values of trust through linear interpolation (Fig. 3).

We also incorporate another explanatory variable, real GDP per capita (GDPPC) in the model in order to circumvent the omission bias. A few missing values were also observed in the Internet users per 100 people (NET) series which were replaced by 3-year moving average values. The variable real GDP per capita (GDPC) is measured at constant 2005 US$. Data on Internet users and real GDP per capita were obtained from the World Development Indicators Database, 2014 (WDI, World Bank, 2013). In order to smooth the trend, variables, GDPPC and Internet usage are expressed in natural logs.

### 3.2. Methodology

#### 3.2.1. Model

Based on the premises of social capital theory and network externality, it is believed that the Internet has the potential to generate trust by enhancing connectivity among people within the same and between groups. Internet use potentially generates social capital through creation and enhancement of online trust (Warren et al., 2014). Also, through the use of the Social Networking Sites (SNS) and by other means, it is claimed that the Internet enables people to enjoy the benefits of positive networking effects, builds trust, strengthens existing trust and social bonds between them (Bauernschuster et al., 2014).

However, Internet may also cause negative network effects through dissemination of biased information (Liang and Guo, 2015; Kaustia and Knupfer, 2012) and thus may affect trust negatively. Given these different views, we explore how Internet use influences the level of trust (either positively/negatively). Trust is arguably the most widely used indicator of social capital in empirical exercises (Fukuyama, 1995a,b; Knack and Keefer, 1997; Gleaser et al., 2000; Zak and Knack, 2001; Westlund and Adam, 2010; Ng et al., 2014) to date. Therefore, we construct and estimate a model where the number of Internet users per hundred people and real GDP per capita are taken as explanatory variables and social capital (proxied by trust) is the dependent variable. The model takes the following form:

$$SC_t = \beta_0 + \beta_1 \, NET_t + \beta_2 \, GDPPC_t + \varepsilon_t \tag{1}$$

where, SC is social capital proxied by trust, NET is the number of Internet users per hundred people and GDPPC is real GDP per capita measured at constant 2005 US$. The subscript $t$ represents the time period.

### 3.3. Estimation procedures

#### 3.3.1. Unit root tests

In order to check for stationarity of data, ADF (Dickey and Fuller, 1979), PP (Phillips and Perron, 1988), and DF-GLS (Dickey and Fuller Generalized Least Squares) unit root tests are conducted. However, none of these tests consider structural break in the series, if any. Therefore, following Kumar et al. (2015a,b,c), this study employs a relatively simple Perron (1997) structural break unit root test which allows single structural break in a series. In order to check for consistency and as recommended by some recent empirical works (Kumar et al., 2015a,b,c; Kumar and Stauvermann, 2014) among others, we conduct another relatively advanced Zivot and Andrews (1992) structural break test.

#### 3.3.2. ARDL bounds testing approach

In order to estimate the short- and the long-run relationship between variables, we employ Autoregressive Distributed Lag model (ARDL) developed by Pesaran et al. (1997; 2001). The ARDL technique has several advantages over other conventional cointegration techniques: First of all, this method can be applied to a small sample size study (Pesaran et al., 2001) and therefore the application of such technique in our study seems to be justified. Secondly, it can be applied even in case of mixed order of integration of variables. Thirdly, it simultaneously estimates the short-run dynamics and the long-run equilibrium with a dynamic unrestricted error correction model (UCEM). Fourth, it estimates the short- and the long-run components simultaneously potentially removing the problems associated with omitted variables and autocorrelation. In addition, this technique generally provides unbiased estimates of the long-run model and valid $t$-statistic even when the model suffers from the problem of endogeneity (Harris and Sollis, 2003). The empirical formulation of ARDL equation for our study is specified as follows:

$$\begin{aligned}\Delta \mathrm{SC}_t = {} & \beta_0 + \beta_1 T + \beta_2 D + \beta_3\,\mathrm{SC}_{t-1} + \beta_4 \ln \mathrm{GDPPC}_{t-1} + \beta_5 \ln \mathrm{NET}_{t-1} \\ & + \sum_{i=1}^{P} \beta_6 \Delta \mathrm{SC}_{t-j} + \sum_{j=1}^{q} \beta_7 \Delta \ln \mathrm{GDPPC}_{t-k} + \sum_{k=0}^{r} \beta_8 \Delta \ln \mathrm{NET}_{t-l} + \varepsilon_t \end{aligned} \quad (2)$$

$$\begin{aligned}\Delta \ln \mathrm{GDPPC}_t = {} & \beta_0 + \beta_1 T + \beta_2 D + \beta_3 \ln \mathrm{GDPPC}_{t-1} + \beta_4\,\mathrm{SC}_{t-1} + \beta_5 \ln \mathrm{NET}_{t-1} \\ & + \sum_{i=0} \beta_6 \Delta \mathrm{SC}_{t-j} + \sum_{J=0}^{q} \beta_7 \Delta \ln \mathrm{NET}_{t-k} + \sum_{k=0}^{r} \beta_8 \Delta \ln \mathrm{GDPC}_{t-l} + \varepsilon_t \end{aligned} \quad (3)$$

$$\begin{aligned}\Delta \ln \mathrm{NET}_t = {} & \beta_0 + \beta_1 T + \beta_2 D + \beta_3 \ln \mathrm{NET}_{t-1} + \beta_4 \ln \mathrm{GDPC}_{t-1} + \beta_5\,\mathrm{SC}_{t-1} \\ & \times \sum_{i=0}^{p} \beta_6 \Delta \ln \mathrm{NET}_{t-j} + \sum_{j=0}^{q} \beta_7 \Delta \ln \mathrm{GDPC}_{t-k} + \sum_{k=0}^{r} \beta_8 \Delta \mathrm{SC}_{t-l} + \varepsilon_t \end{aligned} \quad (4)$$

where, ln GDPPC, SC and ln NET indicate log values of real GDP per capita, real values of social capital (trust), and log values of Internet users per 100 people respectively. $\Delta$ is the difference operator. $T$ and $D$ denote time trend and dummy variable, respectively. The dummy variable is included in the equation to capture the structural break arising from the series. $\varepsilon_t$ is the disturbance term.

To examine the cointegrating relationship, Wald Test or the $F$-test for the joint significance of the coefficients of the lagged variables is applied with the null hypothesis, $H_0 : \beta_3 = \beta_4 = \beta_5$ indicating no cointegration against the alternative hypothesis of the existence of cointegration between variables. $F$ statistics are computed to compare the upper and lower bounds critical values provided by Pesaran et al. (2001) and Narayan (2005).

To check whether the cointegrating relationship between the variables from ARDL bounds test is robust, we employed Gregory and Hansen (1996) residual-based test of cointegration, which allows for a one time change in the cointegrating parameters. The Gregory and Hansen test involves the testing of four models—level, trend, intercept or shifts in the intercept, and slope. We opted for the intercept and slope model that allowed rotation in the long-run equilibrium relationship simultaneously with shift. Once the cointegrating relationship is confirmed, long-run and short-run coefficients are estimated with the application of ARDL. The short-run estimation also involves an error correction term which reflects the speed of convergence of short-run disequilibrium towards the long-run equilibrium.

#### 3.3.3. Diagnostic tests

A number of diagnostic tests such as Lagrange Multiplier (LM) test for serial correlation, Ramsey RESET test for model specification, normality test for heteroscedasticity and model stability graphical plot tests such as CUSUM and CUSUMS are conducted.

**Table 1**
Summary statistics.

| Variable | Obs | Mean | Std. Dev. | Min | Max |
|---|---|---|---|---|---|
| LGPDC | 28 | 10.280 | 0.170 | 10.005 | 10.526 |
| NET | 28 | 0.441 | 0.041 | 0.400 | 0.481 |
| SC | 28 | 34.355 | 32.095 | 0.530 | 82.349 |

**Table 2**
Correlation matrix.

| | Social capital | LGDPC | LNET |
|---|---|---|---|
| Social capital | 1.0000 | | |
| LGDPC | 0.7083 | 1.0000 | |
| LNET | 0.5547 | 0.9550 | 1.0000 |

**Table 3**
ADF and PP unit root tests.

| Variable | ADF | PP | Variable | ADF | PP |
|---|---|---|---|---|---|
| LGPDC | −0.885 | −0.821 | ΔLGDPC | −3.655* | −3.662** |
| NET | 0.612 | 0.176 | ΔNET | −2.567*** | −2.275 |
| SC | −0.634 | 1.484 | ΔSC | −1.047 | −0.997 |

* Indicates 10% level of significance.
** Indicates 5% level of significance.
*** Indicates 1% level of significance.

**Table 4**
DFGLS unit root test.

| Log levels ($Z_t$) | | Log 1st difference ($Z_t$) | | |
|---|---|---|---|---|
| Variable | DFGLS stat | Variable | DFGLS stat | I(d) |
| LGDPPCC | −0.563 | ΔLGDPPC | −3.655* | I(1) |
| NET | −0.565 | ΔNET | −1.599*** | I(1) |
| SC | −1.415 | ΔSC | −4.898* | I(1) |

* Indicates 10% level of significance.
*** Indicates 1% level of significance.

*3.3.4. The VECM Granger causality test*

According to Granger (1969), once the variables are integrated of the same order, the VECM Granger causality test is appropriate for estimating their causal link. Because all of the variables in our study are first difference stationary [I(1)], this study proceeds further to determine the causal direction between them. Identifying the exact direction of causal linkage provides insight crucial to the development of better policy implications (Shahbaz and Lean, 2012). The potential causality pattern for our study is represented by the following VECM specification in a multivariate framework:

$$\Delta SC_t = \beta_{0i} + \sum_{i=1}^{p} \beta_{1i} \Delta SC_{t-i} + \sum_{i=1}^{p} \beta_{2i} \Delta NET_{t-i} + \sum_{i=0}^{p} \beta_{3i} \Delta GDPPC_{t-i} + \varepsilon_t. \quad (5)$$

## 4. Results

Table 1 reports summary statistics. The standard deviations in all the series are quite low implying that the data are more or less normally distributed. Hence, it is appropriate for us to proceed with the datasets for further estimation. Table 2 provides correlation matrix which does not indicate any serious multicollinearity threat in the model.

Table 3 reports results from ADF and PP unit root tests. All variables are found first difference stationary. The DF-GLS unit root test results are reported in Table 4 which also shows that all the series in our study are first difference stationary, i.e. I(1).

In order to avoid the value of $F$ statistic from bounds test being influenced by the presence of structural break, we conduct two structural break unit root tests namely; Perron (1997) unit root test with single structural break and Zivot–Andrews structural break test. The results from these tests are reported in Tables 5 and 6 respectively. As evident from Table 5, Perron structural break test identifies the break periods for the respective series as, 1997 (LGDPPC), 1996 (LNET), 1990 (SC), 1992 (ΔGDPPC), 1997 (ΔNET) and 1995 (ΔGDPPC). In Table 6, Zivot–Andrews break test locates the break points as 2008 (LGDPPC), 2002 (LNET), 1990 (SC), 1993 (ΔGDPPC), 1998 (ΔNET) and 1996 (ΔGDPPC). Although we have got different break periods from two tests, they are not significantly different or inconsistent.

**Table 5**
Perron unit root test in the presence of a structural break.

| Variable | Perron test for level | | | Perron test for 1st difference | | |
|---|---|---|---|---|---|---|
| | *T*-statistic | TB | Outcome | *T*-statistic | TB | Outcome |
| LGDPC | −3.282 | 1997 | Unit root | −5.068* | 1992 | Stationary |
| NET | −5.027** | 1996 | Stationary | −7.181* | 1997 | Stationary |
| SC | −2.871 | 1990 | Unit root | −10.149* | 1995 | Stationary |

* Indicates 10% level of significance.
** Indicates 5% level of significance.

**Table 6**
Zivot–Andrews structural break unit root test.

| Variable | Z&A test for level | | | Z&A test for 1st difference | | |
|---|---|---|---|---|---|---|
| | *T*-statistic | TB | Outcome | *T*-statistic | TB | Outcome |
| LGDPC | −2.795 | 2008 | Unit root | −6.039* | 1993 | Stationary |
| NET | −3.531 | 2002 | Unit root | −4.292** | 1998 | Stationary |
| SC | −2.701 | 1990 | Unit root | −10.043* | 1996 | Stationary |

* Indicates 10% level of significance.
** Indicates 5% level of significance.

**Table 7**
Lag order selection criteria.

| Lag | LogL | LR | FPE | AIC | SC | HQ |
|---|---|---|---|---|---|---|
| 0 | −84.36527 | NA | 0.291403 | 7.280439 | 7.427696 | 7.319507 |
| 1 | 28.20765 | 187.6215[a] | 5.25e−05 | −1.350638[a] | −0.761611[a] | −1.194369 |
| 2 | 39.04103 | 15.34729 | 4.70e−05[a] | −1.503419 | −0.472622 | −1.229948[a] |
| 3 | 44.09944 | 5.901486 | 7.29e−05 | −1.174954 | 0.297614 | −0.784281 |
| 4 | 53.42527 | 8.548674 | 8.90e−05 | −1.202106 | 0.712232 | −0.694232 |

LR: sequential modified LR test statistic (each test at 5% level).
FPE: Final prediction error.
AIC: Akaike information criterion.
SC: Schwarz information criterion.
HQ: Hannan–Quinn information criterion.
[a] Indicates lag order selected by the criterion.

From Table 5, the break periods 1997 and 1992 for Australian economy. The former may be attributed to Asian financial crisis while the latter may be due to productivity shock. For the Internet, the Australian Government for the first time approved the Networking the Nation (NTN) Project in 1996 to promote Internet use but this initiative was deemed inadequate. 1996–1997 was just the beginning for Australian Government to start any initiatives to promote Internet use. From Table 6, the break period of 2008 for Australian economy coincides with the Global Financial Crisis (GFC) and the SARS pandemic although it is claimed that Australia is one of the few countries which survived GFC. The break period of 1993 may be due to some productivity shocks. For the break periods of 1998 and 2002 for the Internet, Australia was still in a primary stage in terms of formulation of a sound and comprehensive digital divide policy to promote Internet use and reduce inequality in its access and use.

Next, we proceed with the tests to examine the cointegrating relationship, if any, among the variables. Since ARDL is sensitive to lag order, for calculating the $F$ statistic, first of all, we need to identify the appropriate lag order. To do this, we choose SC (Schwarz Information Criterion) as it provides better results than other lag length criteria (Lutkepohl, 2006). Table 7 reports results from the lag order selection criteria which suggests that the optimal lag is 1.

The ARDL bounds cointegration results reported in Table 8 suggests that when social capital is dependent variable, the calculated $F$ statistic of 7.679 is higher than the upper bound critical value generated by Pesaran et al. (2001) and Narayan (2005) at the 1% level of significance. Therefore, there is cointegrating relationship between social capital and the predicted variables—Internet users per 100 people, and real GDP per capita. But this test does not consider the presence of structural breaks in the series as detected by Perron and Zivot and Andrew structural break tests. Although ARDL estimate supports cointegration relationship, Hansen Gregory cointegration test that accounts for structural break is also employed which (as reported in Table 9) lends support in favor of the cointegrating relationship among the variables even in the presence of structural break in the series.

Once the cointegrating relationship between variables has been confirmed, it is imperative to conduct a battery of diagnostic tests that precede the estimation of long-run and short-run coefficients. In order to obtain diagnostic test statistics, this study performs the Lagrange Multiplier (LM) test of residual serial correlation ($\chi^2_{sc}$), Ramsey's RESET test for correct functional form, ($\chi^2_{ff}$) the normality test based on the skewness and kurtosis of residuals ($\chi^2_{n}$) and the heteroscedasticity test based on the regression of squared residuals on squared fitted values ($\chi^2_{hc}$). Overall, it is evident from Table 10 that all these test statistics are statistically insignificant at least at 5% level of significance implying that our

**Table 8**
Results from ARDL bounds cointegration test.

| Dep. Var. | SC Lag | $F$-stat. | Probability | Outcome |
|---|---|---|---|---|
| $F_{LGDPC}$ (LGDPPC\|NET, SC) | 1 | 3.787* | 0.045 | Cointegration |
| $F_{NET}$ (NET\|LGDPPC, SC) | 1 | 4.222* | 0.034 | Cointegration |
| $F_{SC}$ (SC\|LGDPPC, NET) | 1 | 7.679* | 0.238 | Cointegration |
| Critical value (Pesaran et al., 2001) | I(0) | I(1) | Narayan (2005) I(0) | I(1) |
| 1% level of significance | 3.29 | 4.37 | 4.280 | 5.840 |
| 5% level of significance | 2.56 | 3.49 | 3.058 | 4.223 |
| 10% level of significance | 2.20 | 3.09 | 2.525 | 3.560 |

* Indicates 10% level of significance.

**Table 9**
Gregory–Hansen test for cointegration with regime shifts, model: Change in regime and trend.

| Test | Statistic | Breakpoint | Date | 1% | 5% | 10% |
|---|---|---|---|---|---|---|
| ADF | −7.13 | 14 | 1998 | −6.89 | −6.32 | −6.16 |
| Zt | −7.16 | 14 | 1998 | −6.89 | −6.32 | −6.16 |
| Za | −36.79 | 14 | 1998 | −90.84 | −78.87 | −72.75 |

**Table 10**
Long run coefficients from ARDL estimates.

| Regressor | Coefficient | Standard error | $T$-ratio |
|---|---|---|---|
| *ln GDPC* | 0.940 | 0.235 | 3.99*** |
| *ln Internet* | −0.059 | 0.006 | 9.84*** |
| *Constant* | −3.314 | 0.712 | −4.65*** |

*ARDL*(1, 0, 0) $(\chi^2_{sc})$: $(\chi^2_1) = 0.412$, $F(1, 21) = 0.338$; $(\chi^2_{ff}) : (\chi^2_1) = 3.522$, $F(1, 21) = 0.338$; $(\chi^2_n) : (\chi^2_1) = 0.456$; $(\chi^2_{hc}) : (\chi^2_1) = 2.195$, $F\ (1,\ 24) = 0.213$; $SER = 0.0029$; $SSR = 0.458$; $\bar{x}_y = 0.458$; $\hat{\sigma}_y = 0.049$; $AIC = 112.883$; $SBC = 110.367$; $LL = 116.883$; $F\text{-}Stat.\ (3, 22) = 2320.00$; $DW\text{-}Stat. = 1.866$

*** Indicates 1% level of significance.

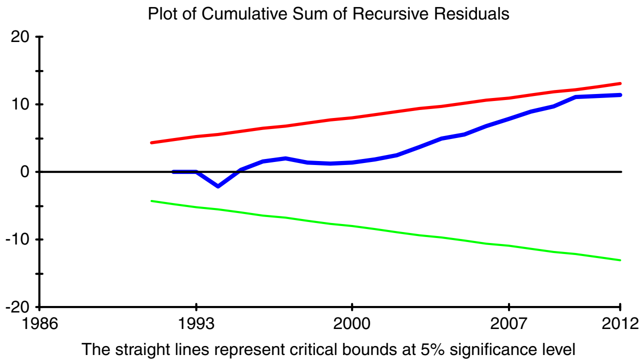


**Fig. 4A.** Plot of cumulative sum of recursive residuals.

model is free from any of these biases. The stability of parameters over time is also reflected through the graphical plots of CUSUM and CUSUM of Squares (Figs. 4A and 4B respectively).

Table 10 reports long-run coefficients from ARDL estimates. We note that the long-run association between Internet use and social capital is negative and statistically significant at 1% level of significance. A 1% rise in Internet use would cause a decline in trust by.05%. In other words, Internet use reduces trust among people. Real GDP per capita is found to stimulate trust and the long-run relation is statistically significant also at 1% level of significance. The findings further indicate that the level of trust rises by 0.94% for a 1% increase in real GDP per capita. This supports the expectation that a higher level of GDP is characterized by a higher volume of transactions in an economy that this leads to an increased level of trust between people involved in the transactions.

The short-run results are presented in Table 11. As indicated, the short-run association between Internet use and social capital is positive and statistically significant at 1% level of significance. It is demonstrated that a 1% rise in Internet use would trigger 0.003% increase in social capital. Real GDP per capita is negatively associated with social capital in the short-run. This negative relation is also significant at 5% level of significance. The coefficient of the error correction term $ECT_{t-1}$ of −0.1120 is statistically significant at 5% level of significance and has the expected sign. It also implies a reasonable

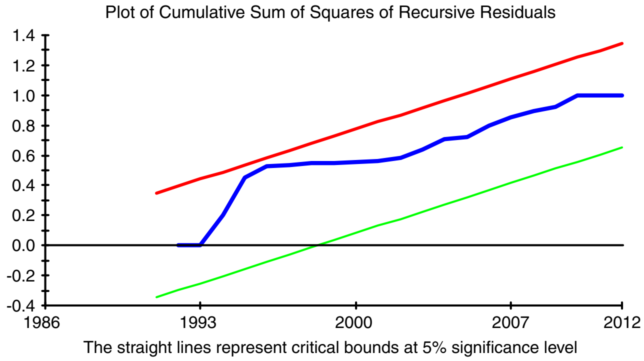


**Fig. 4B.** Plot of cumulative sum of recursive residuals.

**Table 11**
Error correction representation for the selected ARDL model (1, 0, 0) selected based on AIC.

| Regressor | Coefficient | Standard error | $T$-ratio |
|---|---|---|---|
| $\Delta$ ln GDPC | −0.0014 | 0.712 | 2.069** |
| $\Delta$ ln Internet | 0.0039 | 0.340 | 11.592*** |
| $\Delta$C | 0.0480 | 0.016 | 2.901*** |
| ecm(−1) | −0.1120 | 0.077 | −1.449** |
| $R^2 = 0.885$; $\bar{R}^2 = 0.875$; $\bar{x}_{\Delta y} = 0.0041$; $\hat{\sigma}_{\Delta y} = 0.0085$; $F$-$Stat. = F(2, 23) = 88.641$ | | | |

** Indicates 5% level of significance.
*** Indicates 1% level of significance.

**Table 12**
VEC Granger causality/block exogeneity Wald test.

| Excluded | Chi-sq | df | Prob. |
|---|---|---|---|
| Dependent variable: D(LSC) | | | |
| D(LGDPC) | 1.712792 | 2 | 0.4247 |
| D(NET) | 2.964074 | 2 | 0.2272 |
| All | 3.501177 | 4 | 0.4777 |
| Dependent variable: D(LGDPC) | | | |
| D(LSC) | 4.952017 | 2 | 0.0841 |
| D(NET) | 2.903874 | 2 | 0.2341 |
| All | 6.369471 | 4 | 0.1732 |
| Dependent variable: D(NET) | | | |
| D(LSC) | 0.306446 | 2 | 0.8579 |
| D(LGDPC) | 0.051473 | 2 | 0.9746 |
| All | 0.692207 | 4 | 0.9523 |

speed of convergence (the short-run deviations being corrected at the speed of 11% each year) towards the long-run equilibrium.

Granger causality results are presented in Table 12. No causality is observed between Internet use and social capital. A unidirectional causality running from social capital to real GDP per capita is observed.

## 5. Conclusions, policy implications and limitations

### *5.1. Discussion and policy implications*

The findings of the study have important policy implications for Australia. Australia has been pursuing various policies to promote Internet access and use since the early 1990s. Most of the recent literature recognizes the presence of digital divide in Australia (Bowles, 2013; Charlson, 2013; Atkinson et al., 2008) especially in regional and rural Australia. One of the key objectives of the currently ongoing roll out of the NBN is to narrow digital divide by expanding the high speed broadband network across the regional and remote parts of Australia.

The finding of the current study of highly significant long-run negative association between Internet use and social capital is attributed to the negative effects of Internet on social capital. While Internet use may potentially generate social capital by building and strengthening online trust through social networks, it can also cause social isolation as well for relatively disadvantaged and under-privileged section of population of a country. At the micro-level, it is possible that Internet use stimulates trust among various groups of people who are online connected through various SNSs but at the macro-level, the trade-off between increased online interaction and face-to-face interaction which may reduce the level of trust generated online among mass users. Furthermore, rapid increases in Internet use may cause so called 'cyber balkanization' or in other words, create group specific networks resulting in group fragmentation. The possible consequence of such group fragmentation in Australia is that it will further aggravate the current level of digital divide which is already in the danger of widening (Bowles, 2013).

Apart from the potential threat of causing social isolation to the relatively disadvantaged and under-privileged people living in rural and remote Australia (as well as in some urban situations), increased Internet use may even have negative effects on trust among the socially and economically better-off Internet users by reducing the number of their offline interactions (Zhong, 2014; Bauernschuster et al., 2014). It is claimed that absence of face-to-face interactions results in the loss of transmission of much important non-verbal information (Bauernschuster et al., 2014). Several other forms of reduced social interaction due to the use of the Internet are mentioned by Tisdell (2014, pp. 14–15).

Another finding of the study, the significant positive long-run relationship exists between real GDP per capita and social capital. That income generates social capital (trust) is in line with expectations. Higher levels of income are associated with higher frequencies and volumes of transactions traded within the economy. Higher frequencies and volumes of transactions may enhance and strengthen trust among people and this may influence them to engage in more frequent transactions online.

### *5.2. Conclusions and limitations*

This study examined the empirical relationship among social capital (proxied by trust), Internet usage and real GDP per capita using Australian annual time series data for the period of 1985–2013. Data for social capital is generated through linear interpolation for some missing data. ADF, PP and DF-GLS unit root tests, Perron and Zivots and Andrew structural break unit root tests are conducted. All the series are found to be stationary at first difference even in the presence of a structural break. Hansen Gregory and ARDL cointegration tests confirm cointegrating relationship among the variables. The findings from the ARDL estimates suggest that Internet use has had a highly significant negative long-run association with social capital in Australia. However, there is positive significant relation (but of small magnitude) between these variables in the short-run. Also, real GDP per capita positively influences the formation of social capital in the long-run and negatively influences in the short-run. In both cases, the relationships are statistically significant. No causal link is found between Internet use and social capital. A unidirectional causality is observed running from social capital to real GDP per capita.

Despite the novelty of the study, it suffers from a number of limitations. One major weakness is the measurement of social capital by one single indicator from WVS. It is now well documented in literature that social capital is a multi-dimensional concept. Therefore, our findings may not be robust across different measures of social capital. Another weakness of the study is that yearly observations on trust were unavailable which were generated through simple linear interpolation. Use of more data in future would certainly enhance the reliability of the findings. Finally, the findings are not expected to be invariant across different econometric specifications.

Using the only available general indicator of social capital for Australia (the WVS measure), we find that there is no convincing evidence that increased Internet usage has increased the stock of social capital when this is proxied by the WVS trust variable. Instead, the findings of the current study point in the opposite direction. Therefore, one needs to be cautious about claims found in the literature that greater Internet usage has generated social capital. Clearly, more research is needed to resolve this matter. Different dimensions of the social capital may need consideration and less aggregated studies, including case studies (for example, for different regions) would be worthwhile.

Although opinions expressed in the relevant literature about the impact of increased Internet use on social capital vary, the dominant view is that it is likely to be a powerful contributor to the accumulation of social capital. However, our empirical results do not support this hypothesis. In fact, they indicate that increased use of the Internet in Australia has been associated with a long-run decline in social capital when this is measured by the average per capita level of a trust variable; an aggregate measure. We also suggest that growing aggregate use of the Internet has been accompanied by growing inequality in its use by different social groups. In Australia, this increased inequality arises from two sources:

- Differences in the quality of Internet services (and in the supply of such services) available to different groups of individuals; and
- Differences in the ability of groups having access to Internet services to use these.

These differences appear to have resulted in some groups being able to increase their stock of social capital by using the Internet whereas others have suffered absolutely or relatively in this regard.

In developing its Internet development policies, the Australian Government seems to have put greater emphasis on reducing inequality in access to Internet services rather than on reducing inequality in the ability of individuals and groups to make use of their available Internet. There is a case for giving greater attention to the latter problem. In addition, more attention could be given to reducing anti-social behaviors associated with the use of the Internet because ultimately these have a negative effect on the formation of social capital.

Finally, note the social evaluation of the socio-economic consequences of Internet use does not depend solely on its effect on the formation of social capital. Among other things, it is likely to add to the stock of human capital and increase economic productivity. For example, it can play an important role in facilitating education and in supplying information. This aspect may be especially important in rural and remote regions of Australia.

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## CHAPTER FOUR

# PAPER 5

## PAPER 5: DOES INTERNET USE GENERATE SOCIAL CAPITAL? FRESH EVIDENCE FROM REGIONAL AUSTRALIA

# PAPER 5: DOES INTERNET USE GENERATE SOCIAL CAPITAL? FRESH EVIDENCE FROM REGIONAL AUSTRALIA

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## Statement of Contributions of Authorship

To whom it may concern

I, Mohammad Salahuddin contributed 75% to the paper entitled above and mentioned below;

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Signature of Candidate: Date: February 20, 2016

I, as a coauthor recognize and accept that the contribution of the candidate indicated above for the above mentioned PhD output is appropriate.

Khorshed Alam Signature Date: February 20, 2016

**This paper is one of two papers included in Chapter four of the candidate's PhD thesis**

# Does Internet use generate social capital? Fresh evidence from regional Australia

**Abstract**

This study addresses the research question: 'Does Internet use stimulate social capital in regional Australia?' In addressing this question, survey research (N=353) is conducted in the Western Downs Region (WDR) of Queensland, Australia. This research also offers a conceptual framework for the Internet–social capital relationship, quantifying the social capital variable with the application of the summated scale method. This presents a significant contribution to the existing literature on the measurement of social capital, which is still a largely unresolved issue. Regression analysis results indicate a significant positive association between Internet use and social capital, with a 1% increase in Internet use triggering a 0.18% increase in social capital. This study further shows that digital divide due to difference in income is gradually declining in regional Australia. Such findings renew the call for Australian policymakers to include the social capital issue into their digital divide policy. In addition, the research cautions that social inclusion of relatively disadvantaged and marginalised people of rural and regional Australia resulting from Internet use must not be at the cost of social exclusion of other deprived people.

## 1. Introduction

Internet use has grown at a phenomenal speed over the past 20 years in both developed and developing countries. In particular, the first decade of the 21st century witnessed a quantum leap in Internet usage across the globe. Internet penetration on a global level has increased from 18% in 2006 to around 35% in 2011 (ITU, 2011) and to 46% in 2014 (ITU, 2015). The multidimensional effects of the Internet are now well documented in the literature. Its manifold contributions towards the economic, social, environmental, cultural and political aspects of our lives have drawn special attention from researchers around the world.

Australia is one of the world's leading digital economies. An overwhelming majority of Australians are now Internet users (Ewing and Thomas, 2012). In 2014, around 89% of Australians had used the Internet, up from 87% in 2011 and from 81% and 73% in 2009 and 2007, respectively (Deloitte Access Economics, 2015). There has been spectacular growth in Internet use in rural and regional communities also, from 38% in 1998 to 79% in 2013 (ABS, 2014). Such growth in Internet use provides significant potential for building social capital in these communities (Warburton et al., 2013). The vast majority of household Internet connections are now broadband connections (96%), while the proportion of Australians accessing the Internet through a mobile device more than doubled between 2009 and 2011, from 15% to 37% (Ewing and Thomas, 2012). The Internet is believed to have been transforming in the Australian economy in many ways for over a decade now (Deloitte Access Economics, 2015). Despite this claim, ironically, recent empirical works have confirmed the existence of an 'information underclass' reflected in digital divide discourse in Australia, especially with respect to age, education (Alam and Salahuddin, 2015), e-skills (Lee, 2011) and speed (Alam and Imran, 2015). It is further believed that the digital divide in Australia is in danger of widening (Bowles, 2013).

Australia has been implementing the largest-ever broadband infrastructure project – the National Broadband Network (NBN) – since 2009. The purpose of this is to build high-speed broadband infrastructure across the nation in a bid to facilitate the digital delivery of government and public services including health and education, as well as to address the digital divide especially in regional Australia (DBCDE, 2011). This indicates that reducing digital divide in regional Australia is one of the priorities of the NBN rollout (Lee, 2011).

It is argued that social inclusion through social interaction at the community level could play a vital role in narrowing digital divide at the regional level (Broadbent and Papadopoulos, 2013). The Internet may potentially generate social capital through digital inclusion of disadvantaged people in rural and regional areas. Charleson (2013) argued that enhancing empowerment and social capital through the Internet network for those already burdened with disadvantage and marginalisation could be a potential means to narrow the current digital divide in regional Australia.

Although the Internet has the potential to generate social capital, and social capital may potentially reduce digital divide in Australia, in particular, in regional Australia (Notely and Foth, 2008; Zhao and Lu, 2012), no recent study has examined the role of Internet use in generating social capital in a regional Australian context. Therefore, the objective of this study is to examine the effect of Internet use on social capital in the WDR of Queensland, Australia.

The remainder of this study is structured as follows: Section 2 presents the literature review; the methodology used in the study is discussed in Section 3; Section 4 provides the results; and the study concludes in Section 5 with a summary and conclusions.

## 2. Literature review

The relationship between social capital and Internet use has drawn attention from researchers who are interested in examining the social effects of the Internet (Neves, 2013).

The spectacular growth in the use of social networking sites has sparked a phenomenal increase in all types of social networks (Van Deuresen et al., 2015; Van Dijk, 2013). These social networks have significantly boosted social connectivity, resulting in the creation of social capital. Since social capital is a predictor of academic performance, social cohesion, wellbeing and community engagement (Neves and Fonseca, 2015; Neves, 2013; Zin and Ericson, 2008), researchers have used it as a conceptual tool to examine the social effects of the Internet. With the exception of some studies that have demonstrated the negative effects of the Internet (Kim et al., 2011; Turkle, 2011), most empirical studies to date have indicated a positive association between social capital and the Internet (Antoci et al., 2012; Boase et al., 2006; Neves, 2013; Robinson and Martin, 2010; Wang and Wellman, 2010; Xie, 2014).

Recent data confirms that the rural and remote areas in Australia are in a disadvantaged position in terms of various socioeconomic indicators, compared to their urban counterparts (ABS, 2013a). Charleson (2013) suggested that enhancing empowerment and social capital through the Internet network for those already burdened with disadvantage and marginalisation could be a potential option for narrowing the current digital divide in Australia.

Digital divide is currently considered to be caused by more than just inequality in access to technology. Different demographics, ICT needs, capabilities and skills need to be better understood if they are to be aligned with realistic social policy goals (Notely and Foth, 2008). Internet use increasingly enhances the opportunities for social support. It has the potential to generate social capital which, according to Putnam (1993, p. 37), is defined as ‘the features of social organization such as trust, norms and networks that can improve the efficiency of society by facilitating coordinated actions’. One can acquire social capital through purposeful actions and can transform social capital into conventional economic gains. The ability to do so, however, depends on the nature of the social obligations, connections and networks available.

It has been strongly recommended that a successful digital divide policy be included in the social capital framework of Australia (Notely and Foth, 2008). There has been a significant increase in the use of various social networking sites (SNSs) that affect our social, political and economic lives (Ferreira-Lopez et al., 2012), and Kyujin (2013) suggested that online social network services supported by rural Information and Communication Technology (ICT) policy relate to social capital. Several earlier studies addressed the potential of the Internet to generate social capital in Australia on a limited scale, and only a few of these studies (Meredyth et al., 2004; Hopkins, 2005; Fernback 2005; Foth and

Podkalicka, 2007) concluded that ICT use may have a positive impact on an individual's social inclusion and on a community's collective social capital. However, most of these studies were descriptive and dated with regards to policy relevance. Selwyn and Facer (2007) argued that ICT lies at the heart of most of the activities that are seen to constitute 'social inclusion', from playing an active role in one's neighbourhood and community to maintaining one's personal finances.

Simpson (2009) emphasised the interplay between physical infrastructure, soft technologies and social capital for successful implementation, widespread uptake, greater social inclusion and the sustainability of ICT initiatives. Servon (2002) argued that technology is a tool of inclusion or exclusion; she noted that technology includes certain classes of people while excluding others. DiMaggio et al. (2001) argued that the Internet builds social capital by enhancing the effectiveness of community-level voluntary associations.

These findings led to a discussion of what is known as 'network society thesis' (Barney, 2004; Castells, 2000). The central idea of 'network society thesis' is that contemporary social, political and economic practices, institutions and relationships are organised through and around network structures (Barney, 2004; Castells, 2000). The 'network society thesis' is a useful tool to understand new forms of Internet use, because it connects with and then extends the concept of the information society. The arrival of the Internet technology resulted in a significant expansion of network communication (Wellman, 2001; Castells, 2001). Online interactions contribute to the accumulation of Internet social capital (Antoci et al., 2012). A salient feature of this capital is that it allows one to benefit from another's participation through the act of communication, a message or posting a photo, even when the person who did this is offline. Internet social capital also benefits Internet non-users by the information spill-over. Furthermore, the Internet enables new forms of social interaction contributing towards people's inclusion in society (Vosner et al. 2016).

In summary, the above review reveals that there is a significant gap in the literature regarding the Internet–social capital relationship in a regional Australian context, despite several studies investigating the effects of different factors on social capital. No recent study has carried out any in-depth analysis on the empirical link between Internet usage and social capital in regional Australia, although digital divide is best understood from the socioeconomic context related to the issue of social capital (Charleson, 2012) and social inclusion resulting from Internet use is reflected in digital divide discourse. Therefore, the research question this study addresses is: 'Does Internet use stimulate the accumulation of social capital in regional Australia?'

## 3. Methodology

### *3.1 The model*

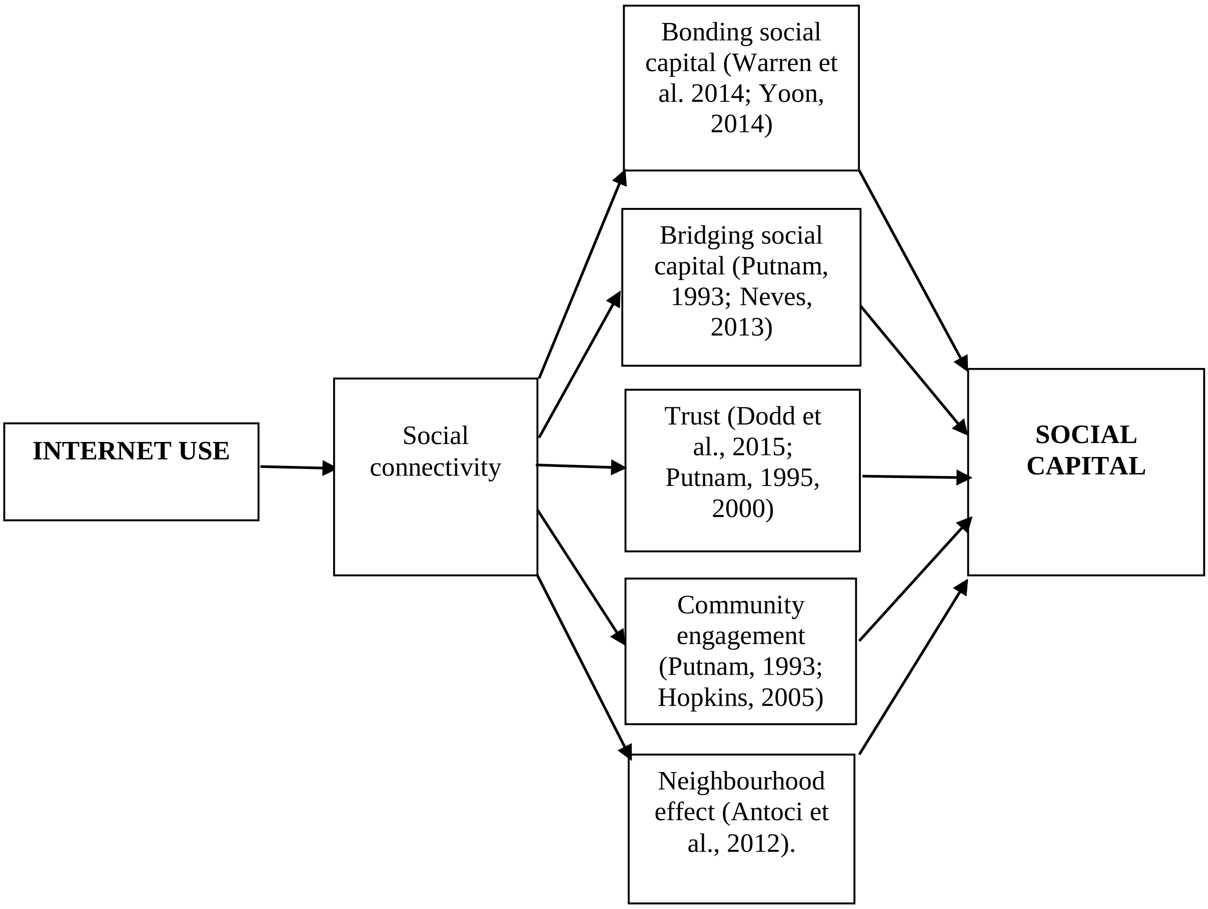
Based on the premise that Internet use potentially builds social capital, this study investigated the effect of Internet use on social capital. Therefore, social capital is hypothesised to be impacted by Internet use. Thus, the functional form of the base model is:

$$SC= F(NET)$$

Most studies (Antoci et al., 2012; Granovetter, 1973, 1974; Hampton, 2011; Neves and Fonseca, 2015; Neves, 2013; Putnam, 1993, 2000; Warren et al. 2014) that have investigated the effect of the Internet on social capital used only two core dimensions – bonding social capital and bridging social capital – for measuring social capital. Drawing upon the theories of social capital to explain the association between Internet use and social capital, this present study considered five key dimensions of social capital: bonding social capital (Antoci et al., 2012; Putnam, 1993, 2000; Warren et al., 2014; Yoon, 2014), bridging social capital (Granovetter, 1973, 1974; Hampton, 2011; Neves and Fonseca, 2015; Neves, 2013; Putnam, 1993, 2000; Warren et al., 2014), trust (Bock et al., 2012; Dodd et al., 2015; Fukuyama, 1995a; 1995b; Glaeser et al., 2008; Knack and Keefer, 1997; Ng et al., 2014; Putnam, 1995, 2000; Coleman, 1998; Zak and Knack, 2001), community engagement (Coleman, 1998; Foth and Podkolicka, 2007; Fernback, 2005; Hopkins, 2005; Meredyth et al., 2004; Putnam, 1993, 2000) and the neighbourhood effect (Antoci et al., 2012; Selwyn and Facer, 2007). The total number of hours of Internet use per week was used for the Internet use variable.

Figure 1 demonstrates the conceptual model of this study. The Internet, primarily, is a useful networking tool that generates a network of networks. According to the network society thesis (Barney, 2004; Castells, 2000), contemporary social, political and economic institutions and relations are organised through and around network structures. The arrival of the Internet revolutionised network connectivity. This network of networks not only helps people connect in the virtual world but also facilitates social interaction in the real world. It also provides a set of useful tools for the proliferation of online social engagement (Zhong, 2014); thus, it enables new forms of social interaction, increasing digital inclusion in society (Vosner et al., 2016). Internet usage generates social capital through networks of relations between people and different communities (Lippert and Spagnolo, 2011). Through its networking potential, the Internet allows people to be part of large networks of interest, to interact with people within their group or from outside their group, develop ties and friendships with them and strengthen existing ties (Neves and Fonseca, 2015). The interaction through the Internet network enhances both bonding and bridging social capital – two core dimensions of social capital – through online connectivity (through email, instant messaging, social networking sites, Skype etc.). The Internet, through online connectivity, also helps build and strengthen online trust through frequent social interaction (Warren et al., 2014). It further helps build a network of association with the members of a neighbourhood (Antoci et al., 2012; Selwyn and Facer, 2007) and enables community engagement (Coleman, 1998; Putnam, 1993, 2000). Therefore, the sequential flow of the conceptual model presented in Figure 1 below focuses, first of all, on the networking feature of the Internet and then proceeds to demonstrate how it affects the five important dimensions of social capital; in other words, how its networking feature results in the creation of social capital.

**Figure 1: Conceptual framework of the proposed Internet–social capital model**




*3.2 Survey area*

The research area selected for this study was the Western Downs Region (WDR) in Queensland, Australia, which was used as a potential case for assessing the Internet–social capital association. The WDR is one of the 20 largest Council areas in Queensland. The region is regarded as one of the emerging energy- and resource-based areas in Australia, and is also known as the energy capital of Australia. The area is rich in natural resources and is dominated by the booming mining sector, agriculture, forestry and fishery. The region is expected to witness a potential investment of $140 billion in the mining industry over the next 10 years. It represents 21% of Australia's gross regional product.

Baum et al. (1999) analysed Census data for all urban areas in Australia to develop measures of economic opportunity, with the geographic unit of analysis being urban Statistical Local Areas (SLAs) which include an urban centre. Each of the SLAs was assigned a score, and each community was ranked based on these scores reflecting its socioeconomic status relative to those of the other communities in the study. Tara, Dalby and Chinchilla – the major towns within the WDR – were identified as SLAs in this study, having Index of Relative Socioeconomic Disadvantage (IRSD) scores of 918.43, 989.52 and 980.14, respectively. These scores are neither at the bottom of the disadvantaged group of regions in Australia nor in the top quintile of disadvantaged groups; therefore, WDR is believed to be representative of other regions in Australia. According to the Rural, Remote and Metropolitan Areas (RRMA) classification criteria (AIHW, 2004), WDR is recognised as a typical Australian region that consists of both rural urban centres and remote urban centres. The three larger towns of Dalby, Chinchilla and Tara were chosen as rural urban centres and other smaller towns were considered to be rural remote centres. In accordance with the proportion of population sizes, the majority of the survey data were obtained from these towns of Dalby, Chinchilla and Tara (over 75%); the rest of the data were obtained from other relatively smaller towns. Despite significant economic potential, the region lacks business diversity compared to urban areas. The NBN rollout can play a significant role in accelerating business and economic activities and reducing the backwardness in technology access within this area.

*3.3 Survey instrument*

The instrument used in this study was a self-administered questionnaire. The questionnaire was derived from extensive literature reviews and expert opinion. A series of pilot tests enabled the completion of the final draft of the questionnaire after necessary corrections and modifications.

*3.4 Target population*

The target population was all households living permanently in the WDR. People floating from and to the region, such as fly-in fly-out, drive-in drive-out or migrant workers temporarily living in the region, were excluded from the sample. Initially, residents were contacted by phone (using the Electronic White and Yellow Pages directories). Once a household gave its consent to participate in the survey, the list of population participants was then finalised. The sample size and the inclusion of all household residents, with the exception of those who refused to participate in the survey, enabled this to become the study population.

*3.5 Sampling and recruitment*

Sample selection was based on the geographic distribution of the household and was representative of the households in the region. A list of households in the entire region was obtained from the Western Downs Regional Council (WDRC) and a total of 2000 addresses were randomly selected. Questionnaires were distributed to these addresses in person and also through a web-based version of the survey, which was made available to facilitate an online survey. Residents over 18 years of age were invited to complete the survey questionnaire. Three larger towns of Dalby, Chinchilla and Tara were chosen as rural urban centres and other smaller towns were considered rural remote centres. Only 422 survey questionnaires were returned, from which we had to eliminate 12 surveys due to a large amount of missing values, eventually resulting in 410 completed survey questionnaires. The final sample size was 410 household residents. The entire process of data collection began in early April 2014 and ran through to the end of August 2014.

*3.6 Participants*

A total of 410 participants completed the survey. Of these, 355 were Internet users (around 89%); 54% of the respondents were female; and the remaining 46% were males. Participants were from a range of age groups starting from 18 years up to 65 years and above. The sample was dominated by participants belonging to the age groups 45–54 and 35–44 years (21.7% and 19.51%, respectively). Fifteen per cent (15%) of the respondents were 65 years or older, and this group has the highest percentage of people who do not have any Internet connection. It was evident from the socio demographic profile of Internet non-users that although digital divide associated with gender is declining in regional Australia, digital divide with respect to age, income and education still threatens the Australian digital landscape, especially in rural and regional areas. This study used data of 353 respondents out of 355 Internet users, as two of them did not fill in the questionnaire appropriately.

*3.7 Measures of variables*

Although there are numerous studies on social capital, only a couple of studies to date (Williams, 2006; Yoon, 2014) have provided a scale of social capital. The present study applied the summated scale method (Sufian, 2009), for the first time in the literature, to measure the dependent variable – social capital. It used four items each for bonding and bridging capital. Bonding social capital refers to resources arising from social interaction from strong ties. It usually takes place within homogeneous groups such as among family members and close-knit relations (Hampton, 2011; Williams, 2006), and such ties facilitate moral and emergency support when needed. On the other hand, bridging social capital results from weak ties. This kind of relationship exists among a relatively diverse and heterogeneous group of people (Hampton, 2011). It refers to resources available from another social networks outside the close networks.

This study further used three items each for community engagement and neighbourhood effect, and two items for trust. Since there are two overlapping items (trust and bonding capital and trust and bridging capital), a total of 14 items were considered, which were measured based on a 5-point Likert scale, where 1=strongly disagree and 5=strongly agree. The scale values of the 14 items were then summated for each of the 353 respondents. Therefore, the scale value of social capital is expected to be within the range of 14 and 70. Total number of hours of Internet use per week by each respondent was considered to measure the variable, Internet use. Age and income of the respondents were also considered in the study as control variables.

## 4. Results

### *4.1 Reliability and validity of the dimensions of social capital*

Table 1 reports commonality scores. The scores for all 14 items are greater than 0.5, which enabled this study to retain all the items for all five dimensions of social capital. The reliability scores (Chronbach's alpha) for four of the five dimensions are higher than 0.7 and thus confirm internal consistency. Since trust is the most powerful dimension of social capital both theoretically and empirically, it was retained in our study despite its relatively low but acceptable reliability score (.559). The reliability scores are reported in Table 2.

**Table 1: Commonality scores**

| Items | Neighbour. 1 | Neighbour. 2 | Neighbour. 3 | Commu. 1 | Commu. 2 | Commu. 3 | Bond. 1 | Bond. 2 | Bond. 3 | Trust 1 | Trust 2 | Brid. 1 | Brid. 2 | Brid. 3 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Initial | 1.000 | 1.000 | 1.000 | 1.000 | 1.000 | 1.000 | 1.000 | 1.000 | 1.000 | 1.000 | 1.000 | 1.000 | 1.000 | 1.000 |
| Extraction | .768 | .764 | .642 | .822 | .808 | .849 | .612 | .660 | .598 | .416 | .274 | .517 | .626 | .611 |

**Table 2: Reliability scores**

| Variable name | No. of Items | Cronbach's Alpha |
|---|---|---|
| Neighbourhood effects | 3 | .769 |
| Trust | 2 | .559 |
| Bonding social capital | 4 | .803 |
| Bridging social capital | 4 | .808 |
| Community engagement | 3 | .936 |

The Kaiser-Meyer-Olkin (KMO) (Kaiser, 1960) sampling adequacy test for all dimensions confirmed that the sample size of this study is appropriate for factor analysis, since all the KMO values are larger than 0.5. Bertlett's sphericity tests confirmed that there is statistically significant correlation between the dimensions, which also allows factor analysis. Results from the KMO and Bertlett's tests are presented in Table 3.

**Table 3: Kaiser-Meyer-Olkin measure of sampling adequacy and Bertlett's test of sphericity results**

| Dimensions of social capital | Kaiser-Meyer-Olkin Measure of Sampling Adequacy | Bartlett's Test of Sphericity approximate Chi-Square | Degrees of freedom | Significance *(p)* |
|---|---|---|---|---|
| Neighbourhood | .616 | 225.695 | 3 | .000 |
| Trust | .500 | 67.996 | 1 | .000 |
| Bonding social capital | .743 | 589.317 | 2 | .000 |
| Bridging social capital | .784 | 517.927 | 2 | .000 |
| Community engagement | .770 | 1031.080 | 3 | .000 |

Table 4 reports results from factor loadings obtained from Principal Component Analysis (PCA). It shows that all five measures of social capital have both construct validity and convergent validity, since both the factor loadings (bold-faced factors in Table 4) and average variance extraction (AVE) exceed the threshold value of 0.5. Table 4 shows the correlation matrix. The eigenvalues of all factors considered are larger than 1 except for trust.

**Table 4. Results from factor loadings based on Principal Component Analysis (PCA)**

| | | | | | | Eigenv. | Var.exp (cum) | Alpha | AVE |
|---|---|---|---|---|---|---|---|---|---|
| Neighbour 1 | **.541** | -.022 | -.004 | .320 | .342 | | | | |
| Neighbour 2 | **.999** | -.008 | .000 | .426 | .999 | 6.204 | 44.315 | .769 | .698 |
| Neighbour 3 | **.537** | .503 | -.142 | .498 | .553 | | | | |
| Community 1 | .309 | **.809** | -.267 | .764 | .829 | | | | |
| Community 2 | .302 | **.823** | -.241 | .775 | .851 | 2.331 | 71.084 | .936 | .793 |
| Community 3 | .346 | **.817** | -.262 | .793 | .862 | | | | |
| Bonding 1 | .249 | .675 | **.542** | .619 | .722 | | | | |
| Bonding 2 | .195 | .685 | **.525** | .642 | .778 | 1.427 | 84.392 | .803 | .642 |
| Bonding 3 | .217 | .564 | **.501** | .485 | .570 | | | | |
| Trust 1 | .131 | .517 | .305 | **.506** | .491 | .733 | 93.911 | .559 | .406 |
| Trust 2 | .123 | .383 | .023 | **.497** | .316 | | | | |
| Bridging 1 | .109 | .590 | .268 | .467 | **.581** | | | | |
| Bridging 2 | .141 | .649 | .311 | .546 | **.637** | 1.541 | 97.795 | .808 | .546 |
| Bridging 3 | .204 | .475 | .401 | .420 | **.501** | | | | |

To confirm discriminant validity of the dimensions of social capital, the correlation matrix was required, as demonstrated by Table 5. In order to test discriminant validity, the square roots of the AVEs were compared with correlation coefficients. All five dimensions of social capital have discriminant validity, since square-rooted values of AVEs are greater than the correlation coefficients. All these findings on the dimensions initially chosen in this study to measure the social capital variable allow the quantitative measurement of the social capital variable with the summation of the scale values of these dimensions.

**Table 5: Correlation matrix of the dimensions of social capital**

| Dimensions | Neighbour | Community | Bonding | Bridging | Trust |
|---|---|---|---|---|---|
| Neighbour | 1.000 | .411 | .292 | .250 | .261 |
| Community | .411 | 1.000 | .622 | .577 | .449 |
| Bonding | .292 | .622 | 1.000 | .816 | .644 |
| Bridging | .250 | .577 | .816 | 1.000 | .460 |
| Trust | .261 | .449 | .644 | .460 | 1.000 |

*4.2 Descriptive statistics and multicollinearity*

Table 6 provides descriptive statistics of all variables. The mean value of social capital is 44.70 and standard deviation is 11.72. Each respondent, on average, uses the Internet for slightly over 15 hours a week. The standard deviation is 12.51, which is quite high and does represent significant variation in Internet use among the users. Descriptive statistics on age and income are reported in Table 6.

**Table 6: Descriptive statistics**

| | SC | NET USE (Hours) | INCOME ($000) | AGE |
|---|---|---|---|---|
| Mean | 44.70799 | 15.43182 | 82.78147 | 43.69421 |
| Median | 46.00000 | 15.50000 | 69.99950 | 39.50000 |
| Maximum | 70.00000 | 45.00000 | 170.0000 | 77.50000 |
| Minimum | 14.00000 | 2.250000 | 9.990000 | 21.00000 |
| Std. Dev. | 11.72604 | 12.51150 | 49.72106 | 14.89132 |
| Skewness | -0.454501 | 1.003750 | 0.539606 | 0.398144 |
| Kurtosis | 3.064958 | 2.979278 | 2.287348 | 2.657612 |
| | | | | |
| Jarque-Bera | 12.56137 | 60.96104 | 25.29765 | 11.36346 |
| Probability | 0.001872 | 0.000000 | 0.000003 | 0.003408 |
| | | | | |
| Sum | 16229.00 | 5601.750 | 30049.67 | 15861.00 |
| Sum Sq. Dev. | 49775.05 | 56666.63 | 894930.4 | 80274.06 |
| | | | | |
| Observations | 353 | 353 | 353 | 353 |

Before performing OLS regression analysis, it is imperative to know that the explanatory variables are free from the threat of multicollinearity. Variance Inflation Factor (VIF) results, as reported in Table 7, indicate that the model is absolutely free from any multicollinearity problem as all the VIF values are far less than 5. Also diagnostic tests such as Heteroscedasticity test and Kolmogorov-Smirnov Normality tests are performed. The results are presented in Table 8 and Table 9. Results confirm the rationale for performing regression analysis as the model passes all the diagnostic tests.

**Table 7. Multicollinearity**

| Variable | Tolerance | VIF |
|---|---|---|
| Average household income | .968 | 1.033 |
| Participant's age group | .991 | 1.009 |
| Hours spent per week on the Internet | .962 | 1.039 |

**Table 8: Heteroscedasticity test**

**Model Summary[f]**

| Model | R | R Square | Adjusted R Square | Std. Error of the Estimate | Durbin-Watson |
|---|---|---|---|---|---|
| 1 | .844[a] | .712 | .711 | 7.33353 | |
| 2 | .945[b] | .894 | .893 | 4.45850 | |
| 3 | .980[c] | .960 | .960 | 2.73462 | |
| 4 | .990[d] | .981 | .981 | 1.88721 | |
| 5 | .998[e] | .995 | .995 | .95719 | 1.832 |

a. Predictors: (Constant), Bonding

b. Predictors: (Constant), Bonding, Neighbour

c. Predictors: (Constant), Bonding, Neighbour, Community

d. Predictors: (Constant), Bonding, Neighbour, Community, Bridiging

e. Predictors: (Constant), Bonding, Neighbour, Community, Bridiging, Trust

f. Dependent Variable: SocialCapital

**Table 9: Normality test**

| | Kolmogorov-Smirnov[a] | | | Shapiro-Wilk | | |
|---|---|---|---|---|---|---|
| | Statistic | df | Sig. | Statistic | df | Sig. |
| SocialCapital | .083 | 406 | .000 | .921 | 406 | .000 |
| Neighbour | .106 | 406 | .000 | .916 | 406 | .000 |
| Community | .134 | 406 | .000 | .891 | 406 | .000 |
| Bonding | .073 | 406 | .000 | .940 | 406 | .000 |
| Bridiging | .093 | 406 | .000 | .963 | 406 | .000 |
| Trust | .134 | 406 | .000 | .846 | 406 | .000 |

*4.3 Regression analysis*

Regression analysis results are reported in Table 10. These show that there is a positive significant association between Internet use and social capital. The Internet use coefficient suggests that a 1% change in Internet use would stimulate a 0.18% change in social capital. Income does not have any significant effect on social capital. Such a finding clearly indicates that the Internet has become cheaper and the digital divide due to income is shrinking in regional Australia. A negative significant association is observed between social capital and age. This implies that older people spend relatively less time on social interaction through the Internet.

**Table 10. Regression analysis (Dependent variable: social capital)**

| Variable | Coefficient (*Beta)* | t- Statistics | Sig(*p*) |
|---|---|---|---|
| Constant | | 18.041 | .000 |
| Average household income | -.013 | -.260 | .795 |
| Participant's age group | -.166 | -3.245 | .001 |
| Hours spent per week on the Internet | .188 | 3.621 | .000 |
| F-stat | | 8.689 | .000 |
| R Square | .068 | | |
| Adjusted R Square | .060 | | |

## 5. Summary and conclusions

This study analysed the effect of Internet use on social capital using survey data on household Internet users in the WDR of Queensland, Australia. It makes a novel contribution to the existing literature on the measurement of social capital by quantifying the social capital variable through the summation of the scale values of its five statistically tested dimensions drawn from social capital theories; most previous studies used two or three dimensions for the measurement of social capital. Based on these five dimensions, a conceptual framework was also developed on the linkage between Internet use and social capital. Nevertheless, this study is believed to be the first such in-depth investigation of the Internet use–social capital association in a regional Australian context.

This empirical exercise regressed Internet use on social capital while controlling for two variables – income and age. A positive significant association was found between Internet use and social capital. No significant relationship was observed between income and social capital. There is significant negative association between age and social capital.

These findings have very important policy implications for regional Australia. Since the Internet is believed to be able to generate social capital, and social capital may potentially reduce digital divide through social inclusion of relatively disadvantaged and marginalised people across rural and regional Australia, the finding of this study of a positive association between Internet use and social capital renews the call for inclusion of social capital into the digital divide policy of Australia.

Recent literature suggests that the gender divide is shrinking in Australia. The insignificant association between Internet use and income evident from this study implies that Internet use has become cheaper in regional Australia, signalling that this income divide is also narrowing. It is a success that perhaps resulted from various digital divide policies that Australia has been pursuing over the years to expand Internet network coverage so as to make it available to regional and rural people at an affordable cost. While one of the main goals of the current rollout of the NBN is to reduce digital divide by addressing the ability of people in rural and regional communities to access broadband internet, various schemes to promote social participation through online Internet-based social networking among the rural and regional people should also be considered. Finally, this paper resolves to some extent the dichotomy between the Internet expansion on one hand and the resulting creation of digital underclass on another. In other words, this study has unlocked the potential of the Internet itself to reduce self-created digital divide through digital inclusion in regional Australia.

Despite the significant contributions of this study, some caveats are in order. First, the generalisability of the findings of this study to other regions of Australia may be limited, as different regions are likely to vary in terms of their economic and social indicators. Social inclusion through social participation may even cause isolation of certain groups of people, thus resulting in group fragmentation – also called cyber-balkanization. In other words, social inclusion of some people should not be at the cost of social exclusion of others. Policymakers need to pay attention to this issue. Finally, the finding of this positive relation between Internet use and social capital may not hold in other contexts as empirical evidence also suggests negative effect of the Internet on social capital, in other words, the Internet may even contribute towards reduction in social capital.

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# CHAPTER FIVE
# PAPER 6 AND PAPER 7

## PAPER 6: INFORMATION AND COMMUNICATION TECHNOLOGY, ELECTRICITY CONSUMPTION AND ECONOMIC GROWTH IN OECD COUNTRIES: A PANEL DATA ANALYSIS

## PAPER 7: INTERNET USAGE, ELECTRICITY CONSUMPTION AND ECONOMIC GROWTH IN AUSTRALIA: A TIME SERIES EVIDENCE

# PAPER 6: INFORMATION AND COMMUNICATION TECHNOLOGY, ELECTRICITY CONSUMPTION AND ECONOMIC GROWTH IN OECD COUNTRIES: A PANEL DATA ANALYSIS

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## Statement of Contributions of Authorship

To whom it may concern

I, Mohammad Salahuddin contributed 80% to the paper entitled above and mentioned below;

Salahuddin, M. & Alam, K., (2016), Information and communication technology, electricity consumption and economic growth in OECD countries: A panel data analysis', *Electrical Power and Energy Systems*, 76: 185–193.

Signature of Candidate: Date: February 17, 2016

I, as a coauthor recognize and accept that the contribution of the candidate indicated above for the above mentioned PhD output is appropriate.

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# Information and Communication Technology, electricity consumption and economic growth in OECD countries: A panel data analysis

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ABSTRACT

This study estimates the short- and long-run effects of Information and Communication Technology (ICT) use and economic growth on electricity consumption using OECD panel data for the period of 1985–2012. The study employs a panel unit root test accounting for the presence of cross-sectional dependence, a panel cointegration test, the Pooled Mean Group Regression technique and Dumitrescu–Hurlin causality test. The results confirm that both ICT use and economic growth stimulate electricity consumption in both the short- and the long run. Causality results suggest that electricity consumption causes economic growth. Both mobile and Internet use cause electricity consumption and economic growth. The findings imply that OECD countries have yet to achieve energy efficiency gains from ICT expansion. Effective coordination between energy efficiency from ICT policy and existing emissions reduction policies have the potential to enable OECD countries reduce environmental hazards arising from electricity consumption for ICT products and services. Introducing green IT and IT for green are also recommended as potential solutions to curb electricity consumption from ICT use especially in the data centers.



## Introduction

Information and Communication Technologies (ICTs) have a wide array of effects on key global systems such as energy and economic systems [28]. The rapid use and expansion of these technologies have a number of economic consequences ranging from increasing productivity, boosting economic growth [46] to reducing corruption [16]. As a result the world is rapidly moving from offline to online. The United Nations Development Program (UNDP, 2001) acknowledged that the Internet improves market efficiency, creates economic opportunities, enhances productivity and promotes political participation. Because of its increasingly important role in human activities, United Nations [50] declared that access to the Internet is one of the basic human rights in the contemporary society. According to Greenpeace International report [18], the global online population will increase from 2.3 billion in 2012 to 3.6 billion in 2017.

The OECD governments are funding rollouts worth billions of dollars for further expansion of the ICT use [49]. ICT use especially the Internet use has been transforming the economies of the OECD countries since the last two decades [55].

ICT use especially the Internet use and the use of mobile cellular phone have been expanding in the OECD countries at a phenomenal speed. The trends of change in these variables [51] during the last two decades are depicted in Figs. 1 and 2.

But all these expansions and the increasingly important role of ICT in the OECD economies are not expected to be without opportunity cost. The expansion of the ICTs has important environmental implications. As such, the studies investigating the energy impacts of ICTs have been profoundly researched in a macro framework [39]. Although the rapid expansion of ICT usage is believed to improve productivity and energy efficiency, there is no consensus as yet on its effect on the environment. Some of the studies support the positive role of ICT in mitigating greenhouse gas emissions while others conclude that ICT use causes GHG emissions through the increased use of electricity which is one of the major sources of global $CO_2$ emissions [20,28,24].

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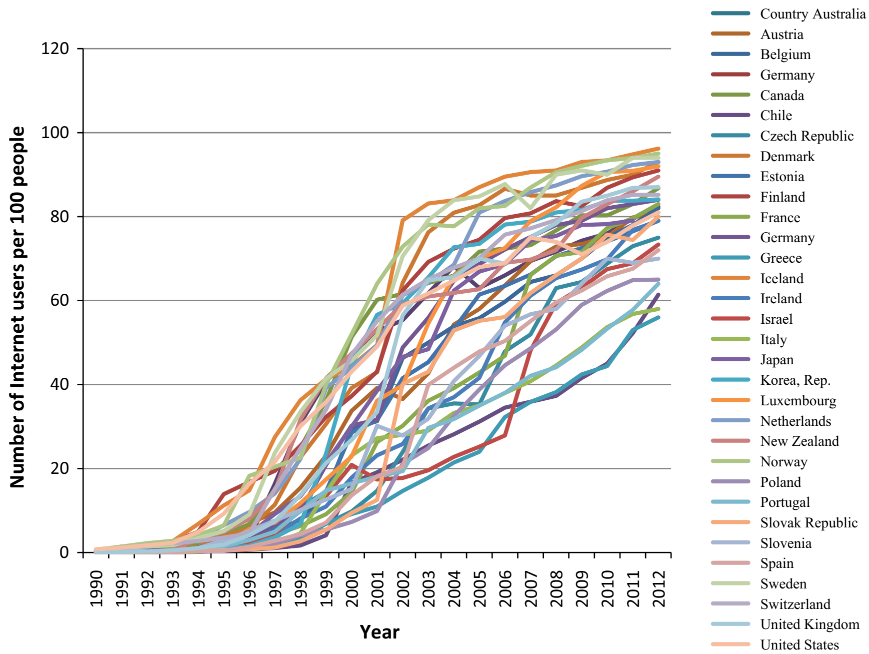


**Fig. 1.** Trends in the Internet usage in OEDC countries during 1990–2012. *Source:* The World Development Indicators Database, The World Bank [51].

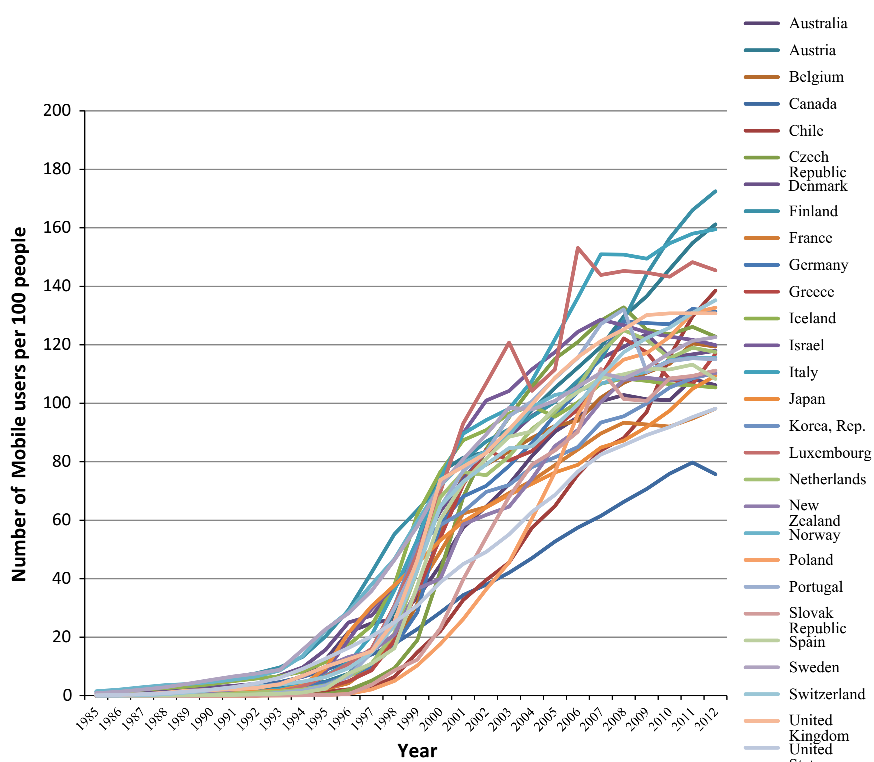


**Fig. 2.** Trends in the Mobile usage in OEDC countries during 1985–2012. *Source:* The World Development Indicators Database, The World Bank [51].

According to some estimates [18], ICT industry is responsible for 2% of global $CO_2$ emissions.

The OECD economies are characterized by the highest level of energy consumption in the world and electricity is one of the key sources of this huge energy supply [44]. The same authors argue that 80% of the power generation in the region is still sourced from non-renewable fossil fuels such as coal and gas in these countries. As a result, there has been a sharp increase in $CO_2$ emissions. Nevertheless, the rapid expansion of ICT use in the region is likely to have significant energy impacts as ICT products and services cannot be operated without electricity. Since no work has so far investigated this impact before, this study is the first ever attempt to examine the short- and long-run effects of ICT use on electricity consumption in a panel of OECD countries.

The current study also includes economic growth as an independent variable in the study. The reason for including economic growth is that usually simple bivariate models may fail to appropriately capture empirical relationship between the series [26,5]. Also, since the mid-eighties and following the second oil shock, enormous literature investigating the relationship between economic growth and electricity consumption evolved [20]. Therefore, assessing the impact of economic growth on electricity consumption has been an important area that has drawn special attention in research since long. Nevertheless, there is no recent literature investigating this relationship in the context of OECD countries. Thus, the inclusion of economic growth in our study is justified.

There are a number of expected contributions of this study to the existing energy, ICT and growth literature. First, it is believed that following Sadorsky [39], this is only the second study that involves panel data to investigate the empirical relationship between ICT use and electricity consumption. The rationale for using panel data instead of time series data is quite obvious. In panel data estimations, the existence of unobservable factors that potentially affect electricity consumption and are country specific can be acknowledged and taken into account in the estimation [37]. Panel data also allows one to control for unobserved time invariant country specific effects resulting from omitted variable bias [22]. Second, the most important contribution of the current study is that the ICT use-electricity consumption relationship is being investigated for the first time ever for the OECD countries which house majority of the data centers in the world as a consequence of rapid expansion of ICT use since the last two decades. Third, although literature on the electricity-growth relationship is abundant, the economic growth-led electricity consumption hypothesis has not yet been examined for this region. Fourth, the current study uses the most recent data for its investigation thus expecting to offer time-befitting policy-oriented discussion. Fifth, it also makes a methodological contribution by employing a sophisticated and a potentially suitable panel data econometric technique, the Pooled Mean Group Regression (PMG) that has never been used before in ICT and energy economics literature. The novelty of this technique is that it simultaneously estimates the short- and the long-run relationship between the concerned variables controlling for endogeneity and small sample bias and sixth, unlike other studies, the findings of the study are expected to provide important implications at a time for ICT policy, energy policy and growth policy for the region of investigation.

The rest of the paper is structured as follows: Section "Literature review" discusses literature review, and methodology is presented in Section "Methods". Section "Empirical results and discussion" presents estimation results and finally the paper ends in Section "Conclusions and policy implications" with conclusions and policy implications.

## Literature review

### *Energy impacts of ICT*

ICT use may potentially impact the environmental basically in two different ways. First of all, during the production of IT products, a number of toxic and non-renewable resources such as lead and mercury are used which are very harmful and dangerous elements for the environment. Waste disposal from the electrical and electronic IT goods also contribute towards environmental pollution. Second, the widespread expansion of ICTs has caused dramatic rise in the demand for electricity over the last two decades. ICT related electricity consumption has increased significantly both in the workplaces and households [23]. The combined electricity consumption related to ICT equipments such as communication networks, personal computers and data centers is growing at a rate of nearly 7% per year [21]. The relative share of these ICT products and services in the global electricity consumption has increased from about 3.9% in 2007 to 4.6% in 2012 [21].

The residential electricity consumption related to ICT also increased significantly during the 1990s and this trend is expected to continue further. The International Energy Agency [23] state that the global residential electricity consumption by ICT equipment rose by nearly 7% per anum between 1990 and 2008 and consumption from electronics is set to increase by 250% by the year 2030. From these developments, ICT is viewed as a new round of electrification and thus has the potential to increase GHG emissions in an economy. A significant percentage of domestic electricity consumption in Europe is linked to the use of ICT products and services [14].

A recent development in ICT service, cloud computing which refers to as the interaction between telecommunications network and the data centers and involves the transfer of vast amount of data from the devices to the data centers require relatively higher level of electricity consumption. According to a recent report of the Greenpeace International [18], data centers will be the fastest growing part of IT sector energy footprint and its electricity demand is expected to rise by 81% by the year 2020. The aggregate electricity demand of the cloud was 684 billion kW h in 2011 and is forecasted to increase by 63% in 2020 (SMARTer2020 report). It also suggests that global carbon footprint of data centers and telecommunications networks would increase carbon emissions on average between 5% and 7% each year up to 2020. But if energy efficiency could be achieved leading to energy saving gains, the positive effect of energy efficiency might outweigh the negative effect of increased electricity consumption.

The environmental implications of ICT use has not drawn any attention from researchers until the early 1990s. Since the early 1990s, researchers started focusing first of all on the energy impacts of ICT use. Ever since, such impacts have been extensively examined in macro studies. One strand of literature directly studied the direct impact of ICT equipment on electricity consumption not least in relation to standby electricity use.

Another strand of literature focuses on the environmental impacts of the application of ICT in various economic domains. Firstly, it emphasizes the role of ICT in improving the environment. In the early 1990s, the potential of ICT to improve the environment was generally recognized. This followed profound researches in the area. Erdmann and Hilty [12] identify two 'green ICT waves' of empirical studies. The first one motivated by the rising Internet economy and the second one focused on the potentials of ICT in reducing GHG emissions. It is argued that ICT can play a significant role to mitigate global climate change through its ability to improve energy efficiency and reduce renewable energy costs [28].

Ever since, it is believed that the Internet economy has the potential to fundamentally alter the historic relationship-allowing faster growth with less energy. Romm [38] label this as the 'new energy economy'. Recently, scholars have attempted to combine ICT and sustainable development as they recognize these two factors to be closely intertwined. This perception eventually led to two recent concepts what are known as 'green ICT' and 'ICT for green'. ICT is said to be green when ICT sector itself can achieve environmental efficiency. ICT for green means when the use of ICT products and services can enhance the energy efficiency in other sectors. It is argued that green ICT can lead to sustainable development only when ICT themselves are green. ICTs are said to be green when they make eco-innovating contributions to ecological economics. According to Schumpeter [43], 'an eco-innovation is an innovation that is able to reduce environmental burdens and contributes to improving a situation according to given sustainable targets'. Despite tremendous potentials of ICT use in economies, its energy impact is mixed and no consensus has yet been realized.

*ICT and electricity consumption*

ICT-electricity consumption nexus is relatively an under-investigated area of research despite its potential implications for environmental sustainability. Most of the studies that have so far been conducted for developed economies are at the country level time series studies or at industry level cross-sectional studies [39].

Romm [38] in a study on the US economy shows that the Internet does not cause increase in electricity demand rather it seems to enhance energy efficiency. Schaefer et al. [42] show that the share of total energy consumption of German mobile telephone sector is only 7% when it did not include electricity use for charging of the handsets. When charging of the handsets is accounted for, the share stands at 45%. Takase and Murota [48] examine the effects of ICT investment on energy consumption and $CO_2$ emissions in Japan and USA. They find that ICT use boosts energy efficiency recommending energy conservation for Japan while for the USA, ICT investment is found to increase energy use.

Cho et al. [9] in a study employ logistic growth model to examine the effects of ICT investment on energy consumption and show that in the service sector and most of the manufacturing sectors, ICT investment increases electricity consumption. However, overall findings of the study support the hypothesis that increased use of ICT leads to increased efficiency. The European Commission E-Business Watch [13] conducts a comprehensive study on the effects of ICT on electricity in Austria, Germany, Denmark, Finland, France, Italy, Spain and the UK. It also conducts a number of case studies at firm level. The findings indicate that at the aggregate level, ICT use increases electricity consumption while at the micro level, it enhances energy efficiency. Heddeghem et al. [21] in a study examine the trend in worldwide electricity consumption and show that the absolute electricity consumption of three key ICT categories, namely, communication networks, personal computers and data centers, has increased in 2012 from its level in 2007.

In arguably the first empirical exercise on the direct association between Internet usage and electricity consumption, Salahuddin and Alam [40] examine the short- and long-run effects of the Internet usage and economic growth on electricity consumption using annual time series data for Australia for the period 1985–2012. The study finds that Internet usage and economic growth cause a rise in electricity consumption in the long-run. A unidirectional causality is observed running from Internet usage to economic growth and electricity consumption.

There is so far none but one panel study [39] which estimated the empirical relationship between ICT investment and electricity consumption in emerging economies. Using a dynamic panel model, it employed the Generalized Methods of Moments (GMM) technique to investigate the link between the ICT and electricity consumption for a sample of emerging economies. The study found that ICT use increases electricity consumption in these countries. One limitation of homogeneous panel data approaches such as the GMM technique that was employed in this study is that it allows the intercept to differ while constraining all other parameters to be the same thus still imposing a high degree of homogeneity ignoring the potential cross-sectional heterogeneity in the panel. Such method of homogeneity has the potential risk of producing biased results. The current study overcomes this limitation by employing a panel estimation technique that allows for cross-country heterogeneity.

Moyer and Hughes [28] use International Futures (IFs) integrated assessment system to explore the dynamic impacts of ICT on economic and energy systems including its impact on carbon emissions. They argue that ICT has the potential to reduce overall carbon emissions across a 50-year time horizon. However, they further caution that the net effect might be limited. The study recommends that global carbon pricing should be in place with ICT expansion.

From the above discussion, it is evident that literature on ICT-electricity consumption nexus is very inadequate although this nexus has significant implications for the environmental sustainability of countries and regions. The available scanty literature mostly dealt with time series country level data. Since, ICT use has rapidly expanded in the OECD countries and that these countries are homes to the majority of the world's data centers [15] for the last two decades, environmental threats arising from this expansion cannot be ruled out. The current study is believed to be the first ever attempt to investigate the empirical link between ICT use and electricity consumption in the OECD countries within a dynamic panel framework.

*Electricity consumption and economic growth*

Literature investigating the relationship between electricity consumption and economic growth is enormous. Since the pioneering work of Kraft and Kraft [27] that examined this relationship in the USA, plenty of literature in the area have emerged. Basically four main streams of literature evolved that investigated this relationship: (i) the electricity consumption-led growth hypothesis (growth hypothesis), (ii) the growth-led electricity consumption hypothesis (conservation hypothesis), (iii) feedback hypothesis, and (iv) neutrality hypothesis.

Most of the empirical studies tested the growth hypothesis and supported its validity [20]. Literature testing conservation hypothesis dealt with both time series and panel data. Different time series techniques such as Error Correction Model (ECM), Autoregressive Distributed Lag (ARDL), Variance Auto Regression (VAR), Dynamic Ordinary Least Squares (DOLS), Fully Modified Ordinary Least Squares (FMOLS) and panel techniques such as Panel cointegration, panel Granger causality and panel Vector Error Correction Model (VECM) were used to test the hypothesis.

Yoo [53] investigates the causal link between real GDP and electricity consumption in four ASEAN countries, namely Indonesia, Malaysia, Singapore and Thailand over the period 1971–2002. Findings indicate a bi-directional relationship for Malaysia and Singapore and a unidirectional relationship in Indonesia and Thailand. Wolde-Rufael [52] examines the causality between electricity consumption and GDP for 17 African countries over 1971–2001. He employed Toda-Yamamoto Granger causality and found that GDP per capita Granger causes electricity consumption for six countries. His findings indicate that electricity consumption Granger causes GDP for three countries and a bi-directional relationship also for three countries. For the rest four countries, he found no causal relationship.

Sqaulli [47] conducts causality testing for 11 OPEC countries using time series data for the period of 1980–2003 and found mixed results. Chen et al. [8] examine the causal relationship for 10 Asian countries. They employ panel causality tests based on the error correction model over the period of 1971–2001. They find a unidirectional short-run causality running from economic growth to electricity consumption and a bi-directional long-run causality between the variables. Narayan and Prasad [29] examined the causal effects between electricity consumption and real GDP for 30 OECD countries. They employ a bootstrapped causal testing method and find that electricity consumption causes real GDP in Australia, Iceland, Italy, the Slovak Republic, Korea, Portugal and the UK. For the rest of the countries, they conclude that electricity conservation policy will not affect real GDP.

Narayan et al. [30] investigate the long-run causality between electricity consumption and real GDP for seven panels consisting of a total of 93 countries. They conduct Canning and Pedroni long-run causality test for the first time in energy literature. They find long-run bi-directional causality for all panels except where only GDP Granger causes electricity consumption. There exist positive relationship between these variables in all the significant panels except in the then G6 countries which means that an increase in electricity consumption will reduce GDP.

Acaravci and Ozturk [1] examine the long-run relationship and causality issues for a panel of 15 transition economies. Their findings do not indicate any cointegrating relationship between electricity consumption and economic growth implying that policies aiming to reduce electricity consumption would have no effect on real GDP in these countries. Ozturk [31] provides a comprehensive survey of the empirical studies on electricity-growth nexus up to the year 2009. The survey highlights the methodologies used in these studies and focused on the conflicting results from these empirical exercises. The study concludes that application of new approaches and new methodologies would reduce the variation in results that will eventually lead to sound and consistent policy discussions.

Yoo and Kwak [54] investigate the causal relationship between electricity consumption and economic growth for seven South American countries for the period of 1975–2006. They find unidirectional, bi-directional and no causal link for different countries across the region. Ciaretta and Zarraga [10] use annual data to investigate the long-run and causal relationship between electricity consumption and real GDP for a panel of 12 European countries for the period of 1970–2007. They estimate a trivariate VECM by GMM. The results show evidence of a long-run equilibrium and a negative short-run relationship between the variables. The findings further confirm bi-directional causality between energy prices and GDP and between electricity consumption and energy prices.

Apergis and Payne [4] undertake a study using a multivariate panel of 88 countries categorized into four panels based on the World Bank income classifications (i.e. high, upper-middle, lower-middle and low income) over the period of 1990–2006. The results reveal long-run equilibrium relationship between real GDP, coal consumption, real gross fixed capital formation and the labor force for the high, upper-middle and lower-middle income country panels. They also find bi-directional causal relationship for high-income and the upper middle-income country panels in both the short- and the long-run. Their findings further indicate unidirectional causal link in the short-run and bi-directional causal link for the lower middle-income country panel and unidirectional causality from electricity consumption to economic growth for the low-income country panel.

Bildirici and Kayikci [6] in a study of 11 Commonwealth Independent States (CIS) employ panel ARDL and the FMOLS methods to examine the causal relationship. They divide the panel of CIS countries into three sub-panels based on income levels. Their empirical findings confirm a cointegrating relationship between the variables in all groups. The results further indicate a unidirectional causal link running from electricity consumption to economic growth for all groups in the long-run. FMOLS and ARDL estimations show that the effect of electricity consumption on GDP is negative for the second group of countries while it is positive for the first group of countries supporting the growth hypothesis. Acaravci and Ozturk [2] performs an empirical exercise to determine the short- and long-run causality between electricity consumption and economic growth in Turkey during the period 1968–2006. The study finds evidence in support of the Growth hypothesis. The role of electricity in stimulating economic growth is also highlighted.

Cowan et al. [11] in a study on BRICS (Brazil, Russia, India, China and South Africa) find support for no causal link between electricity consumption and economic growth in Brazil, India and China. However there is unidirectional causal relationship from electricity consumption to economic growth in Russia and South Africa.

Bouoiyour et al. [7] provides a meta-analysis of the empirical results of 43 studies investigating electricity-growth nexus and published during the period 1996–2013. They suggest mixed findings from these studies. The study attribute these inconclusive findings to different country samples, econometric methodologies, etc. Using different approaches and introducing other relevant variables in the model in future studies are recommended to reduce the disparity in findings.

Salahuddin et al. [41] investigate the causal linkages among economic growth, electricity consumption, carbon dioxide emissions and financial development using panel data for the Gulf Cooperation Council Countries (GCC) for the period 1980–2012. Their findings indicate significant long-run relationship between economic growth, electricity consumption and financial development with carbon dioxide emissions.

Ozturk and Acaravci [32] address the short- and long-run causality issues between electricity consumption and economic growth in selected 11 Middle East and North Africa (MENA) countries using annual data for the period 1971–2006. The study did not find any evidence in support of the positive relationship between electricity consumption and economic growth for most of these countries.

From the above review, it is evident that electricity consumption and economic growth relationship has important implications for energy policy. Despite this importance, such studies involving the OECD countries is almost absent. Only one study [29] attempted to address this issue for the region so far. However, their study analyzed data up to the period of 2002 and as such, the findings of this work has little policy relevance in the present context. This study is expected to fill this gap by using the most recently available dataset (up to 2012).

## Methods

### *Data*

A dynamic panel dataset is constructed with 26 OECD countries. We deal with an unbalanced panel as some of the data for some countries are missing. Electricity consumption per capita, real GDP per capita and mobile cellular subscription data were obtained for the period of 1985–2012 while data for internet user per 100 people was available for the period of 1990–2012. A few missing values were observed in the Internet users per 100 people and mobile cellular users per 100 people series which were replaced by 3-year moving average values. Also, six OECD countries were dropped from our dataset for having too many missing values. All data were obtained from the The World Data Bank, 2013 (previously, The World Development Indicators database [51]). The variable per capita electricity consumption (EC) is measured by electric power consumption (kW h per capita), real GDP per capita (GDPPC) is measured at constant 2000 US$ and two measures of ICT usage, namely, the number of internet users per 100 people (ICTINTERNET) and the number of mobile cellular subscription per 100 people (ICTMOB) are considered for the study. All variables are expressed in natural logs.

Table 1 presents the descriptive statistics of all the variables. It reveals from the standard deviations that the data for all the series

**Table 1**
Descriptive statistics.

| Variables | Obs | Mean | Std. dev. | Min | Max |
|---|---|---|---|---|---|
| L electric power use (per capita) | 784 | 8.894 | 0.621 | 6.906 | 11.023 |
| L GDP (per capita) | 784 | 10.127 | 0.626 | 8.084 | 11.381 |
| L mobile cellular subscription | 784 | 13.498 | 4.494 | 0 | 19.552 |
| L Internet use (per 100 people) | 784 | 1.228 | 3.438 | −13.778 | 4.564 |

are fairly dispersed around the mean. This allows us to proceed with the data for further estimation.

Table 2 presents the correlation matrix. The correlation coefficients between all variables are moderate except between the number of the Internet users per 100 people and mobile cellular subscription per 100 people. However the high coefficient of 0.78 between these two variables do not pose any multi collinearity threat as these two variables are considered in two separate models as indicators of ICT use.

*Methodology*

*The model*

Following Sadorsky [39] and Narayan et al. [30], we propose and estimate an econometric model where electricity consumption is assumed to be a function of ICT use and economic growth in OECD countries. Therefore, the functional form of the model is:

$$\mathrm{EC} = F(A, \mathrm{ICT}, \mathrm{GDPPC}) \quad (1)$$

or

$$\mathrm{EC}_{it} = A.(\mathrm{ICT}_{it})^{\beta 1}(\mathrm{GDPPC}_{it})^{\beta 2} \quad (2)$$

Log-linearizing both sides of the equation, we obtain:

$$1/E \ln E = \beta_0 + \beta_1 \mathrm{ICTINTER}_{it} + \beta_2 \mathrm{GDPPC}_{it} + \varepsilon_{it} \quad (3)$$

$$\text{or, } \Psi \ln E = \beta_0 + \beta_1 \mathrm{ICTINTER}_{it} + \beta_2 \mathrm{GDPPC}_{it} + \varepsilon_{it} \quad (4)$$

When we measure the Internet with the number of mobile subscribers per 100 people, our model takes the form of:

$$\Omega \ln E = \beta_0 + \beta_1 \mathrm{ICTMOB}_{it} + \beta_2 \mathrm{GDPPC}_{it} + \varepsilon_{it} \quad (5)$$

The subscripts $i$, and $t$ represent the country and time period, respectively.

*Estimation procedures*

The estimation of our model proceeds as follows: (i) a cross-sectional dependence (CD) test is conducted to assess the presence of cross-sectional dependence across the panel; (ii) as the presence of cross-sectional dependence is detected, an appropriate panel unit root test (i.e., CIPS) is carried out to determine the stationarity properties of all the series; (iii) to see whether the variables have a cointegrating relationship between them, the Pedroni cointegration test is implemented and (iv) a PMG estimation is employed to estimate the short-run and long-run relationships among the variables.

*Tests for cross sectional dependence and unit roots*

It is extremely likely that there will be cross-sectional dependence among the OECD countries due to shocks such as global financial crisis or oil price shock, which affects all countries but with varying magnitude. To verify the existence of such dependence in the panel, the cross-sectional dependence (CD) test developed by Pesaran [35] is conducted. Pesaran [35] defines CD statistic as:

$$\mathrm{CD} = \left[\frac{TN(N-1)}{2}\right]^{1/2}\bar{\hat{\rho}},$$

where

$$\bar{\hat{\rho}} = \left(\frac{2}{N(N-1)}\right)\sum_{i=1}^{N-1}\sum_{j=i+1}^{N}\hat{\rho}_{ij}$$

in which $\hat{\rho}_{ij}$ is the pair-wise cross-sectional correlation coefficients of residuals from the conventional Augmented Dickey Fuller (ADF) regression and $T$ and $N$ are sample and panel sizes, respectively.

Having found the presence of cross-sectional dependence in the panel, an appropriate unit root test referred to as the cross-sectionally augmented IPS (CIPS) test was performed [36]. The test statistic provided by Pesaran [36] is given by:

$$\mathrm{CIPS}(N, T) = N^{-1}\sum_{i=1}^{N} t_i(N, T)$$

where $t_i(N,T)$ is the $t$ statistic of $\beta_i$ in Eq. (2). The critical values of CIPS($N,T$) are available in Table II(c) of Pesaran [36].

*Panel cointegration test*

The presence of the unit root in the series enforce us to conduct Pedroni test [33,34] which involves several panel cointegration tests for both models. Pedroni test is justified for this study as it controls for country size and heterogeneity allowing for multiple regressors (as in our case). Pedroni [33] provides seven panel cointegration statistics for seven tests. Four of these are based on the within-dimension tests, and the other three are based on the between-dimension or group statistics approach. To conserve space, the test statistics are not provided here (please refer to Pedroni [34] for detailed derivation of the statistics).

*3.2.5 Dumitrescu–Hurlin (DH) causality test*

Assessing the causal link between variables helps with a discussion of better policy implications of findings [45]. Taking into cognizance this fact, the current study employs a recently introduced Dumitrescu–Hurlin (DH) causality test which has two advantages over the traditional Granger [17] causality test. In addition to considering fixed coefficients like Granger causality test, the DH test considers two dimensions of heterogeneity: the heterogeneity of the regression model used to test the Granger causality and the heterogeneity of the causal relationship.

**Table 2**
Correlation matrix.

| Variables | L GDP (per capita) | L electric power use (per capita) | L Internet use (per 100 people) | L mobile cellular subscription |
|---|---|---|---|---|
| L GDP (per capita) | 1.000 | | | |
| L electric power use (per capita) | 0.755 | 1.000 | | |
| L Internet use (per 100 people) | 0.389 | 0.399 | 1.000 | |
| L mobile cellular subscription | 0.374 | 0.264 | 0.789 | 1.000 |

## 4. Empirical results and discussion

The CD test and unit root test results are demonstrated in Table 3. The CD results demonstrate that there is cross-sectional dependence in all the series considered in our study. This kind of dependencies usually arise from the presence of multiple unobserved common shocks that different countries respond in different ways. There may be strong factors such as oil price shocks or the global financial crisis and weak factors like local spill-over effects that contribute to such error dependencies. The CIPS unit root results confirm that all the variables are first-difference stationary, i.e. I(1), even in the presence of cross-sectional dependence.

Tables 4A and 4B present the results of the Pedroni panel cointegration test for model A and model B, respectively. All Pedroni test statistics except the v statistic have a critical value of −1.64. The v statistic has a critical value of 1.64. Table 4A shows that four out of seven test statistics support the presence of cointegration among the variables in model A. It is evident from Table 4B that the statistical values of six out of the seven tests are greater than the critical values (−1.64) which indicate that the null hypothesis of no cointegration is rejected. Nevertheless, among the seven test statistics, the group rho statistic has the best power [19], which is also greater than the critical value. Thus, it can be concluded that there is a long-run cointegrating relationship among the variables in model B. The presence of the cointegrating relationship between the variables in both models allow us to proceed with further investigation of the short- and the long-run relationship among them.

Tables 5A and 5B present the results from the PMG estimations for both models A and B, respectively. The findings indicate that for both measures of ICT use, the estimated coefficients are positive, persistent and significant at 1% level of significance. In model A, the long-run estimated coefficient of the variable, the number of the Internet users per 100 people is .026 which means that a 1% increase in the number of the Internet users per 100 people increases per capita electricity consumption by .026%. In model B, the estimated long-run coefficient of the number of mobile cellular users per 100 people is 0.010, meaning a 1% rise in the number of mobile cellular users per 100 people causes 0.010% increase in per capita electricity consumption. These findings are consistent with the expected energy impact of ICT use. In other words, ICT use stimulate electricity consumption meaning increased use of ICT leads to increased demand for electricity eventually leading to its increased consumption. Thus the findings are also robust across different measures of ICT use.

There is also highly significant positive short-run and the long-run relationship between economic growth and electricity consumption in both models. The estimated long-run coefficient of economic growth rate (log of GDP per capita) is 0.25 in model A. This means that a 1% economic growth rate will cause .25% increase in per capita electricity consumption. The estimated coefficient of economic growth varies in model B from model A. The long-run coefficient of economic growth in model B is 0.130 which

**Table 3**
Panel unit root test results.

| Variables | $\hat{\rho}$ | CD | Levels CIPS | First differences CIPS |
|---|---|---|---|---|
| L GDP (per capita) | 0.930 | 95.66*** | −1.699 | −2.592*** |
| L electric power use (per capita) | 0.728 | 70.52*** | −1.243 | −2.579*** |
| L Internet use (per 100 people) | 0.988 | 101.68*** | −2.640*** | −3.288*** |
| L mobile cellular subscription | 0.934 | 96.11*** | −3.318*** | −3.333*** |

*Note*: *, ** and *** denote 1%, 5% and 10% levels of significance respectively.

**Table 4A**
Panel cointegration test results (Pedroni Residual Cointegration Test) for model A.

| | Statistic | Prob. | Weighted Statistic | Prob. |
|---|---|---|---|---|
| *Alternative hypothesis: common AR coefs. (within-dimension)* | | | | |
| Panel v-Statistic | 1.330477 | 0.0917 | 2.073177 | 0.0191 |
| Panel rho-Statistic | 0.724972 | 0.7658 | −1.789434 | 0.0368 |
| Panel PP-Statistic | 1.051950 | 0.8536 | −3.333802 | 0.0004 |
| Panel ADF-Statistic | -0.529274 | 0.2983 | −3.486336 | 0.0002 |
| *Alternative hypothesis: individual AR coefs. (between-dimension)* | | | | |
| Group rho-Statistic | −0.855397 | 0.1962 | | |
| Group PP-Statistic | −3.589833 | 0.0002 | | |
| Group ADF-Statistic | −4.608395 | 0.0000 | | |

**Table 4B**
Panel cointegration test results (Pedroni Residual Cointegration Test) for model B.

| | Statistic | Prob. | Weighted Statistic | Prob. |
|---|---|---|---|---|
| *Alternative hypothesis: common AR coefs. (within-dimension)* | | | | |
| Panel v-Statistic | 1.044619 | 0.1481 | 1.946064 | 0.0258 |
| Panel rho-Statistic | 1.649529 | 0.9505 | −0.797989 | 0.2124 |
| Panel PP-Statistic | 2.965696 | 0.9985 | −2.111578 | 0.0174 |
| Panel ADF-Statistic | 1.644944 | 0.9500 | −2.177232 | 0.0147 |
| *Alternative hypothesis: individual AR coefs. (between-dimension)* | | | | |
| Group rho-Statistic | 0.521711 | 0.6991 | | |
| Group PP-Statistic | −2.323784 | 0.0101 | | |
| Group ADF-Statistic | −2.559930 | 0.0052 | | |

**Table 5A**
Results from PMG estimation for model A.

| Dependent variable: electric power consumption | Pooled mean group | |
|---|---|---|
| Variable | Coefficient | Standard error |
| *Long-run coefficients* | | |
| LGDPC | 0.252*** | 0.053 |
| Net use (per 100 people) | 0.026*** | 0.002 |
| *Error correction coefficient* | −0.176*** | 0.049 |
| Δ LGDPC | 0.566*** | 0.051 |
| Δ net use (per 100 people) | 0.008*** | 0.005 |
| Intercept | 1.124 | 0.320 |

*Note*: *, ** and *** denote 1%, 5% and 10% levels of significance respectively.

**Table 5B**
Results from PMG estimation for model B.

| Dependent variable: electric power consumption | Pooled mean group | |
|---|---|---|
| Variable | Coefficient | Standard error |
| *Long-run coefficients* | | |
| LGDPC | 0.130*** | 0.032 |
| L mobile cellular | 0.0104*** | 0.001 |
| *Error correction coefficient* | −0.174*** | 0.042 |
| Δ LGDPC | 0.528*** | 0.050 |
| Δ L mobile cellular | 0.0012*** | 0.005 |
| Intercept | 1.357*** | 0.340 |

*Note*: *, ** and *** denote 1%, 5% and 10% levels of significance respectively.

**Table 6**
Pairwise Dumitrescu Hurlin panel causality tests.

| Null hypothesis | W-stat. | Zbar-stat. | Prob. |
|---|---|---|---|
| LGDPC does not homogeneously cause LEC | 3.85804 | 8.85025 | 0.0000 |
| LEC does not homogeneously cause LGDPC | 2.60799 | 4.85215 | 1.E−06 |
| MOB does not homogeneously cause LEC | 2.75485 | 5.30600 | 1.E−07 |
| LEC does not homogeneously cause MOB | 8.52791 | 23.7292 | 0.0000 |
| NET does not homogeneously cause LEC | 3.64957 | 7.70658 | 1.E−14 |
| LEC does not homogeneously cause NET | 3.94185 | 8.59689 | 0.0000 |
| MOB does not homogeneously cause LGDPC | 2.46452 | 4.37949 | 1.E−05 |
| LGDPC does not homogeneously cause MOB | 13.7760 | 40.4773 | 0.0000 |
| NET does not homogeneously cause LGDPC | 4.90493 | 11.5305 | 1.E−.27 |
| LGDPC does not homogeneously cause NET | 6.16437 | 15.3668 | 0.0000 |
| NET does not homogeneously cause MOB | 5.12691 | 12.2067 | 0.0000 |
| MOB does not homogeneously cause NET | 8.55127 | 22.6374 | 0.0000 |

means a 1% growth rate will cause a 0.13% increase in per capita electricity consumption. This finding supports the argument that economic growth is always accompanied by increased demand for electricity use. This is quite expected as economic growth leads to increased economic activities and consumption for electronic appliances is expected to rise resulting in a rise in electricity consumption. Overall, these are expected findings as most of the empirical literature suggest that economic growth is accompanied by increase in domestic energy demand and in particular, electricity demand.

Dumitrescu–Hurlin (DH) causality results as reported in Table 6 suggest that electricity consumption causes economic growth. There is unidirectional causal link running from mobile and Internet use to electricity consumption and economic growth in the OECD countries.

## 5. Conclusions and policy implications

This study uses panel data to examine for the first time ever the short- and long-run effects of ICT use and economic growth on electricity consumption in OECD countries for the period of 1985–2012. It employs a battery of powerful econometric techniques including non-conventional panel unit root test that accounts for the presence of cross-sectional dependence, panel cointegration test, the Pooled Mean Group Regression (PMG) method and recently introduced Dumitrescu–Hurlin (DH) causality test. The panel unit root test confirms that all the series in the study are first-difference stationary even in the presence of cross-sectional dependence indicating cointegrating relationship between the variables. Panel Pedroni cointegration test results confirm the cointegrating relationship between the variables in both models using two different indicators of ICT use. Estimation results suggest a highly positive significant relationship between ICT use and electricity consumption and between electricity consumption and economic growth both in the short- and the long-run. The findings are robust across both models. Also causality results suggest that electricity consumption causes economic growth. Both mobile and Internet use cause electricity consumption and economic growth.

The findings of the current study in that both ICT use and economic growth stimulate electricity consumption in OECD countries in the short- and the long-run have important policy implications. The positive relationship between ICT use and electricity consumption suggest that OECD countries are yet to achieve energy efficiency gains from ICT expansion although a target was set to achieve this goal by the year 2015 for those OECD countries which are also European countries [23]. The unidirectional causal link from electricity consumption to economic growth imply that positive relationship between economic growth and electricity consumption imply that the OECD countries cannot reduce electricity generation to combat pollution effects but rather, they need to pursue policies that will improve electricity generation efficiency which will have no adverse effect on their economic growth. To achieve this, they need to focus on energy savings gains from ICT based electricity efficiency strategy. If the energy efficiency gains from ICT use could be achieved, it is likely to further promote the expansion of the ICT use in the region as this will reduce the cost of using ICT products and services which is further expected to play an important role in reducing digital divide both within and between the OECD countries.

This study also recommends that the OECD countries should further expand Carbon Capture and Storage (CCS) facilities as this appears to be an effective method to combat $CO_2$ emissions in the region. Also, the governments might invite the private entrepreneurs and build public–private partnership (PPP) that might play a significant role in boosting investment funds for CCS plants in the region. Integration of CCS in GHG policies also appears to be important.

Boosting nuclear energy may be another potential option for the OECD countries for power generation. Usually nuclear energy plants involve huge investment and the benefits are likely to be due only in the very long-run. Since most of the OECD economies are generally characterized by stable economies, large scale investment in nuclear energy is not very challenging for them.

Apart from strengthening the above mentioned measures which are already in place in most of the OECD countries, the Governments of these countries need to pursue energy policy that is directed towards encouraging investment to find innovative ways to make ICT products, networks and especially data centers that involve the highest level of electricity consumption among ICT products and services, more energy efficient. The data centers that exceed the requirement of certain level of electricity consumption may be monitored and regulated through appropriate means.

Also, the Governments of OECD countries need to focus more on and gradually implement two methods as advocated by the International Energy Association [23]. That is, they need to gradually switch to more efficient technologies that represent the shortest life cycle of ICT products and the best available technologies that imply better use of equipments and components which ensure the use of power by ICT products only when it is needed. These can be achieved by reinforcing policy that would encourage data centers to continue with their energy-saving measure of turning on/off a large number of machines that operate within these data centers. A recent study [15] concludes that energy savings from shutting on/off policy in data centers outweigh the costs involved therein.

The study further recommends that OECD countries promote green IT and IT for green that have the potential to substantially reduce $CO_2$ emissions through eco-efficiency and eco-design processes [25]. Also the policy makers in these countries must not rule out the potential that electricity sector itself provides substantial opportunities for reducing emissions if measures such as fuel switching and generation efficiency improvement initiatives are taken [3]. Finally, an effective coordination among ICT policy, energy policy and growth policy is vital to address the climate change issue in the region.

Despite important and significant findings, this study suffers from a number of limitations. First of all, six of the OECD countries had to be dropped from the study due to a lack of availability of data. Thus, one should be cautious about the generalizability of our findings to the whole OECD region. Second, although the sample period covered in this study is sufficient for the application of the PMG technique, a larger sample period would have offered more reliable findings. Nevertheless, the PMG technique imposes long-run homogeneity of the parameters across the panel (as the study considers only OECD countries), but in the real world some possibly substantial degree of cross-country heterogeneity may still exist in the long-run. Also, the findings are not expected to be invariant across different econometric methodologies. Also, with the expansion of ICT use and especially with the massive roll out of the Internet infrastructure in almost all OECD countries, the electricity demand will rise as evident from the findings of this study. The increasing demand for electricity and subsequently its increasing consumption is likely to raise the level of $CO_2$ emissions. Therefore, assessing the direct impact of the Internet usage on $CO_2$ emissions in the region, could be a potential topic for further investigation. This is left for future research.

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## Appendix A. Supplementary material

Supplementary data associated with this article can be found, in the online version, at http://dx.doi.org/10.1016/j.ijepes.2015.11.005.

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# PAPER 7: INTERNET USAGE, ELECTRICITY CONSUMPTION AND ECONOMIC GROWTH IN AUSTRALIA: A TIME SERIES EVIDENCE

## Statement of Contributions of Authorship

To whom it may concern

I, Mohammad Salahuddin contributed 80% to the paper entitled above and mentioned below;

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Signature of Candidate: Date: January 26, 2016

I, as a coauthor recognize and accept that the contribution of the candidate indicated above for the above mentioned PhD output is appropriate.

Khorshed Alam Signature : Date: January 26, 2016

**This paper is one of two papers included in Chapter five of the candidate's PhD thesis**

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# Internet usage, electricity consumption and economic growth in Australia: A time series evidence

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ABSTRACT

This study estimates the short- and long-run effects of the Internet usage and economic growth on electricity consumption using annual time series macro data for Australia for the period 1985–2012. ARDL bounds test for cointegration and Granger causality test for causal link are applied. Results from ARDL estimates indicate that the Internet use and economic growth stimulate electricity consumption in Australia. Internet usage and economic growth have no significant short-run relationship with electricity consumption. Multivariate Granger causality test confirms unidirectional causal link running from Internet usage to economic growth and electricity consumption. The findings are robust across different econometric specifications. The findings imply that Australia is yet to achieve electricity efficiency gains from ICT expansion and that it may pursue energy conservation policy without any adverse effect on its economy. Australia needs to promote its existing carbon capture and storage facilities, significantly boost investment in the renewable energy sector, in particular, in solar energy and build nuclear power plants for electricity generation to reduce $CO_2$ emissions. Also promoting green IT and IT for green might be potential means to curb environmental damage from Internet usage. A coordination between ICT policy, energy policy and growth policy is also recommended.



## 1. Introduction

Information and communication technologies (ICTs) have a wide array of effects on key global systems (Moyer and Hughes, 2012). The rapid use and expansion of these technologies have proved to contribute towards increasing productivity, boosting economic growth (Shahiduzzaman and Alam, 2014a,b) and reducing energy intensity (Moyer and Hughes, 2012). As such, the study on environmental impacts of ICT has drawn special attention since the early 1990s. Ever since, the studies investigating the energy impacts of ICTs have been profoundly researched in a macro framework. Although the rapid expansion of ICT usage is believed to improve productivity and energy efficiency, there is no consensus as yet on its effect on the environment. Some of the studies support the positive role of ICT in mitigating greenhouse gas emissions while others conclude that ICT use exerts pressure on energy use (Moyer and Hughes, 2012) hence leading to an increase in electricity consumption – one of the key sources of global $CO_2$ emissions (Hamdi et al., 2014).

Since 1970s, there was a general interest in how to reduce energy consumption and $CO_2$ emissions in economies through the expansion of ICTs. Schumpeter (1934, cited in Walker, 1985) coined the idea that it was possible to reduce energy

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0736-5853/

demand while allowing the economy to grow by the expansion of ICTs that potentially contribute towards energy saving gains. The widespread expansion of ICTs has caused dramatic rise in the demand for electricity in the last two decades. ICT related electricity consumption has increased significantly both in the workplaces and households (IEA, 2009). The combined electricity consumption related to ICT equipments such as communication networks, personal computers and data centers is growing at a rate of nearly 7% per year (i.e., doubling every 10 years). The relative share of these ICT products and services in the global electricity consumption has increased from about 3.9% in 2007 to 4.6% in 2012 (Heddeghem et al., 2014).

A significant percentage of domestic electricity consumption in Europe is linked to the use of ICT products and services (Faucheux and Nicolai, 2011). According to some estimates (Greenpeace International, 2014), ICT industry is responsible for 2% of global $CO_2$ emissions. Because all ICT products need electricity to operate, rapid expansion of ICT use leads to increasing demand for electricity threatening environmental sustainability through greenhouse gas emissions and Australia is no exception. But if energy efficiency could be achieved leading to energy saving gains, the positive effect of energy efficiency might outweigh the negative effect of increased electricity consumption.

Since the mid-1990s, the Internet usage has been increasing at a rapid speed in Australia (Fig. 1). An overwhelming majority of Australians are using the Internet. In 2011, 87% of the Australians had used the Internet up from 81% in 2009 and 73% in 2007. The vast majority of household connections are now through broadband (96%) while the proportion of Australians accessing the Internet through a mobile device more than doubled between 2009 and 2011 from 15% to 37% (Ewing and Julian, 2012). It is claimed that the Internet has been transforming the Australian economy for the last 10 years (Bowles, 2012; Deloitte Access Economics, 2011) and is anticipated to play even more significant role in the future as it looks forward to becoming a leading digital economy. In 2010, the direct contribution of the Internet to the Australian economy was AUS$ 50 billion or 3.6% of its Gross Domestic Product (GDP). The contribution of the Internet to the economy will further increase and is projected to be around AUS$ 70 billion by 2015 (Deloitte Access Economics, 2011). Not only these numeric figures reflect the Internet's recent role in Australian economy in growth and productivity, two most recent empirical studies (Shahiduzzaman and Alam, 2014a,b) support the persistent positive role of ICT capital in boosting its economic growth and productivity.

Nevertheless, in its bid to be a leading digital economy, Australia has been undergoing the construction of the largest ever broadband rollout project, the National broadband network (NBN) with a view to expanding high speed internet (broadband) to the regional and remote areas of the country. One of the key objectives of the NBN is to narrow the digital divide in the country (Lee, 2011) which is believed to be in the danger of widening (Bowles, 2012). While the NBN rollout is justified and is consistent with Australia's move to be a leading digital economy, the benefits reaped from the massive expansion of the broadband infrastructure is not expected to be without opportunity cost. In other words, the future energy impacts of this expansion cannot be ruled out. Australia is one of the top $CO_2$ emitters in the world alongside USA, Canada, Germany, the UK, Saudi Arabia and Qatar on a per capita basis (Shafiei and Salim, 2014). The same authors argue that 90% of the power generation in Australia is still sourced from non-renewable fossil fuels such as coal, gas and oil. As a result, there has been a sharp increase in $CO_2$ emissions. Nevertheless, the rapid expansion of ICT use in the region is likely to have significant energy impacts as ICT products and services cannot be operated without electricity.

Energy is largely sourced from electricity in Australia (Salahuddin and Khan, 2013) and it is one of the major industries of the country. Electricity generation is the single largest contributor to greenhouse gas (GHG) emissions producing 38% of total emissions in Australia and 90% of electricity was generated from the burning of fossil fuels dominated by coals, gas and oil in 2012 (Asafu-Adjaye and Mahadevan, 2013). Coal provided 68% of Australia's electricity needs in 2012. Per capita electricity consumption has been steadily rising in Australia for most of the period during the last four decades (Fig. 2). Although energy

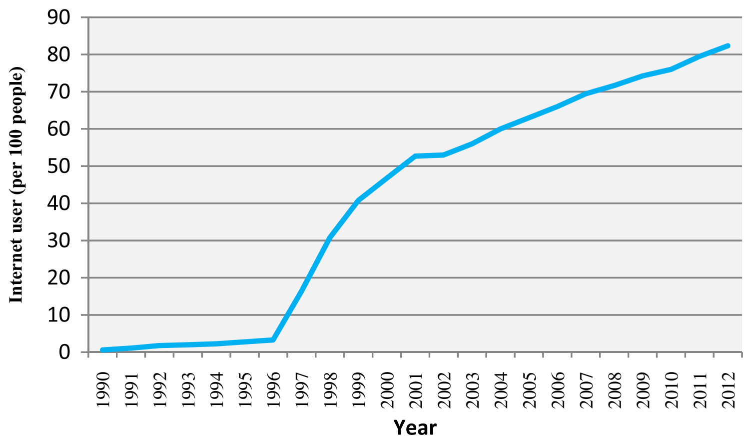


**Fig. 1.** Trend in the number of Internet users per hundred people (%) in Australia during 1990–2012. *Source:* World Development Indicators Database, The World Bank (2013).

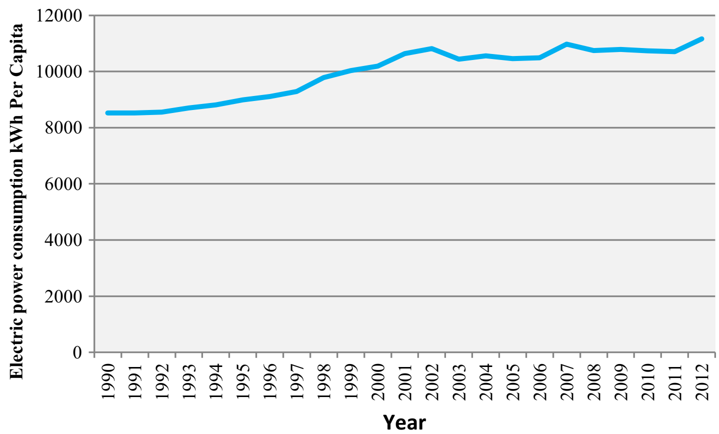


**Fig. 2.** Trend in per capita electricity consumption (kWh) in Australia during 1990–2012. *Source:* World Development Indicators Database, The World Bank (2013).

intensity has been on a declining trend (Fig. 3) during the same period and also for most of the period during 1970–2012, it is still struggling to embrace transition to a low carbon economy despite the fact that Australia also has some decoupling experiences. During the period 1971–2012, it experienced some extent of relative decoupling while it also performed absolute decoupling during 1970–72, 1981, 1985, 1992, 1994 and again during 2000–2002 and 2010–2012 (Fig. 4). Two key reasons for this declining trend in energy intensity and for enjoying some decoupling experiences are fuel efficiency gains from technological improvement and fuel switching and the rapid growth of less energy intensive service sector. However, despite these developments, to combat GHG emissions still remains a challenge for Australia.

A recent study (Salahuddin and Khan, 2013) reports that energy consumption contributes towards $CO_2$ emissions in Australia and more than 20% of the total energy is sourced from electricity. Nevertheless, the rapid expansion of the Internet is expected to exert pressure on domestic demand for electricity consumption. Its further expansion in future due to the NBN rollout is likely to spark concerns for future environmental sustainability of Australia. As such, this study examining the impact of the Internet usage on electricity consumption in Australian context whose energy policies are already at the crossroads (Falk and Settle, 2011) is worth-investigation and also is likely to receive growing importance in energy and digital divide literature.

Also, since the mid-eighties and following the second oil shock, enormous literature investigating the relationship between economic growth and electricity consumption for different countries and regions evolved (Hamdi et al., 2014) but such relationship was rarely investigated in Australian context despite its important implications for energy policy. To fill this vacuum, the current study also examines the impact of economic growth on electricity consumption. Another reason for including economic growth is that usually simple bivariate models may fail to appropriately capture empirical relationship between the series (Karanfil, 2009; Bartleet and Gounder, 2010). Therefore, the extension of our model with the inclusion of economic growth is further justified.

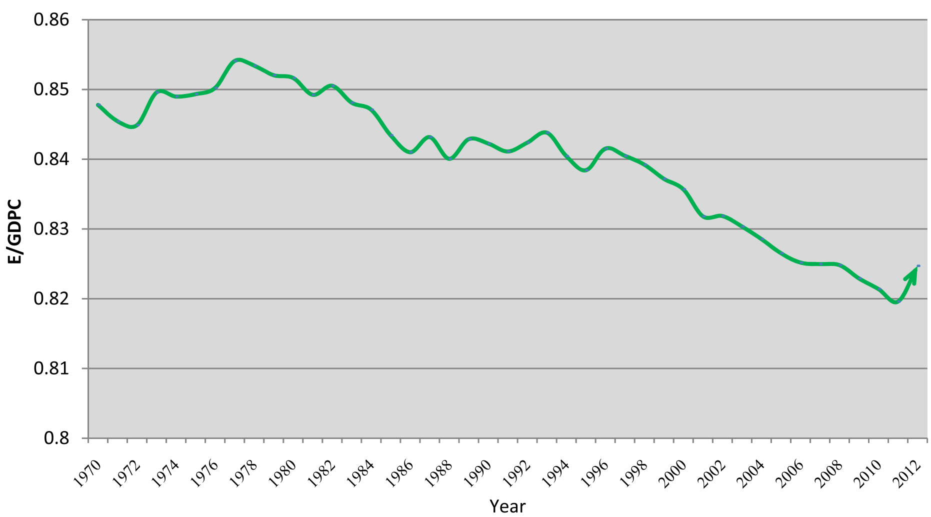


**Fig. 3.** Trend in energy intensity in Australia during 1970–2012. *Source:* International Energy Agency (2013).

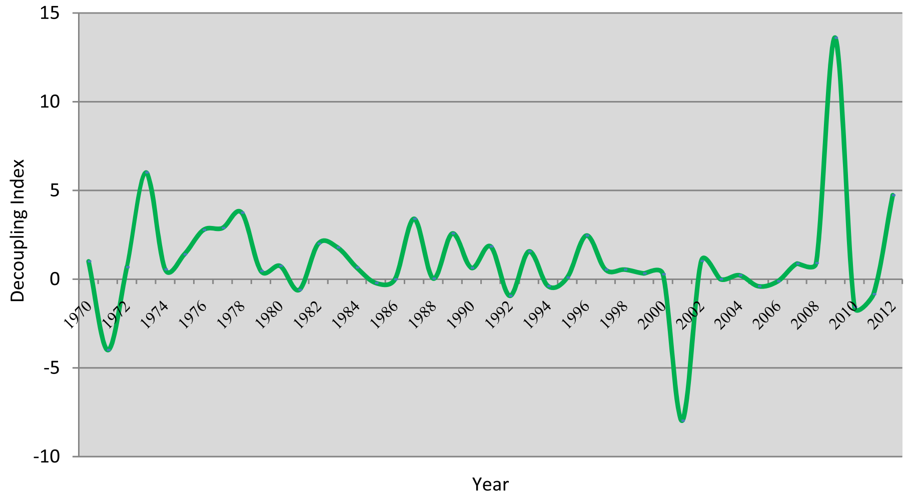


**Fig. 4.** Decoupling index values of $CO_2$ emissions from economic growth in Australia during 1970–2012.

There are a number of contributions of this study to the existing energy, Internet and growth literature. First, the most important contribution is that the Internet usage and electricity consumption relationship is being investigated for the first time ever for Australia. Second, although literature on the electricity–growth relationship is abundant, the economic growth-led electricity consumption hypothesis was never examined in the Australian context. Third, the current study uses the most recent data, the analysis of which, is expected to offer policy-oriented findings. Fourth, it also makes a methodological contribution by employing a couple of sophisticated and potentially suitable time series econometric techniques, the autoregressive distributive lag (ARDL) model and Innovation Accounting Approach (IAA) that have never been used before to estimate the Internet usage and electricity consumption relationship for any previous time series study, let alone for Australia and fifth, unlike other works, the findings of the study are expected to provide important implications at a time for ICT policy, energy policy and economic growth policy for Australia.

The rest of the paper is structured as follows: Section 2 discusses literature review, and methodology is presented in Section 3. Section 4 presents estimation results and finally the paper ends up in Section 5 with conclusions and policy implications of the research.

## 2. Literature review

### 2.1. ICT and electricity consumption

Environmental impact of the ICT use especially the impact of the astonishing increase in the Internet use and subsequently the energy intensity of the Internet has recently been one of the rising concerns. The electricity mix used for data centers is an issue of increasing importance (Coroama and Hilty, 2014). ICT-electricity consumption nexus is relatively an under-investigated area of research despite its potential implications for environmental sustainability. Most of the studies that have so far been conducted for developed economies are at the country level time series studies or at industry level cross-sectional studies (Sadorsky, 2012).

Arguably in one of the most cited studies on energy impacts of ICT so far, Romm (2002) labels the US economy characterized by the astonishing growth of the Internet use as the 'Internet economy'. His findings suggest that the use of the Internet does not cause a rise in electricity demand rather it drives electricity efficiency. Thus, the study found that the Internet use has resulted in the decline in electricity intensity as well as in energy intensity in all the sectors of the USA economy. The study concludes that the Internet use potentially leads to economic growth with less energy consumption calling it a 'New Energy Economy' which is expected to have profound environmental implications. Schefer et al. shows that the share of total energy consumption of German mobile telephone sector is only 7% when it did not include electricity use for charging of the handsets. When charging of the handsets is accounted for, the share stands at 45%. Collard et al. (2005) estimate a factor demand model to assess the impact of IT investment on capital goods on the electricity intensity of production in the French service sector. Using panel data combining time series and cross sectional dimensions, they find that during the period 1986–1998, electricity intensity of production has declined with the diffusion of communication devices while it increased with the use of computers and software.

Cho et al. (2007) use time series data for South Korea to examine the effects of ICT investment and energy price on industrial electricity demand. They employ logistic growth model for analysis of data. Their findings indicate that ICT investment increases electricity intensity in the service sector and in those manufacturing sectors that consume relatively higher amount of electricity. The study further suggests that more efforts are required to achieve electricity efficiency in the service sector. It concludes that ICT investment in some of the manufacturing sectors have the potential for reduction in electricity consumption through energy efficiency. The European Commission e-Business Watch (2006) conducts a comprehensive study on the effects of ICT on electricity in Austria, Germany, Denmark, Finland, France, Italy, Spain and the UK as well as a number of company case studies. The findings indicate that at the aggregate level, ICT use increases electricity consumption while at the micro level, it enhances energy efficiency. Heddeghem et al. (2014) in a study examine the trend in worldwide electricity consumption and show that the absolute electricity consumption of three key ICT categories, namely, communication networks, personal computers and data centers, has increased in 2012 from its level in 2007.

There is so far none but one panel study (Sadorsky, 2012) which estimated the empirical relationship between ICT investment and electricity consumption in emerging economies. Using a dynamic panel model, it employed the Generalized Methods of Moments (GMM) technique to investigate the link between the ICT and electricity consumption for a sample of emerging economies. The study found that ICT use increases electricity consumption in these countries. One limitation of homogeneous panel data approaches such as the GMM technique that was employed in this study is that it allows the intercept to differ while constraining all other parameters to be the same thus still imposing a high degree of homogeneity ignoring the potential cross-sectional heterogeneity in the panel. Such method of homogeneity has the potential risk of producing biased results. The current study overcomes this limitation by employing a panel estimation technique that allows for cross-country heterogeneity.

Moyer and Hughes (2012) use International Futures (IFs) integrated assessment system to explore the dynamic impacts of ICT on economic and energy systems including its impact on carbon emissions. They argue that ICT can have a downward impact on overall carbon emissions across a 50-year time horizon. However, they further caution that the net effect might be limited. The study recommends that ICT promotion must be coupled with a global price on carbon.

Despite the growing concern of the energy impacts of ICT expansion, there is so far none but only one panel study (Sadorsky, 2012) which estimated the empirical relationship between ICT investment and electricity consumption in emerging economies. Using a dynamic panel model, it employed the Generalized Methods of Moments (GMM) technique to investigate the link between the ICT and electricity consumption in emerging economies. Moyer and Hughes (2012) use International Futures (IFs) integrated assessment system to explore the dynamic impacts of ICT on economic and energy systems including its impact on carbon emissions. They argue that ICT can have a downward impact on overall carbon emissions across a 50-year time horizon. However, they caution that the net effect might be limited. The study further recommends that ICT promotion must be coupled with a global price on carbon.

An overview of the above literature review suggests that energy literature suffers from an absolute vacuum of any Australian study that directly examines the impact of the Internet usage on electricity consumption. The rapid increase of the Internet usage since mid-1990s and the ongoing NBN rollout to expand the Internet infrastructure further have obviously been exerting some pressure on domestic electricity demand and Australia may already be experiencing possible environmental consequences through $CO_2$ emissions from this rollout. This study will dig into depth this possibility and is expected to provide with a fine-grained understanding of this burning issue.

### *2.2. Electricity consumption and economic growth*

Literature investigating the relationship between electricity consumption and economic growth is enormous. Since the pioneering work of Kraft and Kraft (1978) that examined this relationship in the USA, plenty of literature in the area have emerged. Basically four main streams of literature evolved that investigated this relationship: (i) the electricity consumption-led growth hypothesis (growth hypothesis) (ii) the growth-led electricity consumption hypothesis (conservation hypothesis), (iii) feedback hypothesis and (iv) neutrality hypothesis.

Most of the empirical studies tested the growth hypothesis and supported its validity (Hamdi et al., 2014). Literature testing conservation hypothesis dealt with both time series and panel data. Different time series techniques such as error correction mechanism (ECM), autoregressive distributed lag model (ARDL), variance autoregression (VAR), ordinary least squares-augmented group (OLS-AG), Dynamic Ordinary Least Squares (DOLS), fully modified ordinary least squares (FMOLS) and panel techniques such as panel cointegration, panel Granger causality and panel vector error correction model (VECM) were used to test the hypotheses.

In a study, Yoo (2006) investigates the causal link between real GDP and electricity consumption in Indonesia, Malaysia, Singapore and Thailand over the period 1971–2002. Findings indicated a bi-directional relationship for Malaysia and Singapore and a unidirectional relationship for Indonesia and Thailand. Overall, for all these countries, the growth hypothesis was found to hold meaning that economic growth causes increase in electricity consumption. Wolde-Rufael (2006) undertook the massive time series estimation for 17 African countries to examine the long-run relationship between real GDP per capita and electricity consumption per capita as well as determining the causal direction of the relationship over the period 1971–2001. He employed unrestricted error correction model (UECM) to assess cointegrating relationship and Toda-Yamamoto Granger causality for the determination of the direction of causal link between the variables. For 9 of the 17 countries, cointegrating or long-run relationship between real GDP per capita and electricity consumption per capita was found while for 5 countries, long-run relationship was found with real GDP per capita as the dependent variable. For 4 countries, a cointegrating relationship was found when electricity consumption per capita was used as a dependent variable. For 6 of the countries, no long-run relationship was observed. The findings further showed that GDP per capita Granger causes electricity consumption for six countries and electricity consumption Granger causes GDP for three countries. A bi-directional relationship was also observed for three countries. For the rest four countries, he found no causal relationship.

Squalli (2007) used time series data for the Organization of Petroleum Exporting Countries (OPEC) to estimate the long-run relationship and the direction of the causal link between electricity consumption and economic growth for the period of 1980–2003. He employed autoregressive distributed lag model (ARDL) to estimate the long-run relationship and modified Wald test (MWT) to identify the causal direction of the relationship. The study found long-run relationship between the variables for all the OPEC countries. A unidirectional relationship was found for 6 of the countries while a strong bi-directional relationship was evident in the rest five countries.

Chen et al. (2007) estimate the cointegrating and the causal relationship between GDP and electricity consumption for 10 rapidly growing Asian countries over the period 1971–2001. This is one of the unique studies that employ both time series and panel data techniques for estimation of the relationship. Both time series and panel unit root tests were conducted to assess the stationarity of data. Both time series cointegration and panel cointegration tests reveal long-run steady-state relationship between GDP and electricity consumption. Time series causality results suggest different causal directions for different countries. The panel causality test based on the error correction model finds significant bi-directional causality between the variables. A unidirectional short-run causality running from economic growth to electricity consumption was also found.

Narayan and Prasad (2008) conducted causality tests to investigate the causal relationship between electricity consumption and real GDP for 30 OECD countries. They employed a bootstrapped causal testing method and found that electricity consumption causes real GDP in Australia, Iceland, Italy, the Slovak Republic, Korea, Portugal and the UK. For the rest of the countries, no evidence of causal relationship was found. They also carried out a regression analysis for each of the 30 OECD countries and obtained positive relationship between real GDP and electricity consumption.

Narayan et al. (2010) investigate the long-run causality between electricity consumption and real GDP for seven panels consisting of a total of 93 countries. They conduct Canning and Pedroni long-run causality test for the first time in energy literature. They find long-run bi-directional causality for all panels except where only GDP Granger causes electricity consumption. There exist positive relationship between these variables in all the significant panels except in the then G6 countries which means that an increase in electricity consumption will reduce GDP. Acaravci and Ozturk (2010) examine the long-run relationship and causality issues between electricity consumption and economic growth for a panel of 15 transition economies. It is one of the very few studies, findings of which, do not indicate any cointegrating relationship between electricity consumption and economic growth implying that policies aiming to reduce electricity consumption would have no effect on real GDP in these countries.

Yoo and Kwak (2010) investigate the causal relationship between electricity consumption and economic growth for seven South American countries for the period of 1975–2006. They find unidirectional, bi-directional and no causal link for different countries across the region. Ciaretta and Zarraga (2010) use annual data to investigate the long-run and causal relationship between electricity consumption and real GDP for a panel of 12 European countries for the period of 1970–2007. They estimate a trivariate VECM by GMM. The results show evidence of a long-run equilibrium and a negative short-run relationship between the variables. The findings further confirm bi-directional causality between energy prices and GDP and between electricity consumption and energy prices.

Apergis and Payne (2011) in a multivariate panel of 88 countries categorized into four panels based on the World Bank income classifications (i.e., high, upper-middle, lower-middle and low income) over the period of 1990–2006. The results reveal long-run equilibrium relationship between real GDP, coal consumption, real gross fixed capital formation and the labor force for the high, upper-middle and lower-middle income country panels. They also find bi-directional causal relationship for high-income and the upper middle-income country panels in both the short- and the long-run. Their findings further indicate unidirectional causal link in the short-run and bi-directional causal link for the lower middle-income country panel and unidirectional causality from electricity consumption to economic growth for the low-income country panel.

Bildirici and Kayikci (2012) in a study of 11 Commonwealth Independent States (CIS) apply panel ARDL and the FMOLS methods to examine the causal relationship. They divide the panel of CIS countries into three sub-panels based on income levels. Their empirical findings confirm a cointegrating relationship between the variables in all groups. The results further indicate a unidirectional causal link running from electricity consumption to economic growth for all groups in the long-run. FMOLS and ARDL estimations show that the effect of electricity consumption on GDP is negative for the second group of countries while it is positive for the first group of countries supporting the growth hypothesis.

Cowan et al. (2014) in a study use data on BRICS (Brazil, Russia, India, China and South Africa) for the period 1990–2010 and conduct panel causality analysis which accounts for cross sectional dependence and the potential heterogeneity across countries. They do not find any support for causal link between electricity consumption and economic growth for Brazil, India and China. However, a unidirectional causal relationship running from electricity consumption to economic growth in Russia and South Africa is found. Since findings of the causal direction between variables are different for different countries, the study fails to recommend any unique prescription for policy implications for these countries. Wolde-Rufael (2014) uses a similar method and analyzes the empirical relationship between electricity consumption and economic growth in 15 transition economies for the period 1975–2010. He employs a bootstrap panel causality technique that takes into account both cross sectional dependence and cross country heterogeneity. The findings offer limited support for electricity-led growth hypothesis. As expected, evidence of diverse directions of causality is found. The study concludes that these countries are yet to achieve energy efficiency as they are lagging behind according to international standard.

Several studies have examined the relationship between energy or electricity consumption and economic growth at country level. Wolde-Rufael (2006) investigates the relationship between per capita electricity consumption and real GDP per capita in Algeria, Zambia and Zimbabwe. He employed Toda-Yamamoto causality test and found no causal link between electricity consumption and real GDP for Algeria. For Zambia and Zimbabwe, he found that economic growth Granger caused electricity consumption supporting the conservation hypothesis. Chen et al. (2007) examines electricity consumption-real GDP nexus in China using Johansen-Juselius cointegration technique. They also found no causal link between the variables.

Mojumder and Marathe (2007) employ the same method to estimate this relationship for Bangladesh. Their findings indicated unidirectional relationship running from real GDP to electricity consumption. Narayan and Singh (2007) employed ARDL bounds testing method and VECM to investigate the empirical link between electricity consumption, real GDP and labor force in the Fiji islands. Their findings supported that electricity consumption Granger caused real GDP and labor force. Pao (2009) examines the causal relationship between electricity consumption and economic growth for Taiwan for the period 1980–2007. The results indicate long-run cointegrating relationship between the variables. Also unidirectional short and long-run causal relationship running from economic growth to electricity consumption is found. The study further suggests that there was no structural change during the period of the study and that the estimated parameters of the error correction mechanism (ECM) were stable. Shahbaz and Lean (2012) investigate the empirical relationship between electricity consumption and economic growth in Pakistan using time series data for the period 1972–2009. They find significant positive long-run relationship between these variables. Also electricity consumption and economic growth are found to cause each other. Solarin and Shahbaz (2013) show a bi-directional causal link between electricity consumption and economic growth in Angola. Hamdi et al. (2014) employ ARDL technique to study the relationship between electricity consumption and economic growth in Bahrain. They use quadratic sum match method to convert annual data into quarterly frequency. Their findings support feedback hypothesis which means that there is bi-directional causality between electricity consumption and economic growth. Javid and Qayyum (2014) apply structural time series technique to examine the relationship among electricity consumption, real economic activity, real price of electricity and the underlying energy demand trend (UEDT) at the aggregate and sectoral levels, namely, for the residential, commercial, industrial and agricultural sectors. The study finds a non-linear and stochastic trend at the aggregate level. The UEDT for the residential, commercial, and agricultural sectors show upward slope which imply that these sectors are yet to gain energy efficiency and even if, there are some energy efficiency improvements due to technical progress, they are outclassed by other factors.

Another strand of literature has focused on the decoupling issue to assess how economic growth is faring with the $CO_2$ emissions in countries. OECD (2002) first proposed the concept of 'decoupling' which occurs when the growth of environmental pressure is slower than the economic growth. Ever since, OECD countries have attached great importance to the research on the decoupling theory and its application dividing the decoupling concept into relative decoupling and absolute decoupling. Relative decoupling occurs when emissions grow at a slower rate than economic growth while absolute decoupling happens when emissions decline with the economy growing. Jukneys (2003) proposed the concept of primary decoupling, secondary decoupling and double decoupling. According to him, primary decoupling refers to delinking natural resources consumption from economic growth while secondary decoupling is decoupling of environmental pollution from consumption of natural resources. Double decoupling occurs when primary decoupling and secondary decoupling occur simultaneously.

Empirical research focusing on decoupling issue is scarce. Zhang and Wang (2013) examines the occurrence of decoupling between growth rates in economic activity and $CO_2$ emissions from energy consumption during 1995–2009 in Jiangsu province which is one of the most developed regions in China. They show that during the study period, Jiangsu experienced weak decoupling and strong decoupling except during 2003–2005. The decoupling states for the secondary and tertiary industries are similar to that of the whole economy. Wang et al. (2013) in another study in the same region show that economic activity is the critical factor in the growth of energy related $CO_2$ emissions and the energy intensity effect plays vital role in reducing $CO_2$ emissions. Andreoni and Galmarini (2012) use decomposition analysis to assess the progress in decoupling economic growth from $CO_2$ emissions in Italy. They split data for the periods of 1998–2002 and 2002–2006. The study considers five key sectors and four explanatory variables, $CO_2$ emissions, $CO_2$ intensity, energy intensity, structural changes and economic activity. The findings indicate that Italian economy did not perform absolute decoupling during both the periods in terms of economic growth and $CO_2$ emissions and that economic growth and energy intensity are mostly responsible for $CO_2$ emissions. The highest level of decoupling is observed in 2009.

Ren and Hu (2012) investigates the trend of decoupling effects in non-ferrous metal industry in China. The study observes four decoupling stages in the industry; strong negative decoupling stage (1996–1998), weak decoupling stage (1999–2000), negative decoupling stage (2001–2003) and weak decoupling stage (2004–2008). The study further suggests that the rapid growth of the industry is the most important factor responsible for the increase of $CO_2$ emissions. The increase in electric energy consumption contributed to increased $CO_2$ emissions. Freitas and Kaneko (2011) examine the state of decoupling of growth and $CO_2$ emissions from energy consumption during the period 2004–2009 in Brazil. Using decomposition analysis based on Log-mean Divisia Index (LMDI), the study finds that carbon intensity and energy mix are the two factors that need to be addressed to curb $CO_2$ emissions. They also observe several periods of relative decoupling in the country. Kveilborg (2004, 2007) and Kveilborg and Fosgerau (2005) found that use of larger vehicles, increased average loads and empty running were the key factors that contributed towards the decoupling of traffic growth from economic growth in Denmark.

Mckinon (2007) and Sorrell et al. (2010) had similar findings for the United Kingdom. So far, there is no study that estimated the decoupling index values for Australia. This study is the first attempt to do it for an assessment of the current environmental situation of Australia.

Although energy sector is one of the major industries in Australia, time series studies in the area of electricity consumption and economic growth is relatively scanty. Fatai et al. (2004) conducted a study examining the link between electricity consumption and economic growth in Australia and found support for the conservation hypothesis that is, economic growth Granger caused electricity consumption. This finding was further corroborated by Narayan and Smith (2005). In another study, Narayan and Prasad (2008) found unidirectional causality running from electricity consumption to economic growth in case of Australia. Salahuddin and Khan (2013) found bidirectional causal link between energy consumption and economic growth in Australia. They employed cointegration, vector autoregression (VAR), Granger causality and generalized impulse response functions to estimate the relationship using annual macro data for the period 1965–2007. Their findings also indicate that energy consumption in Australia has persistent positive effects on $CO_2$ emissions.

From the above literature review, it is evident that there is no recent study which investigated the empirical relationship between electricity consumption and economic growth in Australian context although such a topic is worth-investigation given the strong empirical evidence of such relationship in the literature and its subsequent environmental implications especially for a country like Australia which is one of the top $CO_2$ emitters in the world and that its major source of energy is electricity which is a key factor for $CO_2$ emissions. This study also uses the most recent data and the findings are thus expected to provide significant policy implications.

## 3. Data and methodology

### 3.1. Data

We employ historical data from the International Energy Agency (IEA, 2013) on per-capita $CO_2$ emissions and per capita energy consumption over the period from 1970–2012 to estimate the decoupling effects in order to report the overall emissions scenario of Australia. Annual time series data on electricity consumption per capita, real GDP per capita, internet users per 100 people for the period of 1985–2012 were obtained from the World Data Bank, (previously, World Development Indicators database, The World Bank, 2013) for econometric investigation of the relationship between variables. A few missing values were observed in the internet users per 100 people series which were replaced by 3-year moving average values. The variable per capita electricity consumption (EC) is measured by electric power consumption (kWh per capita) per capita, real GDP per capita (GDPC) is measured at constant 2005 US$ and the number of internet users per 100 people (NET) are considered for the study. All variables are expressed in natural logs.

### 3.2. Methodology

#### 3.2.1. The model

Following Sadorsky (2012) and Narayan et al. (2010), we propose and estimate an econometric model where electricity consumption is assumed to be a function of Internet usage and economic growth in Australia. Therefore, the functional form of the model is:

$$\mathrm{EC} = F(A, \mathrm{NET}, \mathrm{GDPPC}) \tag{1}$$

or

$$\mathrm{EC}_t = A.(\mathrm{NET}_t)^{\beta 1}(\mathrm{GDPPC}_t)^{\beta 2} \tag{2}$$

Log-linearizing both sides of the equation, we obtain:

$$\ln E_t = \beta_0 + \beta \ln \mathrm{NET}_t + \beta_2 \ln \mathrm{GDPPC}_t + \varepsilon_t \tag{3}$$

The subscript $t$ represent the time period.

### 3.3. Estimation procedures

#### 3.3.1. Estimation of decoupling effects in Australia during 1970–2012

Following Bithas and Kalimeris (2013), we estimate decoupling index for energy and GDP per capita ratio for Australia. The decoupling index (DI) refers to the ratio of the change in the rate of consumption of a given resource, to the change in the rate of economic growth (in terms of GDP), within a certain time period (typically one year). The DI for Australia is estimated from the following formula;

$$\mathrm{DI} = \frac{E_t - E_{t-1}/E_{t-1}}{\mathrm{GDP}_t - \mathrm{GDP}_{t-1}/\mathrm{GDP}_{t-1}} \tag{4}$$

When DI > 1, no decoupling is taking place.
When DI = 1, it is the turning point between absolute coupling and relative decoupling is represented.
When 0 < DI < 1, relative decoupling is taking place.
When DI = 0, it is implied that the economy is growing while resource consumption remains constant. This is the turning point between relative and absolute decoupling.
When DI < 0, the relationship can be described as absolute decoupling.

### 3.3.2. Unit root tests

Since unit root test helps us with a robust causality assessment, we employ the DF-GLS (Dickey Fuller – Generalized Least Squares) test proposed by Eliott et al. (1996) to determine the order of integration of variables as this test is more powerful than other conventional tests such as ADF (Dickey and Fuller, 1979), PP (Phillips and Peron, 1988) and KPSS (Kwiatkowski et al., 1992). However, despite its superiority over other tests, it fails to identify the presence of structural break, if any, in the series (Baum, 2004). Therefore, we also conduct Zivot and Andrews (1992) unit root test which accommodates a single structural break point in the level. If we consider our series as $X$, the structural tests take the following form;

$$\Delta X_t = \alpha + \alpha X_{t-1} + bT + cD_t + \sum_{j=1}^{k} d_j \Delta X_{t-j} + \varepsilon_t \tag{5}$$

$$\Delta X_t = \beta + \beta X_{t-1} + ct + bD_t + \sum_{j=1}^{k} d_j \Delta X_{t-j} + \varepsilon_t \tag{6}$$

$$\Delta X_t = \gamma + \gamma X_{t-1} + ct + dDT_t + \sum_{j=1}^{k} d_j \Delta X_{t-j} + \varepsilon_t \tag{7}$$

$$\Delta X_t = \Omega + \Omega X_{t-1} + ct + dD_t + dDT_t + \sum_{j=1}^{k} d_j \Delta X_{t-j} + \varepsilon_t \tag{8}$$

where $D$ is a dummy variable and shows the mean shift at each point and $DT_t$ is a trend shift variable. The null hypothesis in Zivot and Andrews (1992) is $c = 0$ meaning the presence of unit root in the absence of structural break hypothesis against the alternative that the series is trend stationary with an unknown time break. Then, this unit root test selects that time break which reduces one-sided $t$-statistic to test $c(=c-1)=1$.

### 3.3.3. ARDL bounds testing approach

Since conventional cointegration techniques have certain limitations with their findings in the presence of structural break in macroeconomic dynamics (Uddin et al., 2013), we employ ARDL (Autoregressive Distributed Lag model) bounds testing approach developed by Pesaran (1997) and Pesaran et al. (2001) to estimate the long-run relationship between the variables. The ARDL technique has several advantages over other conventional cointegration techniques; first of all, this method can be applied to a small sample size study (Pesaran et al., 2001) and therefore conducting bounds testing is justified for the present study. Secondly, it can be applied even in case of mixed order of integration of variables [both for $I(0)$ and $I(1)$ variables]. Thirdly, it simultaneously estimates the short-run dynamics and the long-run equilibrium with a dynamic unrestricted error correction model (UCEM) through a simple linear transformation of variables. Fourth, it estimates the short- and the long-run components simultaneously potentially removing the problems associated with omitted variables and autocorrelation. In addition, the technique generally provides unbiased estimates of the long-run model and valid $t$-statistic even when the model suffers from the problem of endogeneity (Harris and Sollis, 2003). The empirical formulation of ARDL equation for our study is specified as follows:

$$\begin{aligned}\Delta \ln \mathrm{EC}_t = {} & \beta_0 + \beta_1 T + \beta_2 D + \beta_3 \mathrm{EC}_{t-1} + \beta_4 \ln \mathrm{GDPC}_{t-1} + \beta_5 \mathrm{NET}_{t-1} + \sum_{i=1}^{p} \beta_6 \Delta \ln \mathrm{EC}_{t-j} \\ & + \sum_{j=1}^{q} \beta_7 \Delta \ln \mathrm{GDPC}_{t-k} + \sum_{k=0}^{r} \beta_8 \Delta \ln \mathrm{NET}_{t-1} + \varepsilon_t\end{aligned} \tag{9}$$

$$\begin{aligned}\Delta \ln \mathrm{GDPC}_t = {} & \beta_0 + \beta_1 T + \beta_2 D + \beta_3 \ln \mathrm{GDPC}_{t-1} + \beta_4 \mathrm{EC}_{t-1} + \beta_5 \mathrm{NET}_{t-1} \\ & + \sum_{i=1}^{p} \beta_7 \Delta \ln \mathrm{GDPC}_{t-j} + \sum_{j=0}^{q} \beta_9 \Delta \ln \mathrm{NET}_{t-k} + \sum_{k=0}^{r} \beta_{10} \Delta \ln \mathrm{EC}_{t-l} + \varepsilon_t\end{aligned} \tag{10}$$

$$\begin{aligned}\Delta \mathrm{NET}_t = {} & \beta_0 + \beta_1 T + \beta_2 D + \beta_3 \mathrm{NET}_{t-1} + \beta_4 \ln \mathrm{GDPC}_{t-1} + \beta_4 \mathrm{EC}_{t-1} + \sum_{i=0}^{p} \beta_8 \Delta \ln \mathrm{NET}_{t-j} \\ & + \sum_{j=0}^{q} \beta_9 \Delta \ln \mathrm{GDPC}_{t-k} + \sum_{k=0}^{r} \beta_{10} \Delta \ln \mathrm{EC}_{t-l} + \varepsilon_t\end{aligned} \tag{11}$$

where lnGDPC, lnEC and lnNET indicate log values for real GDP per capita, electricity consumption per capita and internet users per 100 people, respectively. $\Delta$ is the difference operator. $T$ and $D$ denotes time trend and dummy variable, respectively. The dummy variable is included in the equation to capture the structural break arising from the series. $\varepsilon_t$ is the disturbance term.

To examine the cointegrating relationship, Wald Test or the $F$-test for the joint significance of the coefficients of the lagged variables is applied with the null hypothesis, $H_0$: $\beta_3 = \beta_4 = \beta_5$ indicating no cointegration against the alternative hypothesis of the existence of cointegration between variables. $F$ statistics are computed to compare the upper and lower bounds critical values provided by Pesaran et al. (2001).

### 3.4. The vector error correction model (VECM) Granger causality test

According to Granger (1969), once the variables are integrated of the same order, the VECM Granger causality test is appropriate to estimate their causal link. Since all the variables in our study are first difference stationary [$I(1)$], this study proceeds further to determine the causal direction between them. Knowledge about the exact direction of causal link helps with better policy implications of the findings (Shahbaz et al., 2013). The potential causality pattern for our study is represented by the following VAR specification in a multivariate framework;

$$\Delta \ln EC_t = \beta_{0i} + \sum_{i=1}^{p} \beta_{1i} \Delta \ln EC_{t-1} + \sum_{i=0}^{p} \beta_{2i} NET_{t-i} + \sum_{i=0}^{p} \beta_{3i} \Delta \ln GDPC_{t-i} + \varepsilon_t \quad (12)$$

#### 3.4.1. Impulse response function (IRF) and variance decompositions

One major weakness of the VECM Granger causality is that it is unable to provide reliable estimates of the causal strength of relationship between variables beyond the selected 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 Innovation Accounting Approach (IAA) which consists of variance decomposition and generalized impulse response functions. The generalized impulse response function is preferred over the simple Choleski fractionalization impulse response analysis as the generalized impulse response function is insensitive to the order of the VECM (Shahbaz et al., 2013). It also indicates whether the impacts of innovations are positive or negative or whether they have short-run or long-run effect. The general representation of this procedure is available in the seminal works of Sims (1980, 1986) and Bernanke (1986). Although impulse response function traces the effect of a one standard deviation shock on the current and future values of all the endogenous variables through the dynamic structure of VECM, it doesn't provide the magnitude of such effect. Consequently, variance decomposition method is employed to examine this magnitude.

Variance decomposition (Pesaran and Shin, 1999) measures the percentage contribution of each innovation to h-step ahead forecast error variance of the dependent variable and provides a means for determining the relative importance of shocks in explaining the variation in the dependent variable. Engle and Granger (1987) and Ibrahim (2005) argued that variance decomposition approach produces more reliable results as compared to those from other traditional approaches.

#### 3.4.2. Dynamic Ordinary Least Squares (DOLS)

Finally, we apply the Dynamic Ordinary Least Squares (DOLS) method (Stock and Watson, 1993) and estimate the long-run coefficients between the variables in order to check for the robustness of the findings from the ARDL estimates. The application of this method for robustness check is appropriate in that this estimator is robust to small sample bias and eliminates simultaneity problem. Moreover, the obtained co-integrating vectors from DOLS estimators are asymptotically efficient.

## 4. Estimation results

Table 1 reports descriptive statistics. The standard deviations in all the series are quite low implying that the data are evenly dispersed around the mean. Hence it was convenient for us to proceed with the datasets for further estimation.

The DF-GLS unit root results are reported in Table 2 which shows all the series in our study are first difference stationary, i.e., $I(1)$. The weakness of this test is that it does not consider the presence of structural break (Baum, 2004) in the series. Due to different types of internal and external shocks, it is expected that there will be some structural breaks in the data. To overcome this shortcoming, we employ Zivot and Andrews (1992) unit root structural break test. The results of this test are presented in Table 3 which detects a number of break points in the early and late 1990s as well as in the late 2000s. The results further confirm that all the series are first difference stationary, i.e., $I(1)$, in the presence of structural break.

Next we proceed with the estimation of short-run and the long-run relationship among the variables. Since ARDL is sensitive to lag order, for calculating the $F$ statistic, first of all, we need to identify the appropriate lag order. To do this, we choose AIC (Akaike Information Criterion) as it provides better results than other lag length criteria (Lutkepohl, 2006). The reported ARDL results in Table 4 suggests that the calculated $F$ statistic of 4.689 is higher than the upper bound critical value generated by Pesaran et al. (2001) at the 1% level of significance. Therefore, there is highly significant cointegrating

**Table 1**
Descriptive statistics.

| Variable | Obs | Mean | Std. Dev. | Min | Max |
|---|---|---|---|---|---|
| LEPU | 23 | 9.174 | 0.118 | 8.926 | 9.320 |
| LGDPC | 23 | 10.300 | 0.160 | 10.044 | 10.525 |
| NET | 23 | 2.540 | 1.968 | −0.634 | 4.410 |

**Table 2**
Unit-root test DF-GLS.

| Log levels ($Z_t$) | | Log 1st difference ($Z_t$) | | |
|---|---|---|---|---|
| Variable | DFGLS stat | Variable | DFGLS stat | $I(d)$ |
| LEPU | −0.460 | ΔLEPU | $-3.855^{a}$ | $I(1)$ |
| NET | 0.796 | ΔNET | $-3.267^{a}$ | $I(1)$ |
| LGDPC | −2.518 | ΔFD | $-3.277^{b}$ | $I(1)$ |

*Note:* a, b, and c indicate 1%, 5%, and 10% significance level respectively.

**Table 3**
Zivot–Andrews structural break unit root test.

| Variable | Z & A test for level | | | Z & A test for 1st difference | | |
|---|---|---|---|---|---|---|
| | *T*-Statistic | TB | Outcome | *T*-Statistic | TB | Outcome |
| LEPU | −3.675 | 2002 | Unit Root | $-4.594^{a}$ | 1992 | Stationary |
| NET | $-12.545^{a}$ | 1997 | Stationary | $-4.891^{c}$ | 1998 | Stationary |
| LGDPC | −3.747 | 2008 | Unit Root | $-6.010^{a}$ | 1993 | Stationary |

*Note:* a, b, and c indicate 1%, 5%, and 10% significance level respectively.

**Table 4**
Results from bounds test.

| Dep. Var. | *F*-stat. | 95% Lower bound | 95% Upper bound | Outcome |
|---|---|---|---|---|
| $F_{LEPU}$(LEPU\|GDPC, NET) | 7.249 | 4.5690 | 5.7521 | Cointegration |
| $F_{LGDPC}$(LGDPC\|LEPU, NET) | 4.743 | 4.5690 | 5.7521 | No cointegration |
| $F_{NET}$(NET\|LGDPC, LEPU) | 2.919 | 4.5690 | 5.7521 | No cointegration |

**Table 5**
Estimated long run coefficients using the ARDL approach (1,0,1) based on AIC, dependent variable is EPU.

| Regressor | Coefficient | Standard Error | *T*-Ratio[Prob] |
|---|---|---|---|
| GDPC | $0.889^{a}$ | 0.005 | 167.962[0.000] |
| NET | $0.002^{a}$ | 0.767 | −2.750[0.012] |
| DT | 0.005 | 0.004 | 1.352[0.191] |

*Note:* a, b, and c indicate 1%, 5%, and 10% significance level respectively.

relationship between per capita electricity consumption and the predicted variables – the Internet users per 100 people and economic growth.

Table 5 reveals that the Internet usage and economic growth stimulate Australia's per capita electricity consumption in the long-run. The findings are consistent with expectations. This means that an increased usage of the Internet leads to an increase in electricity consumption of Australia. Also higher level of income causes more consumption of electric appliances and thus cause higher consumption of electricity.

Table 6 reports the short-run effects of the independent variables on growth. The findings indicate that there is highly significant (at 1% level of significance) positive short-run effects of the Internet usage and economic growth on per capita electricity consumption in Australia. The coefficient of the error correction term, $ECT_{t-1}$ is −0.3 and has the expected sign. It also implies a relatively speedy convergence (the short-run deviations being corrected at the speed of 53% towards the long-run equilibrium each year).

Table 7 demonstrates results from the diagnostic tests carried out from the ARDL lag estimates. The LM test confirms no serial correlation while Ramsey's RESET test suggests that the model (Eq. (1)) has the correct functional form. The normality

**Table 6**
Error correction representation for the selected ARDL model (1,0,1) selected based on AIC, dependent variable is dLEPU.

| Regressor | Coefficient | Standard error | $T$-Ratio[Prob] |
|---|---|---|---|
| dGDPC | 0.488 | 0.125 | 3.885[0.001] |
| dNET | 0.013 | 0.005 | 2.351[0.029] |
| DT | −0.006 | 0.001 | −3.601[0.002] |
| ecm(−1) | −0.536 | 0.139 | −3.854[0.001] |

**Table 7**
Diagnostic test.

| Test statistics | LM version |
|---|---|
| $R^2$ 0.97 | Adjusted $R^2$ 0.97 |
| Serial correlation $\chi^2(1) = 0.449[0.503]$ | Normality $\chi^2(2) = 1.001[0.606]$ |
| Functional form $\chi^2(1) = 2.218[0.136]$ | Heteroscedasticity $\chi^2(1) = 4.617[0.032]$ |

test reveals that the disturbance terms are normally distributed and are homoscedastic as supported by the heteroscedasticity test. The stability of parameters over time is reflected in the graphical plots of CUSUM and CUSUM of Squares (Figs. 5 and 6 respectively).

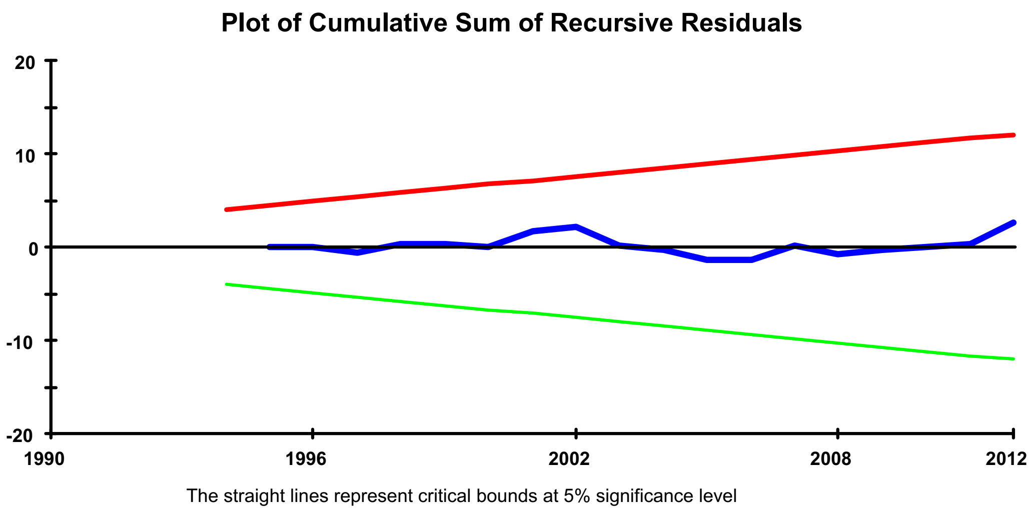


**Fig. 5.** Plot of Cumulative Sum of Recursive Residuals.

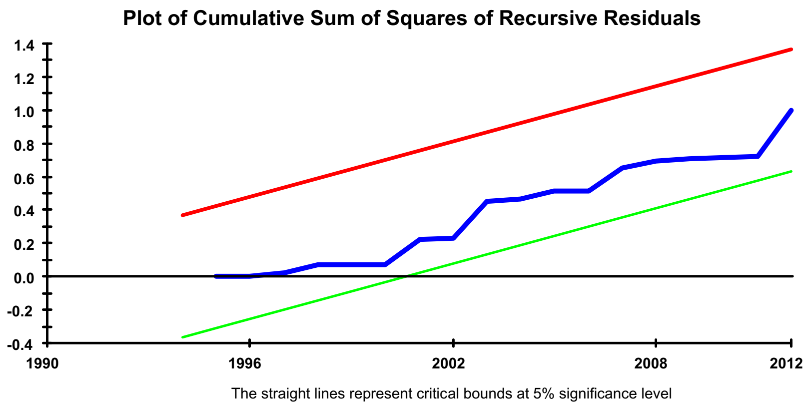


**Fig. 6.** Plot of Cumulative Sum of Squares of Recursive Residuals.

From Fig. 7, we see that the standard deviation of per capita electricity consumption leads to positive increase in future per capita electricity consumption in Australia. The response of per capita electricity consumption to the shocks in the Internet users per 100 people and per capita GDP demonstrates expected signs but with different magnitudes. The accumulated response of per capita electricity consumption to a shock in the Internet users per 100 people is positive and significant. The accumulated response of per capita electricity consumption to future shocks in GDP per capita is also positive and significant. Thus the findings are supportive of the earlier ARDL estimates of this study.

Results from the variance decomposition analysis are reported in Table 8. The study allows a 27 year forecasting horizon. Interestingly, at the 5-year forecasting horizon, about 75% of the one-step forecast variance in per capita electricity consumption is accounted for by its own innovations and altogether 25% is accounted for by economic growth and Internet users per 100 people. In the long-run after a period of 27 years, the response to own innovative shocks declines to around 60% while

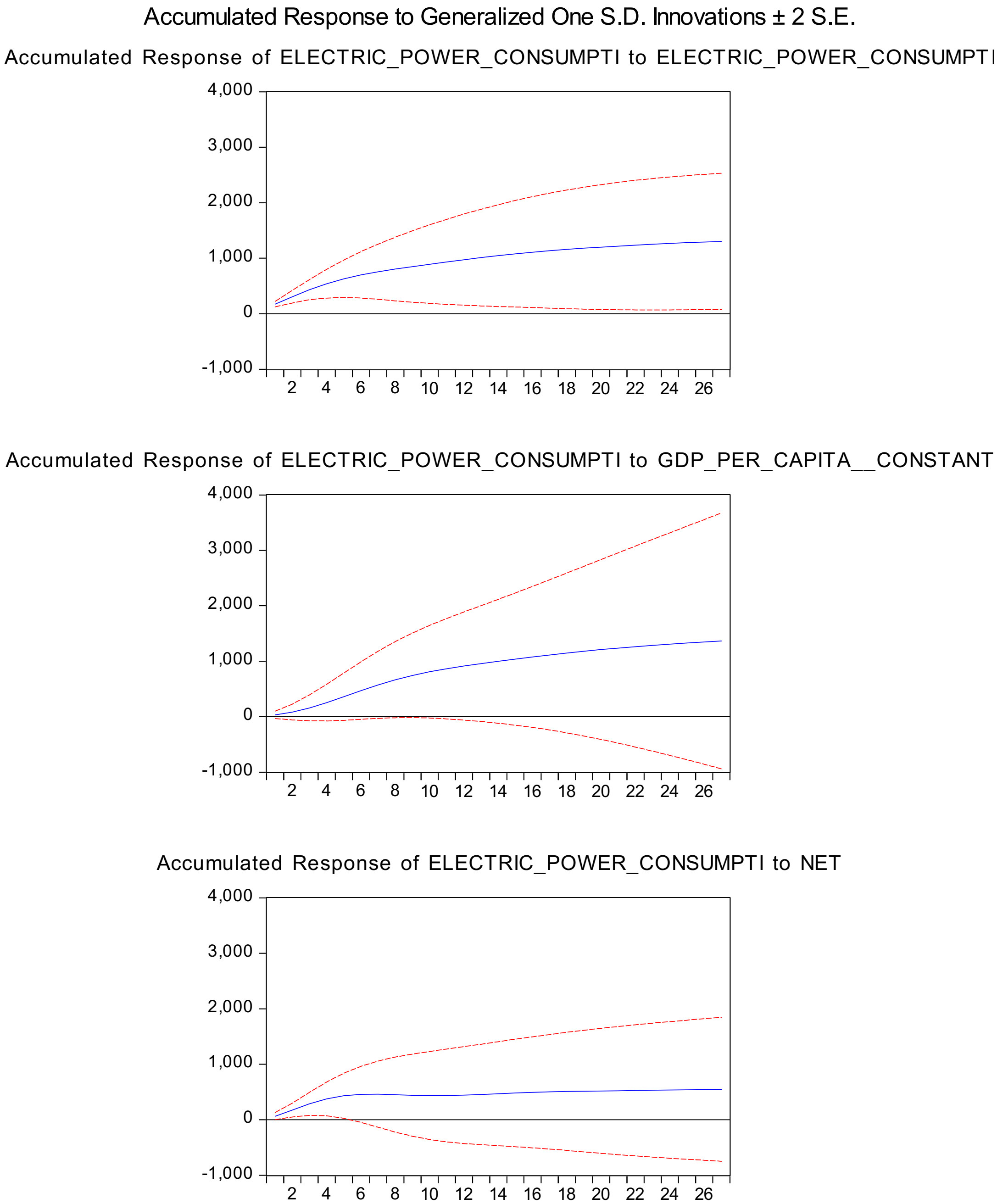


**Fig. 7.** Impulse response of per capita electricity consumption in Australia during 1990–2012.

**Table 8**
Variance decomposition of per capita electricity consumption in Australia during 1990–2012.

| Period | S.E. | Electricity per capita | GDPC | NET |
|---|---|---|---|---|
| 1 | 173.7531 | 100.0000 | 0.000000 | 0.000000 |
| 2 | 227.9662 | 90.94899 | 1.406215 | 7.644797 |
| 3 | 274.1514 | 84.89115 | 4.511362 | 10.59749 |
| 4 | 307.6305 | 79.62123 | 9.782656 | 10.59611 |
| 5 | 333.6356 | 74.66736 | 16.08726 | 9.245379 |
| 6 | 355.1638 | 69.82367 | 21.92443 | 8.251905 |
| 7 | 373.2043 | 65.60150 | 26.29822 | 8.100283 |
| 8 | 387.5592 | 62.42995 | 29.11257 | 8.457478 |
| 9 | 398.2287 | 60.37314 | 30.76351 | 8.863357 |
| 10 | 405.8273 | 59.21604 | 31.70109 | 9.082868 |
| 11 | 411.2985 | 58.64765 | 32.24687 | 9.105477 |
| 12 | 415.4926 | 58.39109 | 32.59284 | 9.016070 |
| 13 | 418.9596 | 58.25786 | 32.84996 | 8.892183 |
| 14 | 421.9721 | 58.14605 | 33.08246 | 8.771483 |
| 15 | 424.6403 | 58.01427 | 33.32139 | 8.664343 |
| 16 | 427.0068 | 57.85543 | 33.57171 | 8.572853 |
| 17 | 429.0916 | 57.67915 | 33.82227 | 8.498578 |
| 18 | 430.9075 | 57.50088 | 34.05734 | 8.441789 |
| 19 | 432.4678 | 57.33496 | 34.26514 | 8.399897 |
| 20 | 433.7914 | 57.19073 | 34.44095 | 8.368321 |
| 21 | 434.9051 | 57.07135 | 34.58605 | 8.342593 |
| 22 | 435.8415 | 56.97510 | 34.70510 | 8.319793 |
| 23 | 436.6333 | 56.89758 | 34.80375 | 8.298673 |
| 24 | 437.3097 | 56.83379 | 34.88719 | 8.279027 |
| 25 | 437.8936 | 56.77949 | 34.95949 | 8.261020 |
| 26 | 438.4019 | 56.73171 | 35.02347 | 8.244817 |
| 27 | 438.8467 | 56.68867 | 35.08086 | 8.230469 |

**Table 9**
Results from dynamic OLS.

| | Coefficient | Robust Std. Err. | *P*-Value |
|---|---|---|---|
| LGDPC | 0.055[a] | 0.019 | 0.004 |
| Internet use | 0.050[a] | 0.001 | 0.000 |
| Intercept | 8.490 | 0.196 | 0.000 |
| $R^2$ 0.999 | | | |

*Note:* a, b, and c indicate 1%, 5%, and 10% significance level respectively.

**Table 10**
VECM Granger causality.

| Excluded | Chi-sq | df | Prob. |
|---|---|---|---|
| *Dependent variable: D(EPU)* | | | |
| D(GDPC) | 1.523377 | 2 | 0.4669 |
| D(NET) | 4.972489 | 2 | 0.0832 |
| All | 7.831430 | 4 | 0.0980 |
| *Dependent variable: D(GDPC)* | | | |
| D(EPU) | 1.696555 | 2 | 0.4282 |
| D(NET) | 0.426328 | 2 | 0.8080 |
| All | 1.903370 | 4 | 0.7535 |
| *Dependent variable: D(NET)* | | | |
| D(EPU) | 0.436823 | 2 | 0.8038 |
| D(GDPC) | 1.187753 | 2 | 0.5522 |
| All | 1.551416 | 4 | 0.8175 |

the response of per capita electricity consumption to the shocks in GDP per capita and Internet users per 100 people rise to 43% from the first 5-year forecast horizon of 25%. Among the 43% of the variance, approximately 8% variance is due to the shocks in the variable of the Internet users per 100 people and around 35% variations are attributed to GDP per capita. The findings remind that while GDP per capita have strong forecasted impact on per capita electricity consumption, the impact of the Internet usage is also likely to be evident in the future. This leads to the justification that electricity efficiency policy in Australia needs to incorporate development and deployment of the Internet issues in its future policy framework to reduce the potential environmental damage from the expansion of Internet infrastructure.

Table 9 reports results from DOLS estimates. Although the coefficients vary, it confirms the robustness of the findings of ARDL long-run estimates. Multivariate Granger causality results are presented in Table 10. It shows a unidirectional causal link running from Internet usage to economic growth and electricity consumption.

## 5. Conclusions, policy implications and limitations

This study examines the empirical relationship among the Internet usage, electricity consumption and economic growth using Australian annual time series data for the period 1985–2012. Because of the long sample period, structural break unit root test is conducted. Having found the presence of structural break in the series, an ARDL bounds testing approach is applied taking into account the structural break. Granger causality test is performed to determine the causal link between the variables under study. The findings from the ARDL estimates suggest that the Internet usage and economic growth have long-run positive and significant effects on electricity consumption while these effects in the short-run are insignificant. Multivariate Granger causality test confirms unidirectional causal link running from the Internet usage to economic growth and electricity consumption. The causality of the relationship is robust as checked by impulse response functions and variance decomposition analysis. Another econometric technique Dynamic Ordinary Least Squares method (DOLS) also lends support to the long-run relationship between the variables. The baseline model used in the study succeeded all the conventional diagnostic tests.

The findings of the current study that both the Internet usage and economic growth stimulate electricity consumption in Australia in the long-run have important policy implications. The positive relationship between the Internet usage and electricity consumption suggest that Australia is yet to achieve energy efficiency gains from ICT expansion. Since 90% of electricity in Australia is still generated from non-renewable fossil fuels mostly from coal and gas, additional pressure on the demand for electricity will only worsen the environmental situation. Nevertheless, Australia is a coal abundant country and the largest exporter of coal in the world since 1986 (Falk and Settle, 2011). It may not be realistic for it to give up coal-fired generation of electricity that plays a significant role in Australian economy (The Gournot Report). Instead, it is recommended that Australia controls $CO_2$ emissions in the atmosphere through Carbon Capture and Storage facilities (CCS). CCS technology is not new in Australia and it is reported (Huaman and Jun, 2014) that Australia already has five large scale integrated CCS (LSIP) but this technology is yet to succeed in reducing $CO_2$ emissions significantly. For Australia, post combustion capture (PCC) is considered the only viable means of carbon capture (Qadir et al., 2013). Also Carbon pricing could be another option as it is argued that carbon pricing (emissions trading scheme) is a cost-effective method to reduce emissions which commenced in Australia from July, 2012. But it has just been abolished by the current Abbott government and whether it is gone for good or will be reinstated again remains to be seen. The abrogation of the emissions trading scheme (ETS) has put Australia in isolation from the international community in its efforts to reduce emissions.

Australia is also blessed with significant renewable resources such as wind, tidal energy, wave energy and geothermal energy although currently only 5% renewable energy is used for electricity production (Asafu-Adjaye and Mahadevan, 2013). Among the renewable resources, solar energy is the most valid option for reducing emissions as Australia is one of the sunniest countries in the world and that it is blessed with very strong wind (Byrnes et al., 2013). Queensland, one of the largest provinces of Australia is known as the sunshine state for its affluence in sunlight. Currently, there is no assistance to firms for investment in renewable energy sources even in solar energy. Aggressive investment for technological improvement in the renewable sector is important for Australia in order to achieve its target of producing 20% of electricity from the use of renewables by the year 2020. Apart from massive investment in the renewable sector, building nuclear energy is another potential option for Australia for power generation. Usually nuclear energy plants involve huge investment and the benefits are likely to be due only in the very long-run. Public investment in this sector is a preferred choice. Since Australia is one of the few developed countries whose economy remained stable for a long time now, large scale investment in nuclear energy is not very challenging. However, the success and sustainability of nuclear energy plants also depend on the consensus among the political parties.

Another finding of the study, the positive long-run relationship between economic growth and electricity consumption imply that Australia is in a position to pursue energy conservation policy without having its economic growth adversely affected (Hamdi et al., 2014). But energy conservation policy is not currently a good option for Australia given its enormous domestic demand for energy for its booming resources such as coal and mining which contribute towards huge export earnings. Energy efficiency gains should be the ultimate goal for significant reduction in its emissions.

This study also emphasizes on the Internet based electricity efficiency strategy to reduce environmental damage caused by $CO_2$ emissions as an inevitable consequence of additional electricity consumption due to massive increase in the Internet usage. Once energy efficiency gains from the growth in the Internet usage are achieved, this is expected to further promote the expansion of the Internet use and its accessories in the country as this will potentially reduce the cost of using the Internet services and the accessories which are likely to play an important role in reducing digital divide in Australia. Australia can in no way pursue or support a policy that may decelerate the growth of the Internet usage since digital divide is already in the danger of widening (Bowles, 2012). Electricity efficiency generated from various measures adopted for introducing and promoting green Internet is expected to encourage the various policies such as the ongoing rollout of the NBN for the growth of the Internet usage to continue. To achieve this goal of electricity efficiency, this study recommends that Australia promotes green Internet, green IT and IT for green that have the potential to substantially reduce $CO_2$ emissions through eco-efficiency and eco-design processes (Jenkin et al., 2011). Also the energy policy experts of Australia must recognize that electricity sector itself provides substantial opportunities for reducing emissions if measures such as fuel switching and generation efficiency improvement initiatives are taken (Ang et al., 2011). Finally, an effective coordination among ICT policy, energy policy and growth policy appears to be vital to address the climate change issue in Australia.

Despite important and significant findings, the current study suffers from a number of limitations. First, this study uses data for the period of 1990–2012 as the Internet data was available only from 1990. Future studies dealing with longer sample period are expected to provide more reliable results. Although, the robustness of the findings have been confirmed through a couple of other econometric techniques, still they might not be invariant across different other econometric methodologies. As the currently ongoing NBN rollout is expanding the Internet infrastructure across Australia, it is expected to lead to the increase in the Internet usage eventually resulting in a further increase in domestic electricity demand. The increase in electricity consumption is expected to cause a higher level of $CO_2$ emissions. Therefore, assessing the direct impact of the Internet usage on $CO_2$ emissions in Australia could be a potential topic for further investigation. This is left for future research.

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## Appendix A. Supplementary data

Supplementary data associated with this article can be found, in the online version, at http://dx.doi.org/10.1016/j.tele.2015.04.011.

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# CHAPTER SIX
# PAPER 8 AND PAPER 9

## PAPER 8: THE EFFECTS OF INTERNET USAGE AND ECONOMIC GROWTH ON $CO_2$ EMISSIONS IN OECD COUNTRIES: A PANEL INVESTIGATION

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# PAPER 8: THE EFFECTS OF INTERNET USAGE AND ECONOMIC GROWTH ON $CO_2$ EMISSIONS IN OECD COUNTRIES: A PANEL INVESTIGATION

## Statement of Contributions of Authorship

To whom it may concern

I, Mohammad Salahuddin contributed 80% to the paper entitled above and mentioned below;

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# The effects of Internet usage and economic growth on $CO_2$ emissions in OECD countries: A panel investigation

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ABSTRACT

This paper estimates the short- and long-run effects of Internet usage and economic growth on carbon dioxide ($CO_2$) emissions using OECD panel data for the period 1991–2012. The Pedroni panel cointegration test confirms that the variables are cointegrated. Although Pooled Mean Group (PMG) estimates indicate a positive significant long-run relationship between Internet usage and $CO_2$ emissions, the coefficient is very small and no causality exists between them, which both imply that the rapid growth in Internet usage is still not an environmental threat for the region. The study further indicates that economic growth has no significant short-run and long-run effects on $CO_2$ emissions. Internet use stimulates both financial development and trade openness. The findings offer support in favor of the argument that OECD countries can promote their Internet usage without being significantly concerned about its environmental consequences. But the future emissions effect of Internet usage cannot be ruled out, as is evident from the variance decomposition analysis. Therefore, this study recommends that in addition to boosting the existing measures for combating $CO_2$ emissions, OECD countries need to use ICT equipment not to simply reduce its own carbon footprint but also to exploit ICT-enabled emissions abatement potential to reduce emissions in other sectors, such as the power, energy, agricultural, transport and service sectors.



**Contents**



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## 1. Introduction

The world has witnessed a significant increase in the growth of Information and Communications Technology (ICT) use over the past three decades [7]. Although this rapid growth in ICT usage is believed to lead to improvements in productivity and energy efficiency, its effects on the environment are still inconclusive. Some studies support the positive role of ICT in mitigating greenhouse gas emissions [18,32,39,45,7,72,73], while others conclude that ICT use exerts pressure on energy use [41] through the resultant increase in electricity consumption [41,62], which is one of the key reasons for global $CO_2$ emissions [25].

It is argued that data centers have grown robustly by 11% per year over the past decade [22]. Statistics indicate that 1.1–1.5% of the world's total electricity consumption is related to the data center industry [16]. Also, globally, electricity consumption caused by ICT products and services has increased from about 3.9% in 2007 to 4.6% in 2012 [26]. A significant percentage of domestic electricity consumption in Europe is attributed to ICT products and services [19]. The rapid growth in ICT use, especially Internet usage, exerts pressure on domestic demand for electricity consumption [62]. According to some estimates [20,66], the ICT industry is responsible for around 2% of global $CO_2$ emissions.

OECD governments are funding Internet network rollouts worth billions of dollars for further expansion of ICT use [42]. ICT use, especially Internet use as the leading ICT variable, has been transforming the economies of OECD countries over the past 20 years [77]. Internet usage has been expanding in these countries at a staggering speed.

OECD economies are characterized by the highest level of energy consumption in the world, and electricity is one of the key sources of this huge energy supply [63]. The same authors argue that about 80% of the power generation is still sourced from non-renewable resources in these countries; as a result, there has been a sharp increase in $CO_2$ emissions. To exacerbate this, ICT-related electricity consumption has increased significantly [30]. Due to the ongoing growth in the data centers, demand for electricity-operating data centers can increase by 15–20% annually [16]. The massive growth in Internet use in the region is likely to exert pressure on energy demand, especially on electricity demand which may or may not cause emissions to rise.

In the light of the twin reality of huge energy demand and massive growth in Internet use in OECD countries, undertaking an investigation into the Internet–$CO_2$ emissions nexus is a worthy one. In addition, to the best of the authors' knowledge, no study has so far investigated this association for OECD countries and as such, this study is the first ever attempt to fill the void. It exploits OECD panel data for the investigation.

The current study also includes real GDP per capita as a proxy for economic growth as an independent variable. The reason for including real GDP per capita is that usually, simple bivariate models may fail to appropriately capture the empirical relationship between the series [43,5]. Also, since the mid-1980s, the income–emissions nexus has been a central focus in the empirical works of energy researchers [25]. Therefore, the inclusion of real GDP per capita in this study as a proxy for economic growth is justified.

This empirical exercise is expected to result in a number of contributions to this area of research. First, it is believed that the Internet–$CO_2$ emissions association is a very promising but a relatively unexplored area. Second, although literature on the effects of income on $CO_2$ emissions is abundant, the current study further enriches the panel literature with the use of most recent data from OECD countries. Third, the study also makes a methodological contribution by employing the Pooled Mean Group Regression (PMG) technique that has never been used before for such investigation, although findings from the application of such a technique are potentially more policy-oriented. Fourth, the results of this study are expected to have important implications for ICT policy, energy policy and growth policy in OECD countries.

The rest of this paper is structured as follows: Section 2 presents a literature review; data and methodology is discussed in Section 3; Section 4 presents the estimation results; and the paper ends with Section 5, with conclusions and policy implications of the findings.

## 2. Literature review

### 2.1. Energy impacts of ICT

The environmental implications of ICT were not researched until the early 1990s, and since then, research on the energy impacts of ICT use began emerging. Cohen et al. [9] and Jokinen et al. [36] were among the authors who first examined such relationships from theoretical and conceptual perspectives. Although the findings of both studies were inconclusive, they remain important as providing a starting point for further research. Roome and Park [59] provided a framework to address information, communication, computing and electronic technologies (ICCE). They concluded that such technologies have both positive and negative implications for sustainability.

Sui and Rejeski [69] cautioned environmental policymakers about the complexity and uncertainty in the relationship between information technology and environmental performance, despite highlighting the positive roles of emerging ICT such as dematerialization, decarbonization and demobilization. Matthews et al. [40] compared the environmental and economic performances of traditional retailing and e-commerce logistic networks in the United States and Japan. The study failed to reach a conclusion about which of the two methods was energy efficient. Toffel and Horvath [72], in their research, concluded that reading newspapers online and video teleconferencing have lower environmental impacts than their traditional counterparts.

Takase and Murota [70] developed and employed economic and energy models to assess the effects of ICT investment on energy consumption in Japan and the USA. Their findings indicated that increases in IT investment would lower energy intensity in Japan and, as such, Japan should conserve more energy by promoting IT. For the USA, future IT investment will have a positive income effect, which is likely to increase domestic demand for energy consumption. Hilty et al. [27], using scenario techniques and expert consultations, contributed towards a general understanding of the environmental impacts of ICTs. Hilty [28] argued that ICT development contributes towards dematerialization through substitution and optimization of energy consumption.

Erdmann and Hilty [18] identified two green ICT waves. The first one focuses on the rising Internet economy and the second one addresses the potential of ICT in reducing emissions. It is argued that ICT can play a significant role in reducing the negative effects of climate change by improving energy efficiency and reducing renewable energy costs [41]. Ropke and Christensen [60] developed a theoretical framework to describe and analyze the energy impacts of ICT from an everyday perspective. The framework assessed how increased ICT use would cope with the energy-demanding features of everyday life. The study also examined the impacts of ICT use over the passage of time and space. It supported the argument that ICTs have great potential to reduce energy consumption, depending on certain economic and political conditions.

Coroama et al. [10] presented the results of a field experiment using ICT as a substitute for more carbon-intensive technology. Their findings suggested a considerable decline in travel-related GHG emissions as a result of virtual participation in conferences. Coroama et al. [11] further suggested that through the e-conversion of books of large sizes, a significant amount of energy could be saved – an audio file consumes much less energy than printing a book. Cai et al. [6], in their study on a panel of firms, showed that appropriate use of IT and IT-related systems and equipment enhances the productivity and energy efficiency of firms in China. Coroama et al. [12] emphasized the substitution effect engendered by the ICT-enabled abatement potential. Khreishah et al. [38] argued that it is possible to reduce emissions caused by data centers through the application of network coding. Funk [21] insisted that there is significant ICT-enabled emissions abatement potential in the transport sector. The widespread use of GPS, smart phones and other connected devices in the public transport sector can potentially contribute towards energy savings. Al-Mulali et al. [1] investigated the influence of Internet retailing on $CO_2$ emissions in 77 developed and developing countries for the period 2000–2013. The results for both panels indicated that GDP growth, electricity consumption, urbanization and trade openness are the main factors that increase $CO_2$ emissions in the investigated countries. Although the results showed that Internet retailing reduces $CO_2$ emissions in general, a disaggregation occurs between developed and developing countries whereby Internet retailing has a significant negative effect on $CO_2$ emissions in the developed countries while it has no significant impact on $CO_2$ emissions in the developing countries.

Ishida [32], in a time series study on Japan, researched the impact of ICT on economic growth and energy consumption. The findings suggested that a decline in energy consumption is possible through energy efficiency gains from ICT use. Zhang and Liu [75] examined the effect of the ICT industry on $CO_2$ emissions in China and found that ICT use reduces $CO_2$ emissions through energy efficiency gains. But this study used data for a very short sample period (2000–2010); hence, the findings may have little policy relevance. Recent studies suggest that ICT use and environmental sustainability are intertwined. The relationship between ICT and environmental sustainability eventually led to two recent concepts that are known as 'green ICT' and 'ICT for green'. Green ICT is the ICT sector's capability to combat its own carbon footprint, while ICT for green is taken to mean ICT's potential to reduce the carbon footprint across other sectors of the economy. From the above discussion, it is obvious that despite significant ICT-enabled emissions abatement potential, its energy impact is still mixed and no consensus on this effect has yet been realized.

It is evident from the above literature review that so far, there has been no study that has assessed the emissions impact of Internet usage in the context of OECD countries. The rapid increase in Internet usage and the ongoing rollouts aiming to expand Internet infrastructure further have obviously been exerting some pressure on domestic electricity demand, and OECD countries may or may not be faring well with its positive or negative environmental consequences. This study conducts thorough research into this possibility and is expected to provide a detailed understanding about this burning issue.

### 2.2. ICT use and electricity consumption

ICT products and services need electricity for operation. ICT use in general, and massive growth in Internet use in particular, is expected to exert increasing pressure on electricity consumption, via which it is likely to cause emissions. Researchers have paid some attention to the ICT–electricity consumption association, although it is a relatively under-investigated area of research despite its potential implications for environmental sustainability. Most of the studies to date involved developed economies and have used time series data or, at an industry level, cross-sectional data [61].

Romm [58], in a study on the US economy, showed that the Internet does not cause increases in electricity demand, rather, it seems to enhance energy efficiency.

Cho et al. [8] employed a logistic growth model to examine the effects of ICT investment on energy consumption and showed that in the service sector and most of the manufacturing sectors, ICT investment increases electricity consumption. However, overall findings of the study supported the view that increased use of ICT leads to increased energy efficiency. The European Commission, E-Business Watch [15] analyzed the effects of ICT on electricity for Austria, Germany, Denmark, Finland, France, Italy, Spain and the UK, as well as for a number of firms. The findings indicated that at the aggregate level, ICT use increases electricity consumption while at the micro level, it enhances energy efficiency. Heddeghem et al. [26] examined the trend in worldwide electricity consumption and showed that the absolute electricity consumption of three key ICT categories – communication networks, personal computers and data centers – increased between 2007 and 2012.

Sadorsky [61] investigated the relationship between ICT use and electricity consumption in emerging economies using a dynamic panel model. The study found that ICT use increases electricity consumption in these countries. Moyer and Hughes [41] estimated the impacts of ICT on carbon emissions. They argued that ICT has the potential to reduce overall carbon emissions across a 50-year time horizon. The study further recommended that the global carbon pricing issue should be incorporated into ICT policy.

In their recent study, Zhang and Liu [75] found very inspiring results for China on the relationship between the ICT industry and $CO_2$ emissions. They used Chinese provincial panel data for the period 2000–2010. Their findings indicated that the ICT industry reduces $CO_2$ emissions. In perhaps the most recent study, Salahuddin and Alam [62] examined the empirical link among Internet usage, electricity consumption and economic growth for Australia. The study indicated that both Internet usage and economic growth stimulate electricity consumption; also, that Internet usage Granger-causes electricity consumption and economic growth in Australia.

Most of the empirical literature on the ICT–electricity and ICT–emissions associations reveals that use of ICTs is very likely to have potential emissions impacts through the increased consumption of electricity. However, literature on the ICT–electricity consumption nexus is still inadequate, although such association has significant implications for environmental sustainability of countries and regions. The literature mostly deals with time series data.

### 2.3. $CO_2$ emissions, economic growth, financial development and trade openness

The increase in $CO_2$ emissions is undisputedly one of the key causes of global warming and climate instability. As such, energy economics literature involves testing the empirical relationship between economic growth and $CO_2$ emissions. The association between $CO_2$ emissions and economic growth is popularly referred to as the Environmental Kuznets Curve (EKC) hypothesis, which postulates that the relationship between economic growth and $CO_2$ emissions can be reflected through an inverted U-shaped curve. 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 proposed and tested by Grossman and Krueger [24]. Numerous studies such as Stern [67], Dinda and Coondoo [13], Ozturk and Acaravci [43], Apergis and Ozturk [4], Shahbaz et al. [65] and Al-Mulali et al. [2] have examined the hypothesis using various datasets and econometric approaches. However, the empirical outcomes of these studies are mixed and inconclusive.

The relationship between $CO_2$ emissions and financial development has also been investigated in the literature. Tamazian et al. [71] found that a high degree of financial development improves environmental conditions. Jalil and Feridun [33] reported that financial development reduces $CO_2$ emissions in China. Zhang [76] found that financial development contributes significantly towards increasing $CO_2$ emissions. Financial development was found to stimulate energy consumption and $CO_2$ emissions in Sub Saharan African countries [3]. Ozturk and Acaravci [44] reported that financial development has no significant effect on per capita carbon emissions in the long run for Turkey. Overall, the literature suggests mixed effects of financial development on $CO_2$ emissions; therefore, further investigation of this relationship is justified. Literature examining the relationship between trade openness and $CO_2$ emissions also provided mixed results.

## 3. Data and methodology

### 3.1. Data

This study used a dynamic panel dataset for 31 out of 34 OECD countries for the period 1991–2012. Three countries, Hungary, Mexico and Turkey were dropped from the study due to non-availability of adequate data. The core variables used in the study were $CO_2$ emissions per capita and the number of Internet users per 100 people, that is, individuals who have worldwide access to and used the Internet from any location in the three months prior to the time of data collection.

Data from the International Energy Agency [31] on per-capita $CO_2$ emissions for OECD countries was used. Annual time series data on Internet users per 100 people for the period 1991–2012 were obtained from the World Data Bank (previously, World Development Indicators database [74]). A few missing values were observed in the series of Internet users per 100 people, which were replaced by three-year moving average values.

Data on Internet usage revealed that the OECD countries experienced a spectacular growth in Internet usage rates during the sample period of this study (Fig. 1). At the start of the sample period in 1991, less than 1% of the population were Internet users in all OECD countries. Iceland, Norway, Sweden, Netherlands, Denmark, Luxembourg and Finland were among the OECD countries that had more than 90% of their population using the Internet, while Greece had the lowest Internet usage rate of 56%. Although the overall growth in Internet usage was phenomenal, it was not uniform across the region. This disparity in the percentage of Internet users between countries is a clear indication that digital divide exists between OECD countries.

As bivariate models are likely to suffer from variable omission bias (Lean and Smyth [37]), this study included a number of other potential variables – real GDP per capita measured at constant 2005 US$, 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. Data for all these variables were also obtained from the World Data Bank, 2013 (previously, World Development Indicators (WDI) database). Logarithmic transformations of data were performed.

### 3.2. The model

To capture the effects of Internet use and other variables on $CO_2$ emissions, an econometric model of the following form was

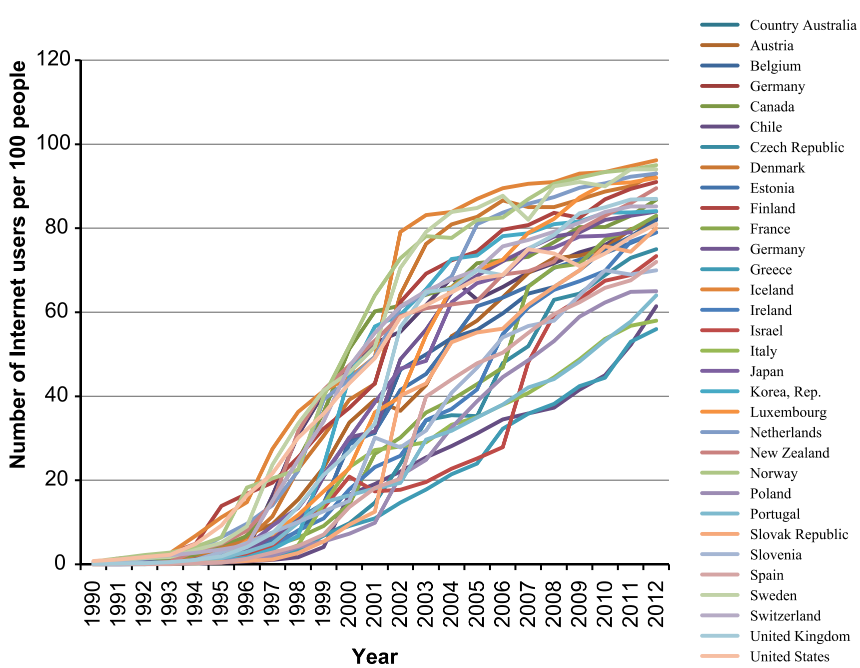


**Fig. 1.** Trends in the Internet usage in OEDC countries during 1990–2012.
*Source*: The World Development Indicators Database, The [74].

estimated in the current study:

$$CO_{2it} = \beta_0 + \beta_1 NET_{it} + \beta_2 GDPC_{it} + \beta_3 FD_{it} + \beta_4 TO_{it} + \varepsilon_{it} \quad (1)$$

where $\mathcal{E}_{it} = \mu_i + \nu_{it}$, while $\mu_i \approx (0, \sigma^2 \mu)$ and $\nu_{it} \approx (0, \sigma^2 \nu)$ are independent of each other and among themselves. $\mu_i$ and $\nu_{it}$ denote country-specific fixed effects and time variant effects, respectively. The subscripts $i$ and $t$ represent country ($i = 1\ldots31$) and time period (1991–2012), respectively.

The coefficients, $\beta_1, \beta_2, \beta_3$ and $\beta_4$ represent the long-run elasticity estimates of $CO_2$ emissions with respect to the number of Internet users per 100 people, per capita real GDP (measured at constant 2005$), financial development and trade openness, respectively. The signs of the effects of the independent variables on $CO_2$ emissions cannot be anticipated at this stage, as the literature offers inconclusive evidence on these relationships.

### 3.3. Estimation procedures

The estimation of our model proceeded as follows:

i. A cross-sectional dependence test was conducted to verify its presence in the panel.
ii. Having found cross sectional dependence across the panel, an appropriate panel unit root test (CIPS) was conducted to assess the stationarity of the data.
iii. The presence of unit root enforced the Pedroni cointegration test to verify the cointegrating relationship among the variables.
iv. Having confirmed the presence of a cointegrating association, the PMG regression method was used to estimate the short- and long-run relationship among the variables, along with the estimation of an error correction term.
v. The Dumitrescu-Hurlin [14] test was conducted to assess causality.
vi. The Dynamic Ordinary Least Squares (DOLS) [68] and Group Mean Fully Modified Ordinary Least Squares (GM-FMOLS) [46,50] methods were applied to check for the robustness of the obtained long-run coefficients from PMG estimates.
vii. Finally, the robustness of the causal association was checked by the variance decomposition analysis technique.

#### 3.3.1. Cross-sectional dependence and unit root tests

First, the cross-sectional dependence (CD) test was applied. This test was developed by Pesaran [51], who defined the CD statistic as:

$$CD = \left[\frac{TN(N-1)}{2}\right]^{1/2} \bar{\hat{\rho}}, \quad (2)$$

where, $\bar{\hat{\rho}} = \left(\frac{2}{N(N-1)}\right) \sum_{i=1}^{N-1} \sum_{j=i+1}^{N} \hat{\rho}_{ij}$, in which $\hat{\rho}_{ij}$are the pair-wise cross-sectional correlation coefficients of residuals from the conventional ADF regression; T and N are sample and panel sizes, respectively.

Having found the cross-sectional dependence across the panel, next, the authors considered the cross-sectionally augmented Dickey-Fuller (CADF) regression as follows:

$$\Delta y_{it} = \alpha_i + K_i t + \beta_i y_{it-1} + \gamma_i \bar{y}_{t-1} + \phi_i \Delta \bar{y}_t + \epsilon_{it}$$
$$t = 1, \ldots, T \text{ and } i = 1, \ldots, N, \quad (3)$$

where $\bar{y}_t = N^{-1} \sum_{i=1}^{N} y_{it}$ is the cross-sectional mean of $y_{it}$. It is a modified version of the t-bar test proposed by Im, Pesaran and Shin (IPS), referred to as the cross-sectionally augmented IPS unit root (CIPS) test. The null hypothesis of the test can be expressed as $H_0$: $\beta_1 = 0$ for all $i$ against the alternative hypothesis $H_1$: $\beta < 0$ for some $i$. The CIPS test statistic was obtained from Pesaran [52] as follows:

$$CIPS(N,T) = N^{-1} \sum_{i=1}^{N} t_i(N,T), \quad (4)$$

where ti ($N$, $T$) is the $t$ statistic of βi in Eq. (3). The critical values of CIPS (N, T) are available in Table II(c) of Pesaran [52].

#### 3.3.2. Panel cointegration test

CIPS unit root test results confirmed the presence of unit root, that is, the data are stationary at first difference [I(1)]. Therefore, we conducted several panel cointegration tests suggested by Pedroni [47] to examine whether a cointegrating relationship between the variables exists. The reason for employing the Pedroni cointegration test is that it controls for country size and heterogeneity allowing for multiple regressors (as in this case). Pedroni [49] provides seven panel cointegration statistics for seven tests. Four of those are based on the within-dimension tests, while the other three are based on the between-dimension or group statistics approach.

The starting point of the residual-based panel cointegration test statistics of Pedroni [61] is the computation of the residuals of the hypothesized cointegrating regression:

$$Y_{i,t} = \alpha_i + \beta_{1,i} X_{1i,t} + \beta_{2,i} X_{2i,t} + \ldots\ldots + \beta_{M,i} X_{Mi,t} + \varepsilon_{i,t} \quad (5)$$

Where $T$ is the number of observations over time, $N$ denotes the number of individual members in the panel, and $M$ is the number of independent variables. It was assumed here that the slope coefficients $\beta_{1i}, \ldots\ldots \beta_{Mi}$ and the member-specific intercept $\alpha_i$ can vary across each cross-section. To compute the relevant panel cointegration test statistics, the panel cointegration regression in Eq. (1) should be estimated first. For computation of the panel-$\rho$ and panel-$t$ statistics, the authors took the first difference of the original series and estimated the residuals Δof the following regression:

$$Y_{i,t} = b_{1i,} \Delta x_{1i,t} + b_{2,i} x_{2i,t} + \ldots\ldots + b_{M,i} \Delta x_{Mi,t} + \pi_{i,t} \quad (6)$$

Using the residuals from the differenced regression, with a Newey-West (1987) estimator, the long-run variance of $\hat{\pi}_{i,t}^2$ which is symbolised as $\hat{L}_{11i}^2$ was calculated as:

$$\hat{L}_{11i}^2 = \frac{1}{T} \sum_{t=1}^{T} \hat{\pi}_{i,t}^2 + \frac{2}{T} \sum_{s=1}^{k_i} \left(1 - \frac{s}{k_i + 1}\right) \frac{1}{T} \sum_{t=s+1}^{T} \hat{\pi}_{i,t} \hat{\pi}_{i,t-s} \quad (7)$$

For panel-$\rho$ and group-$\rho$ statistics, we estimated the regression using $\hat{e}_{i,t} = \hat{\gamma}_i \ \hat{e}_{i,t-1} + \hat{u}_{i,t}$, using the residuals $\hat{e}_{i,t}$ from the cointegration regression (2). Then the long-run variance ($\hat{\sigma}_i^2$) and the contemporaneous variance ($\hat{s}_i^2$)of $\hat{u}_{i,t}$ were computed, where:

$$\hat{s}_i^2 = \sum_{t=1}^{T} \hat{u}_{i,t}$$

$$\hat{\sigma}_i^2 = \frac{1}{T} \sum_{t=1}^{T} \hat{u}_{i,t} + \frac{2}{T} \sum_{s=1}^{k_i} \left(1 - \frac{s}{k_i + 1}\right) \frac{1}{T} \sum_{t=s+1}^{T} \hat{u}_{i,t} \hat{u}_{i,t-s}$$

where ki is the lag length. In addition to this, we also calculated the term:

$$\lambda_i = \frac{1}{2}\left(\hat{\sigma}_i^2 - \hat{s}_i^2\right)$$

On the other side, for panel-$t$ and group-$t$ statistics again using the residuals of $\hat{e}_{i,t}$ of $\hat{e}_{it}$ of cointegration regression (1), we estimated $\hat{e}_{i,t} = \hat{\gamma}_i \hat{e}_{i,t-1} + \sum_{t}^{k} = 1 \hat{\gamma}_{ik} \Delta \hat{e}_{i,t-1} + \hat{u}_{i,t}^*$

In this study, to determine the lag truncation order of the ADF t-statistics, the step-down procedure and the Schwarz lag order selection criterion were used:

$$\hat{s}_i^{*2} = \frac{1}{T} \sum_{t=1}^{T} \hat{u}_{i,t}^{*2}, \ \sim s_{i,t}^{*2} \equiv \frac{1}{N} \sum_{t=1}^{N} \hat{s}_i^{*2}$$

The next step was calculation of the relevant panel cointegration statistics using the following expressions:

a. Pedroni test statistics based on within dimension:

i. Panel v-statistic:

$$Z_v = \left( \sum_{i=1}^{N} \sum_{i=1}^{T} \hat{L}_{11}^{-2} \hat{e}_{it-1}^{2} \right)^{-1} \tag{8}$$

ii. Panel – statistic:

$$Z_p = \left( \sum_{i=1}^{N} \sum_{i=1}^{T} \hat{L}_{11}^{-2} \hat{e}_{it-1}^{2} \right)^{-1} \sum_{i=1}^{N} \sum_{i=1}^{T} \hat{L}_{11}^{-2} \hat{e}_{it-1}^{2} (\hat{e}_{it-1} \Delta \hat{e}_{it} - \hat{\lambda}_i) \tag{9}$$

iii. Panel pp-statistic:

$$Z_t = \left( \hat{\sigma}^2 \sum_{i=1}^{N} \sum_{i=1}^{T} \hat{L}_{11}^{-2} \hat{e}_{it-1}^{2} \right)^{-\frac{1}{2}} \sum_{i=1}^{N} \sum_{i=1}^{T} \hat{L}_{11}^{-2} \hat{e}_{it-1}^{2} (\hat{e}_{it-1} \Delta \hat{e}_{it} - \hat{\lambda}_i) \tag{10}$$

iv. Panel ADF statistic:

$$Z*_p = \left( \hat{S}^{*2} \sum_{i=1}^{N} \sum_{i=1}^{T} \hat{L}_{11}^{-2} \hat{e}_{it-1}^{*2} \right)^{-\frac{1}{2}} \sum_{i=1}^{N} \sum_{i=1}^{T} \hat{L}_{11}^{-2} \hat{e}_{it-1}^{*2} (\hat{e}_{it-1}^{*2} \Delta \hat{e}_{it}) \tag{11}$$

b. Pedroni test statistics based on between dimension

i. Group –$p$ statistic:

$$\tilde{Z}_p = \sum_{i=1}^{N} \left( \sum_{i=1}^{T} \hat{e}_{it-1}^{-2} \right)^{-1} \sum_{i=1}^{T} \hat{e}_{it-1}^{2} (\hat{e}_{it-1} \Delta \hat{e}_{it} - \Delta \hat{\lambda}_i) \tag{12}$$

ii. Group pp-statistic:

$$\tilde{Z}_t = \sum_{i=1}^{N} \left( \hat{\sigma}^2 \sum_{i=1}^{T} \hat{e}_{it-1}^{-2} \right)^{-1/2} \sum_{i=1}^{T} \hat{e}_{it-1}^{2} (\hat{e}_{it-1} \Delta \hat{e}_{it} - \hat{\lambda}_i) \tag{13}$$

iii. Group ADF statistic:

$$\tilde{Z}_t^* = \sum_{i=1}^{N} \left( \sum_{i=1}^{T} \hat{S}^2 \hat{e}_{it-1}^{*-2} \right)^{-1/2} \sum_{i=1}^{T} \hat{e}_{it-1}^{*} (\hat{e}_{it-1} \Delta \hat{e}_{it}) \tag{14}$$

Lastly, we applied the appropriate mean and variance adjustment terms to each panel cointegration test statistic so that the test statistics were standard normally distributed: $\frac{X_{N,T} - \mu\sqrt{N}}{\sqrt{v}} => N(0,1)$where $\chi_{N,T}$ is the appropriately standardized form of the test statistic, and are the functions of moments of the underlying Brownian motion functionals. The appropriate mean and variance adjustment terms for different numbers of regressors ($m$ is the number of regressors without taking the intercept into account) and different panel cointegration test statistics are given in Table 2 in Pedroni [48].

The null hypothesis of no cointegration for the panel cointegration test is the same for all statistics, $H_0$: $\gamma_i$=1 for all $I$, whereas the alternative hypothesis for the between-dimension-based and within-dimension-based panel cointegration tests differs. The alternative hypothesis for the between-dimension-based statistics is $H_1$: $\gamma_i < 1$ for all $i$, where a common value for $\gamma_i=\gamma$ is not required. For within-dimension-based statistics, the alternative hypothesis is $H_1$: $\gamma=\gamma_i < 1$ for all $I$, and it assumes a common value for $\gamma_i = \gamma$.

### 3.3.3. Pooled mean group regression (PMG)

After the Pedroni cointegration test confirmed a cointegrating relationship between the variables, we applied the PMG method [54–56], which allows short-term adjustments and convergence speeds to vary across countries to account for cross-country heterogeneity. It further imposes cross-country homogeneity restrictions only on the long-run coefficients. The justification for common long-run coefficients across OECD countries was that they have access to common technologies and have intensive intra-trade and foreign direct investment.

The PMG method also allows the speed of convergence to the steady state to vary, which was deemed appropriate, as the short-run adjustment depends on country-specific characteristics such as vulnerability to domestic and external shocks (for example, the recent debt crisis in Greece and financial mismanagement, different types of adjustment to the recent global financial crisis), financial market imperfections, lack of sufficient time for implementation of different Internet and digital divide policies, and change in political regime and so on. In order to comply with the requirements for standard estimation and inference, the growth regression equation (Eq. (1)) was incorporated into an ARDL ($p$, $q$) model as follows:

$$\Delta(\mathrm{C_i})_t = \sum_{j=1}^{p-1} \gamma_j^i \Delta(\mathrm{c_i})_{t-j} + \sum_{j=0}^{q-1} \delta_j^i \Delta(\mathrm{x_i})_{t-j} + \varphi^i \left[ (\mathrm{C_i})_{t-1} - \beta_1^i (\mathrm{X_i})_{t-1} \right] + \epsilon_{it} \tag{15}$$

where, $(c_i)_{t-j}$ and $(C_i)_{t-1}$ represent short-run and long-run values of $CO_2$ emissions, respectively; while $\gamma_j^i$ and $\delta_j^i$ are short-run coefficients; $\phi^i$ is the error correction term; $(x_i)_{t-j}$ and $(X_i)_{t-1}$ are the short-run and long-run values of the independent variables, respectively; $\beta_1^i$ are the long-run coefficients; and $\mathcal{E}_{it} = \mu_i + \nu_{it}$ where $\mu_i$ and $\nu_{it}$ denote country-specific fixed effects and time variant effects, respectively.

### 3.3.4. Dumitrescu-Hurlin (DH) causality test

Assessing short-run and long-run association between variables without any knowledge about the causal link between them offers few policy implications [64]. Therefore, the current study employed a recently introduced DH [14] causality test which has two advantages over the traditional Granger [23] causality test. In addition to considering fixed coefficients like the Granger causality test, the DH test considers two dimensions of heterogeneity: the heterogeneity of the regression model used to test the Granger causality, and the heterogeneity of the causal relationship. To conserve space, we did not include the details of the derivation of DH statistic (Please refer to [14] for details).

### 3.3.5. DOLS and FMOLS estimates

Finally, the authors applied DOLS and GM-FMOLS methods and estimated the long-run coefficients between the variables in order to check for the robustness of the long-run coefficients from the PMG estimation. The application of the DOLS method to check robustness was appropriate in that this estimator is robust even when the sample size is small and does eliminate the simultaneity problem. Moreover, the obtained cointegrating vectors from the DOLS estimators are asymptotically efficient.

The GM-FMOLS panel technique [50] 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.

### 3.3.6. Variance decomposition analysis

Despite its importance for policy implications, one of the weaknesses of the causality analysis is that it cannot predict the strength of the causal relationship beyond the sample period. To overcome this limitation and to forecast the Internet–$CO_2$ emissions relationship beyond the sample period, this study employed variance decomposition analysis. The variance decomposition [53] measures the percentage contribution of each shock in the dependent variable as a consequence of shocks in independent variables beyond the selected time period. The main advantage of this approach is that it can be applied regardless of the order of variables. Engle and Granger [17] and Ibrahim [29] 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.

## 4. Empirical results

Table 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 our data.

Table 2 presents the Variance Inflation Factor (VIF) results which clearly demonstrate that all VIF values are less than 5, implying that our model is free from the threat of the multi-collinearity problem.

The unit root results are reported in Table 3. All the variables were found to be first difference stationary, indicating the presence of unit root in the data. This implies the likelihood of the presence of a cointegrating relationship among the variables.

Table 4 presents results from the Pedroni cointegration test. It is evident that the calculated values of four (Panel PP, Panel ADF, Group PP, Group ADF) out of seven test statistics are greater than the critical values, indicating rejection of the null hypothesis of no cointegration. All these four statistics have large negative values with associated probabilities less than 0.05. Thus, it can be concluded that there is a long-run cointegrating relationship among the variables.

Results from PMG estimates are reported in Table 5. The findings indicate that there is a positive significant relationship between Internet usage and $CO_2$ emissions in OECD countries in the long run. The results show that a 1% rise in Internet usage is likely to cause a 0.16% increase in $CO_2$ emissions. No significant relationship is observed between these variables in the short run. Economic growth has no significant association with $CO_2$ emissions both in the short and the long run. Both financial development and trade openness are found to negatively affect $CO_2$ emissions in the long run; however, in the short run, the effect of financial development on emissions is still positive while that of trade openness is negative.

The coefficient of the error correction term is −0.289, which is statistically significant at the 1% level of significance. This implies that the deviation from the long-run equilibrium is corrected by 28.9% each year and a full convergence process is expected to take around 3.5 years to reach the stable path of equilibrium. It further implies that the speed of the adjustment process is reasonable for any shock to $CO_2$ emissions in the region.

Table 6 reports DH causality results. Results show that there is no causal link between Internet usage and $CO_2$ emissions. Both financial development and trade openness are found to have bidirectional causality with $CO_2$ emissions. A unidirectional causal association running from $CO_2$ emissions to economic growth is also observed. Internet usage has a bidirectional causal link with economic growth and trade openness. Internet usage also causes financial development.

Results from GM-FMOLS and DOLS are reported in Table 7 and Table 8, respectively. Both estimates support long-run positive effects of Internet usage on $CO_2$ emissions. GM-FMOLS estimates

**Table 2**
Variance inflation factors.

| Variable | Uncentered VIF |
|---|---|
| LFD | 1.622428 |
| LGDPC | 1.004312 |
| LNET | 2.843832 |
| LTRD | 2.195388 |

**Table 3**
Panel unit root test results.

| Second-generation panel unit-root | | | | |
|---|---|---|---|---|
| Variables | $\hat{\rho}$ | CD | Levels CIPS | First differences CIPS |
| GDP per capita | 0.534 | 10.64*** | −1.030 | −2.118** |
| $CO_2$ emission | 0.415 | 17.41*** | −1.656 | −2.527*** |
| Financial development | 0.679 | 50.57*** | −2.918 | −2.749*** |
| Trade Openness | 0.639 | 63.60*** | −1.374 | −3.011*** |
| Internet | 0.981 | 99.18*** | −2.257** | −3.372*** |

*Note*: * represents significance at 10% respectively
** represents significance at 5% respectively
*** represents significance at 1% respectively

**Table 4**
Pedroni (2004) residual cointegration test results (as dependent variable).

| Alternative hypothesis: common AR coefs. (within-dimension) | | | | |
|---|---|---|---|---|
| | Statistic | Prob. | Weighted Statistic | Prob. |
| Panel v-Statistic | 0.084797 | 0.4662 | −0.855882 | 0.0040 |
| Panel rho-Statistic | 1.231955 | 0.8910 | 0.656587 | 0.0443 |
| Panel PP-Statistic | −4.280742 | 0.0000 | −5.179624 | 0.2432 |
| Panel ADF-Statistic | −3.072082 | 0.0011 | −3.909242 | 0.0000 |
| Alternative hypothesis: individual AR coefs. (between-dimension) | | | | |
| | Statistic | Prob. | | |
| Group rho-Statistic | 3.016381 | 0.9987 | | |
| Group PP-Statistic | −5.862244 | 0.0000 | | |
| Group ADF-Statistic | −3.876085 | 0.0001 | | |

*Notes*: The null hypothesis is that the variables are not cointegrated. Under the null tests, all variables are distributed normal (0, 1). ** indicates statistical significance at the 5% level.

**Table 1**
Descriptive statistics.

| | $LCO_2$ | LFD | LGDPC | LNET | LTRD |
|---|---|---|---|---|---|
| Mean | 2.203537 | 4.454854 | 10.11540 | 2.480347 | 4.287425 |
| Median | 2.184594 | 4.528996 | 10.27471 | 3.405672 | 4.255645 |
| Maximum | 3.311344 | 5.766635 | 11.38187 | 4.536784 | 5.809740 |
| Minimum | 0.871934 | 2.573067 | 8.323933 | -5.253446 | 2.767827 |
| Std.Dev. | 0.391963 | 0.564916 | 0.637163 | 2.059082 | 0.527706 |
| Skewness | 0.144931 | −0.615036 | −0.743011 | −1.079082 | −0.083561 |
| Kurtosis | 3.743080 | 3.229661 | 3.040612 | 3.197728 | 3.566102 |
| Jarque-Bera | 16.22281 | 39.92847 | 56.35276 | 119.7677 | 8.884230 |
| Probability | 0.000300 | 0.000000 | 0.000000 | 0.000000 | 0.011771 |
| Sum | 1348.565 | 2726.371 | 6190.627 | 1517.972 | 2623.904 |
| Sum Sq.Dev. | 93.87100 | 194.9884 | 248.0520 | 2590.529 | 170.1472 |
| Observations | 612 | 612 | 612 | 612 | 612 |

**Table 5**
Results from PMG estimation.

| Dependent variable: per capita $CO_2$ emissions | Pooled mean group | |
|---|---|---|
| Variable | Coefficient | Standard. error |
| *Long-run coefficients* | | |
| LNET | 0.16588** | 0.057978 |
| LGDPC | −0.05596 | 0.045028 |
| LFD | −1.13452 | 0.266819 |
| LTR | −5.770418 | 0.835596 |
| *Error correction Coefficient* | −.2899*** | 0.038967 |
| *Short-run coefficients* | | |
| Δ LNET | −.025687 | 0.066746 |
| Δ LGDPC | −.3648292 | .2671861 |
| Δ LFD | 1.481273 | .4812282 |
| Δ LTR | −2.042441 | .2308911 |
| Intercept | 9.347515 | 1.344647 |

*Notes*. * indicate 10% levels of significance, respectively.
** indicate, 5% levels of significance, respectively.
*** indicate 1%, levels of significance, respectively.

**Table 6**
Results from pairwise Dumitrescu-Hurlin Panel Causality Test.

Sample: 1991 2012
Lags: 1

| Null hypothesis: | W-Stat. | Zbar-Stat. | Prob. |
|---|---|---|---|
| LFD does not homogeneously cause LCO2 | 2.41314 | 4.09086 | 4.E-05 |
| LCO2 does not homogeneously cause LFD | 2.09512 | 3.08090 | 0.0021 |
| LGDPC does not homogeneously cause LCO2 | 3.66061 | 8.05258 | 9.E-16 |
| LCO2 does not homogeneously cause LGDPC | 11.2294 | 32.0895 | 0.0000 |
| LNET does not homogeneously cause LCO2 | 1.20804 | 0.26371 | 0.7920 |
| LCO2 does not homogeneously cause LNET | 1.40607 | 0.89261 | 0.3721 |
| LTRD does not homogeneously cause LCO2 | 1.70925 | 1.85547 | 0.0635 |
| LCO2 does not homogeneously cause LTRD | 0.47843 | −2.05339 | 0.0400 |
| LGDPC does not homogeneously cause LFD | 4.86505 | 11.8777 | 0.0000 |
| LFD does not homogeneously cause LGDPC | 4.86077 | 11.8640 | 0.0000 |
| LNET does not homogeneously cause LFD | 7.44267 | 20.0636 | 0.0000 |
| LFD does not homogeneously cause LNET | 2.88677 | 5.59503 | 2.E-08 |
| LTRD does not homogeneously cause LFD | 3.85329 | 8.66451 | 0.0000 |
| LFD does not homogeneously cause LTRD | 2.34970 | 3.88941 | 0.0001 |
| LNET does not homogeneously cause LGDPC | 8.84301 | 24.5108 | 0.0000 |
| LGDPC does not homogeneously cause LNET | 2.24261 | 3.54930 | 0.0004 |
| LTRD does not homogeneously cause LGDPC | 4.08512 | 9.40075 | 0.0000 |
| LGDPC does not homogeneously cause LTRD | 1.75154 | 1.98978 | 0.0466 |
| LTRD does not homogeneously cause LNET | 2.26584 | 3.62307 | 0.0003 |
| LNET does not homogeneously cause LTRD | 5.34122 | 13.3899 | 0.0000 |

indicate that a 1% increase in Internet usage would stimulate a 0.01% increase in $CO_2$ emissions, while the DOLS estimates suggest that a 1% increase in Internet usage would cause a 0.02% rise in $CO_2$ emissions. Thus, the long-run coefficients obtained from PMG estimates are robust across both DOLS and GM-FMOLS estimations, although the coefficients vary in the range between 0.01% and 0.16%.

Variance decomposition analysis results are presented in Table 9. The results forecast that Internet usage will have an increasing effect on $CO_2$ emissions in the region in the future. In the first 5-year time horizon (up to 2017), 0.01% of the variation in $CO_2$ emissions is expected to be explained by Internet usage followed by 0.11% in the 10th year. In the 21st year, the forecasted variance in the $CO_2$ emissions to be explained by Internet usage stands at 0.42%. Other variables are also forecasted to continue to affect $CO_2$ emissions during the period. In the 21st year, 1.52%, 1.64% and 1.38% of the variations in $CO_2$ emissions are explained by economic growth, financial development and trade openness, respectively.

**Table 7**
Results from panel fully modified least squares (FMOLS) method.

| Variable | Coefficient | Std. Error | t-Statistic | Prob. |
|---|---|---|---|---|
| LFD | 0.005407 | 0.017955 | 0.301137 | 0.7634 |
| LGDPC | −0.043835 | 0.015624 | −2.805671 | 0.0052 |
| LNET | 0.014714 | 0.004770 | 3.084385 | 0.0021 |
| LTRD | −0.145290 | 0.053488 | −2.716303 | 0.0068 |
| R-squared | 0.956794 | Mean dependent var | | 2.205290 |
| Adjusted R-squared | 0.954118 | S.D. dependent var | | 0.387890 |
| S.E. of regression | 0.083087 | Sum squared resid | | 3.789958 |
| Durbin-Watson stat | 0.552044 | Long-run variance | | 0.013498 |

**Table 8**
Panel Dynamic Least Squares (DOLS) method.

| Variable | Coefficient | Std. error | t-Statistic | Prob. |
|---|---|---|---|---|
| LFD | 0.107332 | 0.027666 | 3.879548 | 0.0001 |
| LGDPC | −0.104226 | 0.023023 | −4.527120 | 0.0000 |
| LNET | 0.025697 | 0.006529 | 3.935623 | 0.0001 |
| LTRD | −0.200264 | 0.068178 | −2.937354 | 0.0036 |
| R-squared | 0.994102 | Mean dependent var | | 2.203537 |
| Adjusted R-squared | 0.986847 | S.D. dependent var | | 0.391963 |
| S.E. of regression | 0.044953 | Sum squared resid | | 0.553689 |
| Long-run variance | 0.001024 | | | |

**Table 9**
Results from variance decomposition analysis.

| Period | S.E. | $LCO_2$ | LFD | LGDPC | LNET | LTRD |
|---|---|---|---|---|---|---|
| 1 | 0.055086 | 100.0000 | 0.000000 | 0.000000 | 0.000000 | 0.000000 |
| 2 | 0.070366 | 98.69685 | 0.503292 | 0.387702 | 0.018650 | 0.393504 |
| 3 | 0.084011 | 98.57094 | 0.487455 | 0.511161 | 0.013114 | 0.417329 |
| 4 | 0.095088 | 98.47460 | 0.429105 | 0.602939 | 0.011215 | 0.482144 |
| 5 | 0.104825 | 98.42014 | 0.360202 | 0.671401 | 0.014051 | 0.534208 |
| 6 | 0.113499 | 98.35277 | 0.307479 | 0.730904 | 0.021317 | 0.587529 |
| 7 | 0.121375 | 98.26373 | 0.278061 | 0.785285 | 0.032820 | 0.640102 |
| 8 | 0.128607 | 98.14834 | 0.273646 | 0.837132 | 0.048100 | 0.692785 |
| 9 | 0.135309 | 98.00652 | 0.293473 | 0.887738 | 0.066725 | 0.745548 |
| 10 | 0.141565 | 97.83972 | 0.335672 | 0.937898 | 0.088261 | 0.798451 |
| 11 | 0.147438 | 97.65019 | 0.397943 | 0.988088 | 0.112303 | 0.851480 |
| 12 | 0.152977 | 97.44046 | 0.477859 | 1.038602 | 0.138472 | 0.904610 |
| 13 | 0.158222 | 97.21312 | 0.573034 | 1.089616 | 0.166426 | 0.957807 |
| 14 | 0.163203 | 96.97068 | 0.681203 | 1.141232 | 0.195850 | 1.011036 |
| 15 | 0.167948 | 96.71551 | 0.800268 | 1.193498 | 0.226465 | 1.064261 |
| 16 | 0.172477 | 96.44980 | 0.928311 | 1.246426 | 0.258017 | 1.117449 |
| 17 | 0.176810 | 96.17555 | 1.063600 | 1.300003 | 0.290281 | 1.170571 |
| 18 | 0.180961 | 95.89456 | 1.204583 | 1.354197 | 0.323057 | 1.223599 |
| 19 | 0.184945 | 95.60848 | 1.349878 | 1.408966 | 0.356168 | 1.276511 |
| 20 | 0.188773 | 95.31874 | 1.498265 | 1.464254 | 0.389459 | 1.329286 |
| 21 | 0.192454 | 95.02663 | 1.648673 | 1.520002 | 0.422791 | 1.381907 |

## 5. Conclusions and policy implications

This study examined the relationship between Internet usage and $CO_2$ emissions for OECD countries for the period 1991–2012. A cross-sectional dependence test was performed to verify its presence in the panel. The stationarity of data was tested using the CIPS unit root test. This was followed by the Pedroni [48] cointegration tests, which confirmed a cointegrating relationship among the variables. The PMG technique was applied to estimate the short- and long-run relationship between Internet usage and $CO_2$ emissions. The causality was determined using the DH causality test. The robustness of the long-run association was checked by the application of the DOLS and FMOLS methods. Also, a forecasting analysis of this relationship was performed with the application of the variance decomposition method to assess how the rapid growth in Internet usage is going to impact $CO_2$ emissions in the region in the future.

Findings from PMG estimates indicated that there is a positive significant relationship between Internet usage and $CO_2$ emissions in OECD countries only in the long run; there is no significant relationship between these variables in the short run. Economic growth has no significant association with $CO_2$ emissions both in the short and long run. Both financial development and trade openness reduce $CO_2$ emissions in the long run; however, in the short run, the effect of financial development on emissions is still positive while that of trade openness is negative. Results from DOLS and GM-FMOLS estimates confirmed the robustness of the long-run association between Internet usage and $CO_2$ emissions, although the coefficients vary in the range between 0.01% and 0.16%. The statistically significant error correction coefficient is $-0.289$, which means that a full convergence process will take around 3.5 years to reach the stable path of equilibrium. The DH causality test revealed that there is no causal link between Internet usage and $CO_2$ emissions. Internet usage has a bidirectional causal link with economic growth and trade openness; Internet usage was also found to cause financial development.

This study attributes the absence of a causal link and small long-run coefficient of the association between Internet usage and $CO_2$ emissions to two potential factors. First, it is obvious that an insignificant amount of OECD's total electricity consumption is accounted for by Internet usage, and even if massive growth in Internet usage causes electricity consumption to rise, its emissions impact is not yet prominently visible, possibly due to the effects of ICT-enabled emissions abatement capacity. However, as Internet usage continues to increase, there will be increasing demand for electricity in the future, which might eventually lead to an increase in $CO_2$ emissions. This is reflected through the findings from variance decomposition analysis.

Therefore, to combat any potential environmental threat arising from the rapid growth of Internet usage, it is recommended that OECD countries continue with their existing measures such as controlling $CO_2$ emissions through post-combustion capture [57]. Also, carbon pricing (the emissions trading scheme) is a cost-effective method to reduce emissions. Investment should be boosted in renewable energy such as solar and wind energy.

In addition to these traditional means for combating emissions, this study further recommends that OECD countries exploit the potential of ICT – not just to reduce its own carbon footprint but also to capitalize on ICT-enabled emissions abatement potential to reduce emissions across other sectors of the economy. ICT-enabled technologies are able to reduce emissions through integration of renewable energy, power grid optimization, the substitution effect and also through increased use of ICT products and services in agriculture, such as smart phones, laptops, and different types of decision support software. Use of ICT-enabled technologies can also reduce emissions in the transport sector [39]. Building smart homes and smart cities, online monitoring of power lines, smart management of electricity consumption, integration of distributed energy sources, and data management through power grids are some of the promising areas where ICT-enabled technologies may significantly contribute towards per capita emissions reduction [34]. Also, more modern technologies such as product group-oriented standards, the hybrid lifecycle assessment technique and integration of carbon footprint into ICT products' supply chain for assessing the carbon footprint of the ICT industry, should be introduced and promoted. ICT can also contribute towards emissions reductions through building smart grid system [39]. To achieve the goal of electricity efficiency, this study also recommends that OECD countries gradually move towards green Internet, which has the potential to substantially reduce $CO_2$ emissions through eco-efficiency and eco-design processes [35]. Finally, effective coordination among ICT policy, energy policy and growth policy is recommended to address the climate change issues in the region.

The insignificant relationship between economic growth and $CO_2$ emissions lends support to the recent view that OECD countries have already achieved a certain level of energy efficiency gains, and as such, they are in a comfortable position to pursue pro-growth policies without being significantly concerned about emissions.

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## Appendix A. Supplementary material

Supplementary data associated with this article can be found in the online version at http://dx.doi.org/10.1016/j.rser.2016.04.018.

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# PAPER 9: IS RAPID GROWTH IN INTERNET USAGE ENVIRONMENTALLY SUSTAINABLE FOR AUSTRALIA? AN EMPIRICAL INVESTIGATION

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## Statement of Contributions of Authorship

To whom it may concern

I, Mohammad Salahuddin contributed 80% to the paper entitled above and mentioned below;

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I, as a coauthor recognize and accept that the contribution of the candidate indicated above for the above mentioned PhD output is appropriate.

Khorshed Alam Signature Date: January 26, 2016

Ilhan Ozturk Signature Date: January 26, 2016

**This paper is one of two papers included in Chapter six of the candidate's PhD thesis**

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RESEARCH ARTICLE

# Is rapid growth in Internet usage environmentally sustainable for Australia? An empirical investigation

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**Abstract** This study estimates the short- and long-run effects of Internet usage and economic growth on carbon dioxide ($CO_2$) emissions using annual time series macro data for Australia for the period 1985–2012. Autoregressive distributive lag (ARDL) bounds and Gregory–Hansen structural break cointegration tests are applied. ARDL estimates indicate no significant long-run relationship between Internet usage and $CO_2$ emissions, which implies that the rapid growth in Internet usage is still not an environmental threat for Australia. The study further indicates that higher level of economic growth is associated with lower level of $CO_2$ emissions; however, Internet usage and economic growth have no significant short-run relationship with $CO_2$ emissions. Financial development has both short-run and long-run significant positive association with $CO_2$ emissions. The findings offer support in favor of energy efficiency gains and a reduction in energy intensity in Australia. However, impulse response and variance decomposition analysis suggest that Internet usage, economic growth and financial development will continue to impact $CO_2$ emissions in the future, and as such, this study recommends that in addition to the existing measures to combat $CO_2$ emissions, Australia needs to exploit the potential of the Internet not only to reduce its own carbon footprint but also to utilize information and communication technology (ICT)-enabled emissions abatement potential to reduce emissions in various other sectors across the economy, such as, power, renewable energy especially in solar and wind energy, agriculture, transport and service.

**Keywords** Carbon dioxide emissions · Economic growth · Internet usage · Granger causality · ARDL · Australia

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## Introduction

Information and communication technologies (ICTs) have a wide array of effects on key global systems (Moyer and Hughes 2012). The rapid use and expansion of these technologies have proved to contribute towards increasing productivity, boosting economic growth (Shahiduzzaman and Alam 2014a, b) and reducing energy intensity (Coroama et al. 2013; Moyer and Hughes 2012; Mattern et al. 2010; Laitner and Ehrhardt-Martinez 2009; SMARTer 2020 Team 2012). Since the early 1990s, studies investigating the energy impacts of ICTs have been mostly researched in a macro framework (Sadorsky 2012; Ishida 2015 etc.). Although the rapid expansion of ICT usage is believed to improve productivity and energy efficiency, there is no consensus as yet on its effects on the environment. Some studies support the positive role of ICT in mitigating greenhouse gas (GHG) emissions (Toffel and Horvath 2004; Pamlin and Pahlman 2008; SMARTer 2020 Team 2012; Coroama et al. 2012; Erdmann and Hilty 2010; Ishida 2015; Hilty and Aebischer 2015), while others conclude that ICT use exerts pressure on energy use especially on electricity consumption (Moyer and Hughes 2012) which

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is one of the key sources of global $CO_2$ emissions (Hamdi et al. 2014).

Widespread expansion in the use of ICT has caused a rise in demand for electricity consumption in the last two decades, both in workplaces and households (IEA 2009). The combined electricity consumption related to ICT equipment is growing at nearly 7 % per year. The relative share of global electricity consumption of these ICT products and services has increased from about 3.9 % in 2007 to 4.6 % in 2012 (Heddeghem et al. 2014). According to some estimates (The Greenpeace International 2014), the ICT industry causes 2 % of global $CO_2$ emissions. Because all ICT products need electricity to operate, rapid expansion of ICT use leads to increasing demand for electricity, threatening environmental sustainability through GHG emissions, and Australia is no exception if the ICT-enabled emissions abatement potential are not exploited properly.

Since the mid-1990s, the use of the Internet—the leading ICT indicator—has been increasing at a rapid pace in Australia (Fig. 1). In 2011, 87 % of Australians used the Internet, up from 73 % in 2007. The proportion of Australians accessing the Internet through a mobile device increased from 15 to 37 % between 2009 and 2011 (Ewing and Julian 2012). Not only do these numeric figures reflect the Internet's recent role in the Australian economy in enhancing growth and productivity, two most recent empirical studies support the persistent positive role of ICT capital in boosting Australia's economic growth and productivity, although the growth in ICT productivity has been observed to decline in recent times (Shahiduzzaman and Alam 2014a, b).

Also, in its bid to be a leading digital economy, Australia is currently undergoing the construction of the largest ever broadband rollout project, the National Broadband Network (NBN). One of the key objectives of the NBN is to narrow the digital divide in the country (Lee 2011). However, to realize benefits from the massive expansion of broadband infrastructure, its potential impact on emissions need to be taken into

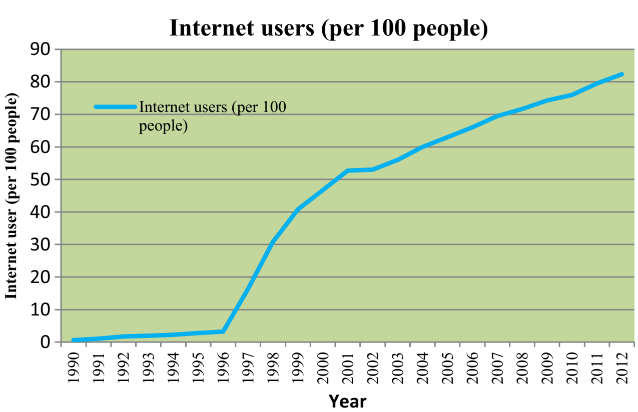


**Fig. 1** Trend in the number of Internet users in Australia during 1990–2012

cognizance. Australia is one of the top $CO_2$ emitters in the world alongside the USA, Canada, Germany, the UK, Saudi Arabia and Qatar on a per capita basis (Shafiei and Salim 2014). Eighty-seven percent of the power generation in Australia is still sourced from non-renewable fossil fuels such as coal, gas and oil (BREE 2014, Australian Energy Statistics).

Electricity generation is the single largest contributor to GHG emissions, producing 38 % of total emissions in Australia, and coal remains the largest source of electricity generation, providing 64 % of Australia's electricity needs in 2012–2013 (BREE 2014, Australian Energy Statistics, Table 8). As a result, there has been a sharp increase in per capita $CO_2$ emissions over the last four decades. Although energy intensity has been on a declining trend (Fig. 2) during the same period and also for most of the period from 1970 to 2012, it is still struggling to embrace a transition to a low-carbon economy despite the fact that Australia also has had some decoupling experiences. From 1971 to 2012, Australia experienced some extent of relative decoupling, while it also experienced absolute decoupling during 1970–1972, 1981, 1985, 1992, 1994 and again during 2000–2002 and 2010–2012 (Fig. 3). Figure 4 shows the logarithmic trends in Internet usage, GDP per capita, $CO_2$ emissions per capita and financial development during the period of 1985–2012.

Two key reasons for this declining trend in energy intensity and for enjoying some decoupling experiences may be the fuel efficiency gains from technological improvement and fuel switching (Shahiduzzaman and Alam 2013), and the rapid growth of a less energy-intensive service sector. However, a reduction in GHG emissions still remains a challenge for Australia.

In Australia, more than 20 % of total energy is still sourced from electricity (BREE 2014, Australian Energy Statistics), and the rapid expansion of the Internet already causes electricity consumption to rise (Salahuddin and Alam 2015) which may lead to higher level of emissions (Suh et al. 2015). But whether this rise in electricity consumption causes higher level of $CO_2$ emissions or not, a further investigation is needed before any conclusion could be drawn a priori. Although ICT causes emissions in all the leading emitting countries such as UK, Brazil, China, USA, Germany, Canada and India, all these countries are also blessed with significant ICT-enabled emissions abatement potential (SMARTer 2020 Team 2012) especially in the power, agriculture, manufacturing, transportation and service sectors. Due to the significant growth in the use of smart phones, a quantum shift from desktop PCs to laptops, arrival of iPads and tablets etc. over the last decade, it is obvious that ICT-enabled solutions are available in the market in Australia which may potentially outweigh its own carbon footprint as well as the emissions in all other sectors. Therefore, the current study will investigate the pollution

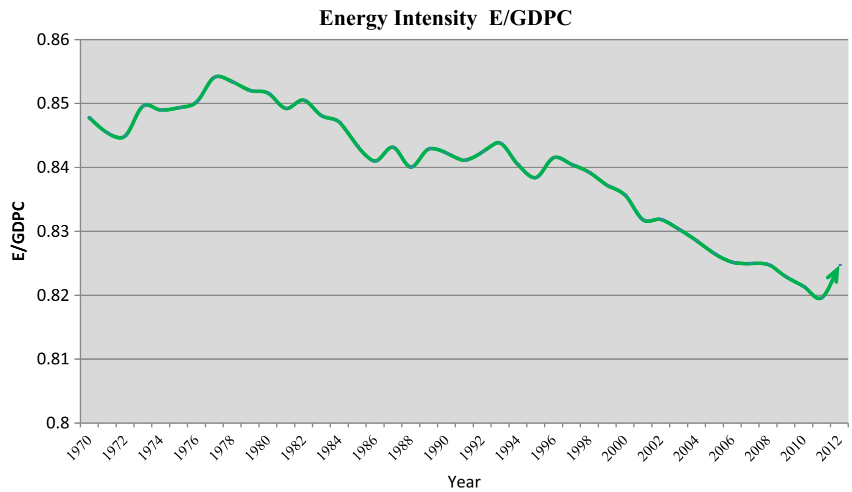


**Fig. 2** Trend in energy intensity in Australia during 1970–2012

effect of the Internet for Australia whose energy policies are already at the crossroads (Falk and Settle 2011).

Although there exists plenty of literature on economic growth and $CO_2$ emissions relationship for different countries and different regions, such a relationship has not been investigated in an Australian context recently. The current study fills this void. Another reason for including economic growth variable in our model is that usually, simple bivariate model fails to appropriately capture the empirical relationship between the series (Karanfil 2009; Bartleet and Gounder 2010). Therefore, the extension of our model with the inclusion of economic growth is justified.

This study is expected to make a number of contributions. The most important one is that the relationship between Internet usage and $CO_2$ emissions is being investigated for the first time ever for Australia which has been experiencing staggering growth in Internet use and at the same time, one of the highest levels of per capita emissions in the world. In addition, this study uses the most recent data available; the analysis of which is expected to offer a policy-oriented discussion especially on how Australia should exploit the '98 % window of opportunity' (Suh et al. 2015) of properly exploiting the ICT-enabled emissions abatement potential in all industries of the economy. Finally, this empirical exercise also makes a methodological contribution by employing a couple of sophisticated and potentially suitable time series econometric techniques, namely the autoregressive distributive lag (ARDL) model and innovation accounting approach (IAA), which to the best of the knowledge of the authors, have never been used for such investigation before.


**Fig. 3** Decoupling trend in Australia during 1985–2010

The remainder of the paper is structured as follows: Section 2 discusses the literature review; methodology is presented in section 3; section 4 presents the estimation results; and section 5 presents conclusions and policy implications of the research.

## Literature review

### Energy impacts of ICT

The energy impacts of ICT are mixed. ICT is believed to positively contribute towards environmental sustainability by reducing GHG emissions through energy efficiency gains (Toffel and Horvath 2004; Pamlin and Pahlman 2008; Erdmann and Hilty 2010; Ishida 2015). On the other hand, ICT use may potentially have negative impacts on the environment, particularly through the energy intensity of Internet usage (Coroama and Hilty 2014)—the relative share of global electricity consumption of ICT products and services has increased from about 3.9 % in 2007 to 4.6 % in 2012 (Heddeghem et al. 2014). Also, during the production of IT products, a number of toxic and non-renewable resources such as lead and mercury are used, which are very harmful for the environment, and waste disposal of the electrical components

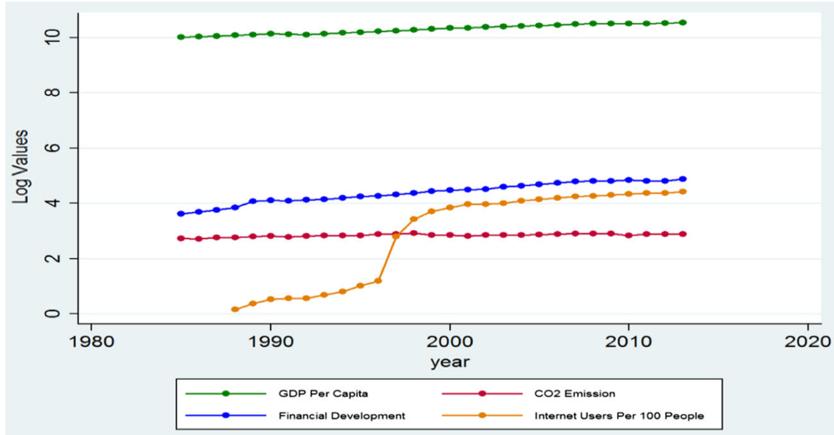


**Fig. 4** Logarithmic trends in per capita GDP, Internet users per 100 people, per capita $CO_2$ emissions and financial development during 1985–2012

and electronic IT goods also contributes towards environmental pollution (Macauley et al. 2003).

The International Energy Agency (IEA 2009) states that ICT-related electricity consumption recorded a rise of 7 % per annum between 1990 and 2008, and the production of electronic products would engender electricity use to rise by 250 % by the year 2030. From these developments, ICT is viewed as a new round of electrification and thus has the potential to increase GHG emissions. Greenpeace International (2014) suggests that the global carbon footprint of data centres and telecommunications networks would increase carbon emissions on average between 5 and 7 % each year up to 2020. This supports the argument that electricity consumption in data centres is a threat to environmental sustainability (Forge 2007). Al-Mulali et al. (2015a) examined the influence of Internet retailing on carbon dioxide ($CO_2$) emission in 77 countries categorized into developed and developing countries during the period of 2000–2013. The results indicated that GDP growth, electricity consumption, urbanization and trade openness are the main factors that increase $CO_2$ emission in the investigated countries. Although the results show that Internet retailing reduces $CO_2$ emission in general, a disaggregation occurs between developed and developing countries, whereby Internet retailing has a significant negative effect on $CO_2$ emission in the developed countries while it has no significant impact on $CO_2$ emission in the developing countries.

The environmental implications of ICT were not researched until the early 1990s. Since then, Cohen et al. (1998) and Jokinen et al. (1998) were among the authors who first investigated information society-sustainable development nexus from theoretical and conceptual perspectives. Although the findings of both studies were inconclusive, they remain important for providing a starting point for further research. Roome and Park (2000)) provided a framework to address information, communication, computing and electronic technologies (ICCE). They concluded that such technologies have both good and bad outcomes, which have important implications for sustainability.

Rejinders and Hoogeveen (2001) conducted a case study focusing on the energy implications of e-commerce for a Dutch online computer reseller and assessed energy consumption resulting from increased online purchases. Sui and Rejeski (2002) cautioned environmental policymakers about the complexity and uncertainty in the relationship between information technology and environmental performance, despite highlighting the positive roles of emerging ICT such as dematerialization, decarbonization and demobilization. Matthews et al. (2002) studied the environmental and economic performances of traditional retailing and e-commerce logistic networks in the USA and Japan. The study failed to reach a conclusion about which of the two methods was more energy efficient. In their study, Toffel and Horvath (2004) concluded that reading newspapers online and video teleconferencing have lower environmental impacts than their traditional wired counterparts.

Takase and Murota (2004) developed and employed economic and energy models to assess the effects of ICT investment on energy consumption in Japan and the USA. Their findings indicated that an increase in IT investment would lower energy intensity in Japan. For the USA, future IT investment would have a positive income effect, which is likely to increase domestic demand for energy consumption. Hilty et al. (2006), using scenario techniques and expert consultations, contributed towards a general understanding of the environmental impacts of ICT. Hilty (2008) argued that ICT development contributes towards dematerialization through substitution and optimization of energy consumption.

Erdmann and Hilty (2010) identified two 'green ICT waves' of empirical studies. The first one was motivated by the rising Internet economy, and the second one focused on the potential of ICT in reducing GHG emissions. It is argued that ICT can play a significant role in mitigating global climate change through its ability to improve energy efficiency and reduce renewable energy costs (Moyer and Hughes 2012).

Ropke and Christensen (2012) developed a theoretical framework to describe and analyse the energy impacts of ICT from an everyday perspective. The study also examined the impacts of ICT with the passage of time and space. It supported the argument that ICTs have great potential to reduce energy consumption depending on certain economic and political conditions.

Coroama et al. (2012) presented the results of a field experiment using ICT as a substitute for more carbon-intensive technology. Their findings suggested a considerable decline in travel-related GHG emissions caused by virtual participation in conferences. Coroama et al. (2013) assessed the direct energy demand of Internet data flows. The study focused on energy saving through dematerialized substitution. For example, they showed that transmitting an e-book with the size of 1 megabyte would cost no more than 0.2 Wh of energy. Also, for a printed book with the size of 500 MB, an audio file would cost only 0.1 kWh. This study also corroborated the earlier findings of Coroama et al. (2012). Cai et al. (2013) argued that with the proper use of IT and IT-related systems and equipments, a firm can improve its competitive advantage while at the same time being energy efficient in China. This study further recommended the formulation of favorable regulatory policies that motivate firms to pursue sustainability through the adoption of IT.

In another study, Coroama et al. (2015) address the dematerialized substitution potential of electronic media with print media. While the study does recognize such potential, it cautions that the amount of resources used throughout the life cycle of media at the macro level of total global media production and consumption needs to be reduced in order to reap environmental benefits. Another finding of the study suggests that energy-saving effect of the virtual participation of conference participants outweigh the rebound effects from increased participation. The study concludes that electronic media doesn't offer a panacea for dematerialization unless its potential is appropriately capitalized.

Ishida (2015), in a time series study in Japan, investigated the impact of ICT on economic growth and energy consumption. The findings suggested that a decline in energy consumption is possible through energy efficiency gains from ICT use. Hilty and Aebischer (2015) proposed and presented a new model on the potential impacts through which ICT can reduce electricity consumption. These potential impacts are life cycle impact, enabling impact and structural impact. Khreishah et al. (2015) showed that network coding under multicast can potentially reduce electricity consumption in data centres. Funk (2015) highlighted the importance of IT contribution towards sustainability by reducing emissions in the transport sector. The study argued that the use of public transportation reduces per capita energy usage and per capita carbon emissions. The widespread use of GPS, smart phones and connected devices in buses and trains in developed countries motivate people's use of public transport and thus contribute towards reducing per capita energy use and per capita emissions.

Recent studies suggest that ICT use and environmental sustainability are intertwined; this led to two concepts known as 'green ICT' and 'ICT for green'. When the use of ICT products and services contributes towards reducing its own carbon footprint, it is known as green ICT. On the other hand, ICT for green focuses on the role of ICT products and services to improve overall environmental quality, energy efficiency and carbon footprint across the economy with a focus on ICT as a solution. A combination of green ICT and ICT for green is described as 'green ICT for green' (Mattern et al. 2010). From the above discussion, it is obvious that despite the tremendous emissions abatement potential of ICT use in economies, its energy impact is still mixed and no consensus has yet been realized.

The review of literature discussed above makes it clear that there has been no study so far that has examined the emissions impact of Internet usage in an Australian context. The rapid increase in Internet usage and the ongoing NBN rollout have obviously been exerting some pressure on domestic electricity demand, and Australia may or may not already be experiencing possible environmental consequences. This study will dig into depth into this possibility, and the findings are expected to provide a greater understanding about this burning issue.

## $CO_2$ emissions, economic growth and financial development

Rising levels of $CO_2$ emissions is considered one of the key causes of global warming and climate instability. As such, one of the most important issues in energy economics literature involves testing the empirical relationship between economic growth and $CO_2$ emissions—this association is popularly termed as the environmental Kuznets curve (EKC) hypothesis, which postulates that this relationship can be reflected through an inverted U-shaped curve. The EKC states that in the initial stages of economic growth, $CO_2$ emissions increase, but after a certain threshold level is achieved, these emissions begin to decline.

The EKC hypothesis was initially proposed and tested by Grossman and Krueger (1991). Numerous studies—such as Lucas et al. (1992), Heil and Selden (1999), Stern (2004), Nohman and Antrobus (2005), Dinda and Coondoo (2006), Coondoo and Dinda (2008), Salahuddin and Khan (2013), Salahuddin and Gow (2014), Apergis and Ozturk (2015) and Al-Mulali et al. (2015b)—have examined this hypothesis. However, the empirical outcomes of these studies provided mixed results, and the validity of the EKC hypothesis remains inconclusive.

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. Salahuddin et al. (2015) shows that financial development causes decline in $CO_2$ emissions in GCC countries. Jalil and Feridun (2011) reported that financial development reduces $CO_2$ emissions in China. However, Zhang and Liu (2015) and Zhang (2011) found that financial development contributes significantly towards increasing $CO_2$ emissions. Financial development was found to stimulate energy consumption and $CO_2$ emissions in sub-Saharan African countries (Al-Mulali 2012), and Shahbaz and Lean (2012) obtained the same results for Tunisia. Ozturk and Acaravci (2013) found that financial development has no significant effect on per capita carbon emissions in the long run for Turkey. Overall, the literature suggests mixed effects of financial development on $CO_2$ emissions. Therefore, further investigation of this relationship is warranted.

## Data and methodology

### Data

We employed historical data from the International Energy Agency (IEA 2013) on per capita $CO_2$ emissions and per capita energy consumption over the period 1985–2012 to estimate the decoupling effects in order to report the overall emissions scenario for Australia. Annual time series data on $CO_2$ emissions per capita, real GDP per capita, Internet users per 100 people and financial development proxied by credit available to the private sector as share of GDP for the period 1985–2012 were obtained from the World Data Bank (previously, World Development Indicators database, The World Bank 2013). A few missing values were observed in the Internet users per 100 people series, which were replaced by 3-year moving average values. The data for 'per capita $CO_2$ emissions (C)' were readily available, while real GDP per capita (GDPPC) was measured at constant 2005 US$; Internet users per 100 people (NET) and private credit as share of GDP were considered for the study. All variables were expressed in natural logs.

### Methodology

Similar to Sadorsky (2012) and Narayan et al. (2010), we proposed and estimated an econometric model where the variable per capita $CO_2$ emissions were assumed to be a function of Internet usage, economic growth and financial development. As such, the baseline equation of our study is

$$\ln C_t = \beta_0 + \beta_1 \ln \mathrm{NET}_t + \beta_2 \ln \mathrm{GDPPC}_t + \beta_3 \ln \mathrm{FD}_t + \varepsilon_t \quad (1)$$

The subscript $t$ represents the time period.

### Estimation procedures

*Estimation of decoupling effects in Australia from 1970 to 2012*

Following Bithas and Kalimeris (2013), we estimated the decoupling index for energy and GDP per capita ratio for Australia. The values of the decoupling index (DI) are obtained from the ratio of the change in the rate of consumption of a given resource, to the change in the rate of economic growth (in terms of GDP), during a certain time period. The DI index is calculated based on annual change. The DI for Australia was estimated with the following formula:

$$\mathrm{DI} = \frac{E_t - E_{t-1}/E_{t-1}}{\mathrm{GDP}_t - \mathrm{GDP}_{t-1}/\mathrm{GDP}_{t-1}} \quad (2)$$

When DI>1, no decoupling is taking place.

When DI=1, the turning point between absolute coupling and relative decoupling is represented.

When 0<DI<1, relative decoupling is taking place.

When DI=0, it is implied that the economy is growing while resource consumption remains constant. This is the turning point between relative and absolute decoupling.

When DI<0, the relationship can be described as absolute decoupling.

*Unit root tests*

Long time series data of macro variables are generally characterized with unit root process which means that the data are likely to be non-stationary. Estimation methods applied to non-stationary data will lead to spurious results. As such, it is important to test the stationarity of data before performing any estimation on them. Therefore, the unit root tests are imperative. Most conventional unit root tests—such as ADF (Dickey and Fuller 1979), PP (Phillips and Perron 1988), KPSS (Kwiatkowski et al. 1992) tests and the DF-GLS (Dickey Fuller Generalized Least Squares) test proposed by Elliott et al. (1996)—fail to identify the presence of a structural break in the series (Baum 2004). Thus, we conducted Zivot and Andrews (1992) unit root test which overcomes this limitation and accommodates a single structural break point in the level. Considering our series as $X$, the structural tests took the following form:

$$\Delta X_t = a + aX_{t-1} + bT + cD_t + \sum_{j=1}^{k} d_j \Delta X_{t-j} + \varepsilon_t \quad (3)$$

$$\Delta X_t = \beta + \beta X_{t-1} + ct + bDT_t + \sum_{j=1}^{k} d_j \Delta X_{t-j} + \varepsilon_t \quad (4)$$

$$\Delta X_t = \gamma + \gamma X_{t-1} + ct + dDT_t + \sum_{j=1}^{k} d_j \Delta X_{t-j} + \varepsilon_t \quad (5)$$

$$\Delta X_t = \Omega + \Omega X_{t-1} + ct + dD_t + dDT_t + \sum_{j=1}^{k} d_j \Delta X_{t-j} + \varepsilon_t \quad (6)$$

where $D$ is a dummy variable and shows the mean shift at each point, and $DT_t$ is a trend shift variable. The null hypothesis in Zivot and Andrews (1992) is $c$=0, meaning the presence of unit root in the absence of structural break hypothesis against the alternative that the series is trend-stationary with an unknown time break. Then, this unit root test selects that time break which reduces the one-sided $t$ statistic to test $c(=c-1)=1$.

*ARDL bounds testing approach*

Since conventional cointegration techniques have certain limitations with their findings in the presence of structural break in macroeconomic dynamics (Uddin et al. 2013), we employed the ARDL bounds testing approach developed by Pesaran (1997) and Pesaran et al. (2001) first, to examine whether any cointegrating or long-run relationship exists between the variables and then, to estimate the coefficients of the long-run association between the variables. The ARDL technique has several advantages over other conventional cointegration and estimation techniques (see Pesaran et al. 2001 for details). The application of ARDL generally provides unbiased estimates of the long-run model and valid $t$ statistic, even when the model suffers from the problem of endogeneity (Harris and Sollis 2003). The empirical formulation of the ARDL equation for our study was specified as follows:

$$\Delta \ln C_t = \beta_0 + \beta_1 T + \beta_2 D + \beta_3 \ln C_{t-1} + \beta_4 \ln GDPC_{t-1} + \beta_5 \ln NET_{t-1} + \beta_6 \ln FD_{t-1} + \sum_{i=1}^{p} \beta_7 \Delta \ln C_{t-j} + \sum_{J=1}^{q} \beta_8 \Delta \ln GDPC_{t-k} + \sum_{k=0}^{r} \beta_9 \ln NET_{t-1} + \sum_{1=0}^{s} \beta_{10} \Delta \ln FD_{t-m} + \varepsilon_t \quad (7)$$

$$\Delta \ln GDPC_t = \beta_0 + \beta_1 T + \beta_2 D + \beta_3 \ln GDPC_{t-1} + \beta_4 \ln C_{t-1} + \beta_5 \ln NET_{t-1} + \beta_6 \ln FD_{t-1} + \sum_{i=1}^{p} \beta_7 \Delta \ln GDPC_{t-j} + \sum_{j=0}^{q} \beta_8 \Delta \ln NET_{t-k} + \sum_{k=0}^{r} \beta_9 \Delta \ln C_{t-1} + \sum_{1=0}^{s} \beta_{10} \Delta \ln FD_{t-m} + \varepsilon_t \quad (8)$$

$$\Delta \ NET_t = \beta_0 + \beta_1 T + \beta_2 D + \beta_3 \ln NET_{t-1} + \beta_4 \ln GDPC_{t-1} + \beta_5 \ln C_{t-1} + \beta_6 \ln FD_{t-1} + \sum_{i=0}^{p} \beta_7 \Delta \ln NET_{t-j} + \sum_{j=0}^{q} \beta_8 \Delta \ln GDPC_{t-k} + \sum_{k=0}^{r} \beta_9 \Delta \ln C_{t-1} + \sum_{1=0}^{s} \beta_{10} \Delta \ln FD_{t-m} + \varepsilon_t \quad (9)$$

$$\Delta FD_t = \beta_0 + \beta_1 T + \beta_2 D + \beta_3 \ln NET_{t-1} + \beta_4 \ln GDPC_{t-1} + \beta_5 \ln C_{t-1} + \beta_6 \ln FD_{t-1} + \sum_{i=0}^{p} \beta_7 \Delta \ln FD_{t-j} + \sum_{j=0}^{q} \beta_8 \Delta \ln GDPC_{t-k} + \sum_{k=0}^{r} \beta_9 \Delta \ln C_{t-1} + \sum_{1=0}^{s} \beta_{10} \Delta \ln NET_{t-m} + \varepsilon_t \quad (10)$$

where lnGDPC, lnC, lnNET and lnFD indicate log values of real GDP per capita, $CO_2$ emissions per capita, Internet users per 100 people and financial development, respectively. Δ is the difference operator, and T and D denote time trend and dummy variable, respectively. The dummy variable is included in the equation to capture the structural break arising from the series. $\varepsilon_t$ is the disturbance term.

To examine the cointegrating relationship, the Wald test or the $F$ test for the joint significance of the coefficients of the lagged variables is applied with the null hypothesis, $H_0$: $\beta_3=\beta_4=\beta_5$, indicating no cointegration against the alternative hypothesis of the existence of cointegration between variables. $F$ statistics are computed to compare the upper and lower bounds critical values provided by Pesaran et al. (2001). Once the cointegrating relationship is confirmed, the long-run and short-run coefficients along with the error correction coefficient are then estimated.

*Gregory–Hansen tests for cointegration*

In order to check the robustness of the cointegrating relationship between the variables, we employed the Gregory and Hansen (1996) residual-based test of cointegration. The Gregory and Hansen test offers the testing of four models—level, trend, intercept or shift in the intercept and slope. We opted for the intercept and slope model that allows rotation in the long-run equilibrium relationship simultaneously with shift.

*Impulse response function and variance decompositions*

Since ARDL estimates do not apply beyond the sample period covered in the study, the IAA—which consists of variance decomposition analysis and generalized impulse response functions—was also applied to assess the forecasted impact of Internet usage, economic growth and financial development on $CO_2$ emissions. The generalized impulse response function is preferred over the simple Choleski fractionalization impulse response analysis, as the former is insensitive to the order of the vector error correction model (VECM) (Shahbaz et al. 2013). It also indicates whether the impacts of innovations are positive or negative, short run or long run. The general representation of this procedure is available in the seminal works of Sims (1980, 1986) and Bernanke (1986). Although the impulse response function traces the effect of a one-standard deviation shock on the current and future values of all the endogenous variables through the dynamic structure of VECM, it does not provide the magnitude of such effect. Consequently, the variance decomposition method was employed to examine this magnitude.

Variance decomposition (Pesaran and Shin 1999) shows the expected percentage variation in the dependent variable explained by the expected percentage variations in the independent variables over a forecasting horizon of period beyond the sample period of the study. Engle and Granger (1987) and Ibrahim (2005) argued that the variance decomposition approach produces more reliable results compared to those from other traditional approaches.

**Table 1** Descriptive statistics

| Variable | Obs. | Mean | Std. Dev. | Min | Max |
|---|---|---|---|---|---|
| LCO2 | 29 | 2.842 | 0.054 | 2.706 | 2.919 |
| LNET | 29 | 2.482 | 1.930 | −0.535 | 4.418 |
| LGDPC | 29 | 10.289 | 0.173 | 10.009 | 10.531 |
| LFD | 29 | 4.385 | 0.373 | 3.612 | 4.879 |

**Table 2** Variance inflation factors

| Variable | Coefficient Variance | Centered VIF |
|---|---|---|
| LFD | 0.005189 | 3.12397 |
| LGDPPC | 0.032860 | 4.59169 |
| LNET | 6.14E-05 | 1.07150 |
| C | 2.502639 | NA |

*NA* not applicable

*Dynamic ordinary least squares*

Finally, we applied the dynamic ordinary least squares (DOLS) method (Stock and Watson 1993) and estimated the long-run coefficients between the variables in order to check for the robustness of the findings from the ARDL estimates. The application of this method for a robustness check was appropriate as this estimator is robust even when the sample size is small and eliminates the simultaneity problem.

## Results

Table 1 reports summary statistics. The standard deviations in all the series are quite low, implying that the data are evenly dispersed around the mean. Hence, it was convenient to proceed with the datasets for further estimation. Results of the VIF test are reported in Table 2 which shows that the model is free from the threat of multicollinearity.

The DF-GLS unit root results are reported in Table 3, which shows all the series in our study are first-difference stationary, i.e. I(1). The weakness of this test is that it does not consider the presence of a structural break in the series (Baum 2004). Due to different types of internal and external shocks, it is expected that there may be some structural breaks in the data. To overcome this shortcoming, we employed the Zivot and Andrews (1992) unit root structural break test. The results of this test are presented in Table 4, and the results indicate a number of break points in the early and late 1990s

**Table 3** Zivot–Andrews structural break unit root test

| Variable | Z and A test for level | | | Z and A test for first difference | | |
|---|---|---|---|---|---|---|
| | *T* statistic | TB | Outcome | *T* statistic | TB | Outcome |
| LGDPC | −3.003 | 2008 | Unit root | −4.258c | 1999 | Stationary |
| LFD | −3.622 | 1990 | Unit root | −4.855b | 2008 | Stationary |
| LNET | −2.551 | 2001 | Unit root | −5.141a | 1998 | Stationary |
| $LCO_2$ | −4.023 | 1997 | Unit root | −7.525a | 2001 | Stationary |

Note that a, b and c indicate 1, 5 and 10 % significance level, respectively

**Table 4** Gregory–Hansen test for cointegration with regime shifts

| Test | Statistic | Break point | Date | Asymptotic critical values statistic | | |
|---|---|---|---|---|---|---|
| | | | | 1 % | 5 % | 10 % |
| ADF | 6.61[a] | 15 | 1999 | 5.77 | 5.28 | 5.02 |
| $Z_t$ | 6.74[a] | 15 | 1999 | 5.77 | 5.28 | 5.02 |
| $Z_a$ | 35.79 | 15 | 1999 | 63.64 | 53.58 | 48.65 |

[a] Represents 1 % level of significance

as well as in the late 2000s. The results further confirm that all the series are first-difference stationary, i.e. I(1), in the presence of structural break.

Next, we proceeded with the estimation of short-run and long-run relationships among the variables. Since ARDL is sensitive to lag order, for calculating the *F* statistic, we needed to identify the appropriate lag order. To do this, we chose the AIC (Akaike Information Criterion), as it provides better results than other lag length criteria (Lütkepohl 2006). The reported ARDL results in Table 5 suggest that the calculated *F* statistic of 4.516 is higher than the upper bound critical value generated by Pesaran et al. (2001) at the 10 % level of significance. Therefore, there is a cointegrating relationship between per capita $CO_2$ emissions and the predicted variables—the Internet users per 100 people and economic growth.

Results from the Gregory and Hansen (1996) structural break cointegration test are reported in Table 6. The findings confirm the reliability and robustness of the cointegrating relationship between the variables in Australia that were observed in the earlier ARDL estimates.

Results presented in Table 7 indicate that the rapid growth in Internet usage does not have any significant effect on $CO_2$ emissions in Australia, implying that the increasing use of the Internet is not yet an environmental threat for Australia. Economic growth has a negative significant long-run effect on $CO_2$ emissions. This supports the fact that Australia has achieved some energy efficiency in recent times. In addition, financial development has a positive significant effect on $CO_2$ emissions in the long run.

Table 8 reports the short-run effects of the independent variables on $CO_2$ emissions. The findings indicate that there is no significant short-run effect of Internet usage and economic growth on $CO_2$ emissions in Australia. The coefficient of the error correction term $ECT_{t-1}$ of −0.19 is significant and has the expected sign. It also implies a reasonable speed of convergence (the short-run deviations being corrected at the speed of 19 % towards the long-run equilibrium each year).

Table 9 presents results from the diagnostic tests carried out from the ARDL estimates. The LM test confirms no serial correlation, while Ramsey's RESET test suggests that the model (Eq. 1) has the correct functional form. The normality test reveals that the disturbance terms are normally distributed and are homoscedastic as supported by the heteroscedasticity test.

The stability of parameters over time is reflected through the graphical plots of CUSUM and CUSUM of Squares (Fig. 5a and b respectively).

From Fig. 6, we see that the standard deviation of per capita $CO_2$ emissions leads to a positive increase in future per capita $CO_2$ emissions in Australia. The response of per capita $CO_2$ emissions to the shocks in Internet users per 100 people and per capita GDP demonstrates expected signs but with different magnitudes. The accumulated response of per capita $CO_2$ emissions to a shock in Internet users per 100 people is positive but insignificant. The accumulated response of per capita $CO_2$ emissions to future shocks in GDP per capita is also positive. Thus, the findings imply that both Internet usage and per capita GDP will continue to affect $CO_2$ emissions in Australia, but the magnitude of these effects is expected to decline over time.

Results from the variance decomposition analysis are reported in Table 10. The study allowed a 27-year forecasting horizon. Interestingly, at the 5-year forecasting horizon, about 55.51 % of the one-step forecast variance in per capita $CO_2$ emissions is accounted for by its own innovations, and altogether, 44.49 % is accounted for by economic growth, Internet users per 100 people and financial development. The role of Internet usage is more important, as it has the highest contribution of approximately 21 % to economic growth by its shocks. In the 27-year period, the contribution of the shocks in Internet usage towards $CO_2$ emissions increased from 21 % in the 5-year forecasting horizon to around 22 %. This is a clear

**Table 5** Result from bounds test

| Dep. Variable | *F* statistic | 95 % | | 90 % | | Outcome |
|---|---|---|---|---|---|---|
| | | L. B. | U. B. | L. B. | U. B. | |
| $F_{LCO2}$(LCO2\| LNET, LGDPC, LFD) | 4.516 | 3.742 | 5.088 | 3.053 | 4.200 | Cointegration |
| $F_{LNET}$(LNET\| LGDPC, $LCO_2$, LFD) | 2.452 | 3.742 | 5.088 | 3.053 | 4.200 | No cointegration |
| $F_{LGDPC}$(LGDPC\| LCO2, LNET, LFD) | 5.369 | 3.742 | 5.088 | 3.053 | 4.200 | Cointegration |
| $F_{LFD}$(LFD\| LGDPC, LNET, LCO2) | 3.833 | 3.742 | 5.088 | 3.053 | 4.200 | No cointegration |

Table 6 Estimated long-run coefficients using ARDL model (1, 0, 1, 0): dependent variable is LCO2

| Regressor | Coefficient | Standard error | *T* ratio [Prob] |
|---|---|---|---|
| LNET | 0.001 | 0.011 | 0.134 [0.894] |
| LGDPC | −0.527 | 0.259 | −2.028 [0.055] |
| LFD | 0.360 | 0.104 | 3.448 [0.002] |
| C | 6.665 | 2.272 | 2.933 [0.008] |

indication that in Australia, the Internet will continue to impact $CO_2$ emissions for a long time. Emissions impacts of economic growth and financial development are found to be of relatively low magnitude.

Results from the dynamic ordinary least squares (DOLS) method are reported in Table 11. Although the coefficients vary, the DOLS estimation produced similar results, indicating that our findings are robust across different methods of estimation.

## Conclusions and policy implications

This study examined the empirical relationship between Internet usage, $CO_2$ emissions and economic growth using the Australian annual time series data for the period 1985–2012. Because of the long sample period, a structural break unit root test was conducted. Having found the presence of a structural break in the series, an ARDL bounds testing approach was applied, taking into account the structural break. The findings from the ARDL estimates suggested that there is no significant long-run relationship between Internet usage and $CO_2$ emissions. Economic growth has long-run positive and significant effects on electricity consumption, while these effects in the short-run are insignificant. The IAA, comprising impulse response functions and variance decomposition, was employed to assess the future impact of Internet usage, economic growth and financial development on $CO_2$ emissions. Results from DOLS estimation lent support to the long-run relationship between the variables. The baseline model used in the study succeeded all the conventional diagnostic tests.

Table 7 Error correction representation for ARDL model (1, 0, 1, 0): dependent variable is ΔLCO2

| Regressor | Coefficient | Standard error | *T* ratio [Prob] |
|---|---|---|---|
| ΔLNET | 0.001 | 0.009 | 0.133 [0.895] |
| ΔLGDPC | 0.331 | 0.455 | 0.727 [0.474] |
| ΔLFD | 0.285 | 0.106 | 2.672 [0.014] |
| ecm(−1) | −0.791 | 0.198 | −3.992 [0.001] |

Table 8 Diagnostic tests

| Test statistics LM version | |
|---|---|
| $R$ square 0.754 | Adjusted $R$ square 0.698 |
| Serial correlation $\chi^2$ (1)=0.882 [0.348] | Normality $\chi^2$ (2)=0.208 [0.901] |
| Functional form $\chi^2$ (1)=0.099 [0.753] | Heteroscedasticity $\chi^2$ (1)=0.465 [0.495] |

Although a recent study (Salahuddin and Alam 2015) found that Internet use stimulates electricity consumption in Australia, the current study finds that this rise in electricity consumption has no significant effect on $CO_2$ emissions. Such insignificant association may be due to the fact that an insignificant amount of Australia's total electricity consumption is accounted for by Internet usage or may be because of the Internet's potential to reduce its own carbon footprint (greening Internet) and in all other sectors of Australia (Internet for green) including power sector, agricultural sector and the service sector which are deemed most ideal sectors for Australia for such benefits.

However, as Internet usage continues to increase, there will be increasing demand for electricity in the future (Suh et al. 2015) which might eventually lead to increased $CO_2$ emissions unless Australia makes sure that it effectively exploits ICT-enabled emissions abatement potentials. Some of the most potential ways in which Australia has a comparative advantage in terms of exploiting the ICT-enabled solutions for making Internet use more energy efficient are promoting the use of renewable energy through integration of renewable energy especially solar and wind energy for which Australia can follow Germany as an ideal case study (SMARTer 2020 Team 2012), saving electricity consumption through power grid optimization, promoting further use of Internet in agricultural sector where ICT-enabled technologies such as smart

Table 9 Pairwise Granger causality tests

| Null hypothesis: | Obs. | *F* Statistic | Prob. |
|---|---|---|---|
| LGDPC does not Granger cause LCO2 | 28 | 2.18266 | 0.1521 |
| LCO2 does not Granger cause LGDPC | | 2.32850 | 0.1396 |
| LNET does not Granger cause LCO2 | 28 | 1.34189 | 0.2576 |
| LCO2 does not Granger cause LNET | | 4.78190 | 0.0383 |
| LFD does not Granger cause LCO2 | 28 | 4.36191 | 0.0471 |
| LCO2 does not Granger cause LFD | | 0.02836 | 0.8676 |
| LNET does not Granger cause LGDPC | 28 | 12.0981 | 0.0019 |
| LGDPC does not Granger cause LNET | | 0.17279 | 0.6812 |
| LFD does not Granger cause LGDPC | 28 | 0.03313 | 0.8570 |
| LGDPC does not Granger cause LFD | | 5.77865 | 0.0240 |
| LFD does not Granger cause LNET | 28 | 0.17195 | 0.6819 |
| LNET does not Granger cause LFD | | 4.36808 | 0.0469 |

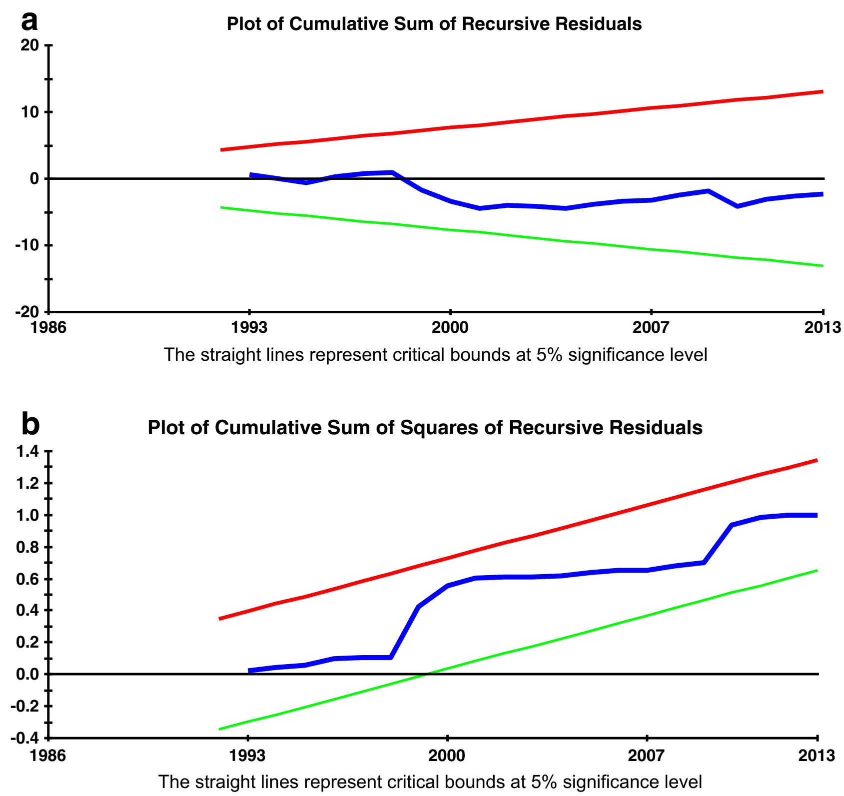


**Fig. 5** **a** Plot of cumulative sum of recursive residuals. **b** Plot of cumulative sum of squares of recursive residuals

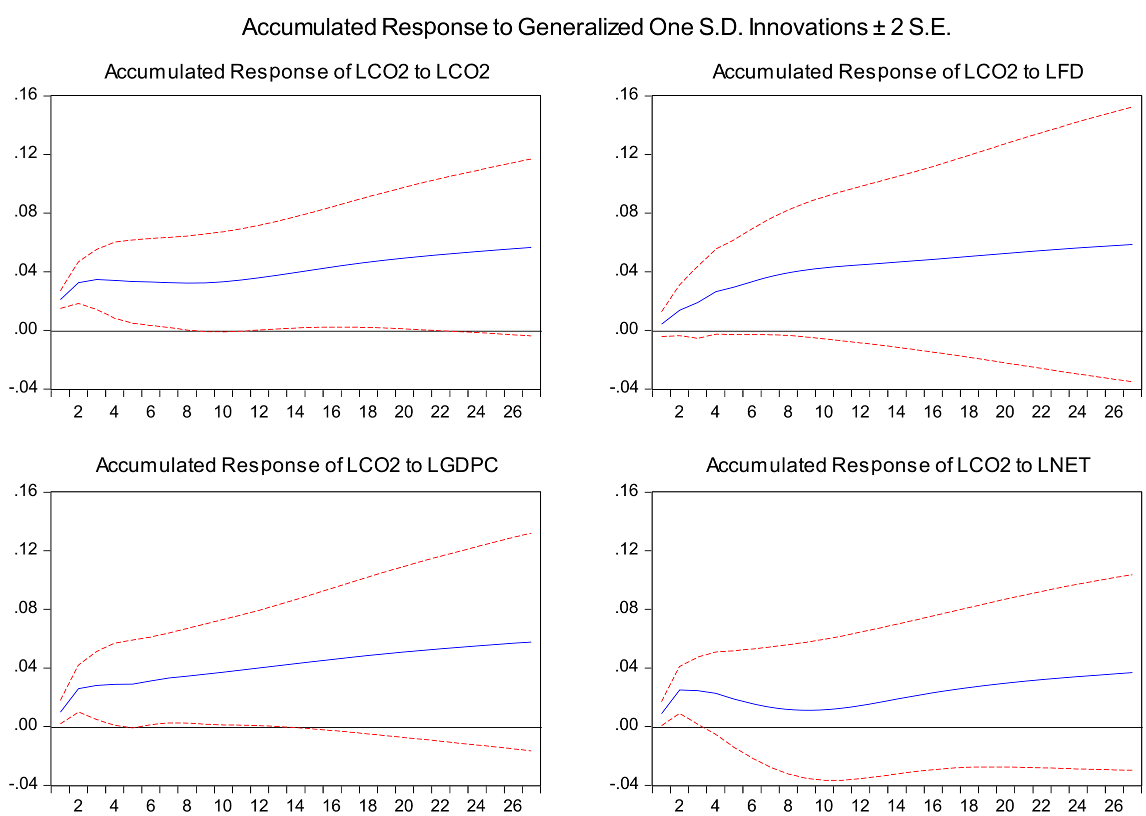


**Fig. 6** Impulse response function

**Table 10** Variance decomposition

| Period | Standard error | LCO2 | LFD | LGDPC | LNET |
|---|---|---|---|---|---|
| 1 | 0.020979 | 100.0000 | 0.000000 | 0.000000 | 0.000000 |
| 2 | 0.030426 | 62.08462 | 5.801970 | 10.10811 | 22.00530 |
| 3 | 0.030941 | 60.52140 | 8.233004 | 9.915229 | 21.33036 |
| 4 | 0.031955 | 56.77465 | 13.28729 | 9.927883 | 20.01017 |
| 5 | 0.032338 | 55.51608 | 14.04372 | 9.769629 | 20.67057 |
| 6 | 0.032683 | 54.35700 | 15.16442 | 9.636625 | 20.84195 |
| 7 | 0.032942 | 53.51830 | 16.08009 | 9.563053 | 20.83856 |
| 8 | 0.033093 | 53.04199 | 16.69877 | 9.500991 | 20.75825 |
| 9 | 0.033155 | 52.84356 | 16.97884 | 9.480898 | 20.69670 |
| 10 | 0.033194 | 52.76746 | 17.08802 | 9.487165 | 20.65736 |
| 11 | 0.033250 | 52.73060 | 17.10501 | 9.493185 | 20.67120 |
| 12 | 0.033330 | 52.70068 | 17.06759 | 9.480925 | 20.75080 |
| 13 | 0.033427 | 52.67436 | 16.99933 | 9.451233 | 20.87508 |
| 14 | 0.033532 | 52.65414 | 16.91914 | 9.412609 | 21.01411 |
| 15 | 0.033635 | 52.64018 | 16.84203 | 9.372089 | 21.14571 |
| 16 | 0.033731 | 52.63023 | 16.77834 | 9.333749 | 21.25769 |
| 17 | 0.033815 | 52.62209 | 16.73272 | 9.299618 | 21.34558 |
| 18 | 0.033887 | 52.61429 | 16.70486 | 9.270426 | 21.41042 |
| 19 | 0.033949 | 52.60592 | 16.69172 | 9.246017 | 21.45634 |
| 20 | 0.034002 | 52.59659 | 16.68930 | 9.225738 | 21.48837 |
| 21 | 0.034047 | 52.58645 | 16.69369 | 9.208786 | 21.51107 |
| 22 | 0.034087 | 52.57599 | 16.70160 | 9.194421 | 21.52799 |
| 23 | 0.034122 | 52.56577 | 16.71056 | 9.182033 | 21.54163 |
| 24 | 0.034154 | 52.55619 | 16.71901 | 9.171144 | 21.55366 |
| 25 | 0.034183 | 52.54745 | 16.72614 | 9.161384 | 21.56503 |
| 26 | 0.034210 | 52.53963 | 16.73165 | 9.152487 | 21.57624 |
| 27 | 0.034235 | 52.53267 | 16.73561 | 9.144267 | 21.58745 |

phones, laptops and decision support software are already widely used, reducing emissions caused by the transport sector (by increased use of GPS, smart phones and other connectivity devices in both private and public transports) and most importantly, the rapidly growing service sector which is already characterized by widespread use of the Internet and which is assumed to be Australia's next growth driver.

**Table 11** Results from DOLS estimation

| Variable | Coefficient | Standard error | *T* statistic | Prob. |
|---|---|---|---|---|
| LFD | 0.296652 | 0.084684 | 3.503062 | 0.0039 |
| LGDPPC | 0.063268 | 0.194969 | −0.324503 | 0.0507 |
| LNET | 0.024406 | 0.007800 | −3.129069 | 0.0080 |
| C | 2.209319 | 1.671850 | 1.321482 | 0.0291 |
| R-squared | 0.895995 | Mean dependent var | | 2.850439 |
| Adjusted R-squared | 0.799991 | S.D. dependent var | | 0.043425 |
| S. E. of regression | 0.019421 | Sum squared resid | | 0.004903 |
| Durbin–Watson stat | 2.609092 | Long-run var | | 0.000185 |

Also, this study recommends that Australia continues with its existing efforts to control $CO_2$ emissions in the atmosphere through a variety of measures. One of the most significant means for controlling $CO_2$ emissions is post-combustion capture (Qadir et al. 2013). Also, carbon pricing (emissions trading scheme) is a cost-effective method to reduce emissions and it had achieved some short-run success in terms of emissions reduction (O' Gorman and Jotzo 2014) after its commencement in July 2012. However, due to political dispute over the scheme's long-run potential to combat emissions, it was repealed in June 2014.

Australia also has a comparative advantage over many other developed countries in renewable resources such as wind, tidal energy, wave energy and geothermal energy. The share of renewables in Australian electricity generation has increased from 8 % in 2003–2004 to 13 % in 2012–2013 (RETS 2014). Among these renewable resources, solar energy—particularly the rooftop solar photovoltaic (PV)—is the most valid option for reducing emissions, as Australia is one of the sunniest countries in the world with very strong wind (Byrnes et al. 2013). ICT-enabled solutions might be very effective to promote rooftop solar photovoltaic in Australia.

Another finding of this study is the negative significant long-run association between economic growth and $CO_2$ emissions. Such finding corroborates the recently published report of the Renewable Energy Target Scheme, 2014 (RETS 2014), that Australia has already achieved a certain level of energy efficiency gains, and as such, it is in a comfortable position to pursue pro-growth policies without being too much concerned about emissions. Also, the energy policy experts of Australia must recognize that the electricity sector itself is potentially capable to reduce emissions if fuel switching (Shahiduzzaman and Alam 2013) and generation efficiency improvement initiatives are taken (Ang et al. 2011). Finally, Australia should effectively exploit the potential of 'green Internet for green' along with boosting a variety of other existing emissions reduction measures for a sustainable energy future.

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**Compliance with ethical standards**

**Ethical statement** The manuscript has not been previously published, is not currently submitted for review to any other journal, and will not be submitted elsewhere before a decision is made by this journal

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# CHAPTER SEVEN
# CONCLUSIONS, RECOMMENDATIONS AND FUTURE RESEARCH DIRECTIONS

## 7.1 INTRODUCTION

This chapter presents the conclusions of the study, together with recommendations and directions for future research. This study carried out a comprehensive empirical analysis of the effects of the Internet on sustainable development through its effects on economic growth, social capital, electricity consumption and $CO_2$ emissions in the context of OECD countries and Australia in particular. To accomplish this aim, this study sets three objectives which are guided by four research questions. To address these research questions, nine journal papers are produced.

Section 7.2 presents a summary of the findings and contributions from all nine papers delivered by this thesis. Section 7.3 discusses recommendations while section 7.4 presents future research directions. This is followed by Section 7.5, which focuses on the scope and limitations of the study. Concluding remarks are presented in Section 7.6.

## 7.2 SUMMARY OF THE KEY FINDINGS AND CONTRIBUTIONS

This study produced nine empirical papers. The research used macro panel data for OECD countries, macro time series data for Australia, and survey data for regional Australia to examine the effects of the Internet on economic growth, social capital, electricity consumption and $CO_2$ emissions, respectively. The PMG regression, the ARDL model and the OLS regression techniques, along with other associated statistical tests, were applied. Findings suggest that the Internet stimulates economic growth while it reduces social capital in OECD countries. However, Internet use is found to boost social capital in regional Australia. Although, Internet use is observed to cause a rise in electricity consumption, it does not have any significant effect on $CO_2$ emissions. These findings altogether imply that Internet contributes positively towards sustainable development in OECD countries and in Australia in particular.

The positive growth effect of the Internet was in line with expectations, although the coefficients in both cases were very small. Economic contributions of the Internet in OECD countries, expressed in numeric terms in various reports, were not significantly reflected in these findings; the presence of different forms of digital divide may be the foremost potential reason for this below-par effect of the Internet. The negative effect of the Internet on social capital may be attributed to the fact that social capital gains from online connectivity are offset by the reduction in offline interactions. Also, digital divide – in the form of social exclusion of disadvantaged and underprivileged people – may be a potential reason for such findings.

Another potential reason may be the use of one single indicator (trust) to measure social capital at the macro level. This further suggests that the Internet's effect on social capital may not be reflected appropriately in the findings of this study. However, Internet use was found to have a positive effect on social capital for the WDR of Australia, when social capital was measured by a number of items drawn from its statistically valid theoretical constructs. While Internet use causes electricity consumption to rise, its panel and country-specific effects on $CO_2$ emissions were insignificant for OECD countries and Australia, respectively. This implies that the rapid growth in Internet use is still environmentally sustainable.

The major contributions of paper one and paper two are that it adds to the existing Internet–growth literature. Another key contribution is that both these papers used a much larger dataset covering a longer period of time – longer datasets allow researchers to apply more sophisticated and advanced statistical techniques that may potentially provide more reliable, robust and policy-oriented findings. Application of more appropriate econometric techniques in both papers to analyse data is believed to be the methodological improvement over previous studies in the same area.

Papers three and four represent the first empirical contributions to the literature that assesses the role of the Internet in building social capital (measured by trust) in the context of OECD countries and Australia in particular. These papers boast significant policy contributions, as researchers have been voicing their concern for quite a while now over the justification for including the social capital issue into the digital divide policies of these countries.

The findings of paper five represent one of the most significant contributions of this thesis. This paper analysed quantitative survey data obtained from the WDR of Queensland in Australia with a view to examining the relationship between Internet use and social capital. Such an in-depth empirical contribution is the first of its kind in the context of regional Australia. The major contribution of this survey research is that it quantified the social capital variable by the application of summated scale method on the items of five statistically valid dimensions (bonding social capital, bridging social capital, trust, neighbourhood effect and community engagement) of social capital. This is a significant contribution to the existing literature on the measurement of the social capital variable. The positive association between Internet use and social capital unfold the importance of the inclusion of the social capital issue into the digital divide policy of Australia. This empirical contribution is expected to generate significant interest among not only the policymakers of Australia alone but also of other OECD countries who have been thriving to reduce digital divide in regional towns and cities.

Paper six and paper seven analysed the effects of the Internet on electricity consumption in OECD countries and in Australia, respectively. Both papers provide strong contributions to this field of research. Although the positive effect of the Internet on electricity consumption was shown to be of insignificant concern for these countries at the moment, it has important implications for policy. This research shows that electricity demand in these countries is expected to keep rising in the near future due to the growth in the number of data centres and other associated Internet-related services.

Paper eight and paper nine each estimated the $CO_2$ emissions effect of the Internet for OECD panel countries and for Australia, respectively. In-depth empirical exercises examining such relationship are believed to be the first of their kind. This demonstrates a major contribution to the field of research in the area. The findings of an insignificant effect of the Internet on $CO_2$ emissions may partly reflect the energy efficiency capability of these economies. Also, energy efficiency gains from 'green Internet' and 'Internet for green' are not ruled out, as many of these countries are blessed with the Internet's emissions abatement potential. Overall, these two empirical contributions suggest that rapid growth in Internet use is still environmentally sustainable in OECD countries including Australia.

Finally, the conceptual framework of this research is believed to be a contribution by itself as it was able to successfully demonstrate an interlinked and sequentially connected flow of potential investigations into three key areas of sustainable development where the Internet can play a game changing role for the countries studied. Nevertheless, the comprehensive literature review covered almost the entire gamut of empirical works on economic, social and environmental effects of the Internet and represents a contribution to existing body of knowledge in the field of sustainable development caused by Internet technology. Although new literature will continue to evolve, future researchers in this field are expected to be able to gain a detailed understanding about the effects of the Internet on sustainable development from the massive volume of literature reviewed in this thesis.

## 7.3 RECOMMENDATIONS

Based on the findings of the positive relationship between Internet use and economic growth from papers one and two, it is recommended that OECD countries focus on demand-side issues of the Internet, such as education and e-skills, more so than the supply-side issues such as the physical infrastructure of the Internet. It is important to acknowledge that the digital divide in these countries is related less to the physical infrastructure but more to demand issues such as education, e-skills and so on. Consequently, uniformity in the speed of the Internet across the country, both in metropolitan and regional areas, is an issue that needs attention.

Although findings in papers three and four indicated that the Internet reduces social capital, the research recommended that the digital divide policies of these countries should not rule out the possibility of including the social capital issue. The research showed that using a single indicator of social capital (trust) may not be enough to judge the value of the findings of these two papers. Nevertheless, given that the coefficients of the negative effect of the Internet on social capital were quite small in both cases (OECD countries and Australia), it may be expected that the Internet will gradually be able to generate social capital and enable social inclusion of the relatively disadvantaged and underprivileged people. This in turn will help to minimise the digital divide. For this reason, the social capital issue needs to be incorporated into the digital divide policies of these countries. Positive findings on the association between Internet use and social capital in the WDR of Queensland lends strong support to such a recommendation.

Although, the finding of insignificant emissions imply that these countries are not still facing environmental risk from the growth in Internet use; however, to address imminent threats and the overall environmental threat from such growth, schemes such as ‘green Internet’ and ‘Internet for green’ should be promoted. It is not sufficient to reduce Internet’s own carbon footprint, it is important to reduce the overall carbon footprint of these countries by exploiting the emissions abatement potential of the Internet and by other means.

## 7.4 LIMITATIONS

As outlined in papers three and four, respectively, a major challenge this research encountered was the poor quality of social capital data used for OECD panel countries and for Australia, in particular. This research had to rely on trust data as a measure of social capital and although trust is the most widely used proxy for the social capital variable in macro empirical studies, it does not adequately capture social capital. This is because social capital is a multidimensional concept and there is no consensus as yet on its measurement. Nevertheless, several data points were missing from the trust data and, consequently, only 19 countries were considered for the OECD panel. The missing data points were replaced with data points generated through linear interpolation.

The second limitation of this research was in regards to the generalizability of the findings. This thesis limited its analysis to OECD countries only. Economic, social capital and energy effects of Internet technology seem to be even more relevant for developing countries – many are also going through the Internet’s rapid diffusion and are in need of "catching up" with their developed counterparts in order to survive in a digital world. Nevertheless, digital divide with respect to access, education, age and ability are even more prominent issues for developing countries. However, policymakers from developing countries can also take messages from the key findings of this thesis to steer them towards the formulation of policies that are relevant to them. Third, future empirical investigations using data of longer sample periods are expected to provide more reliable findings than those obtained from this study.

Fourth, although modern econometric and statistical techniques for the analysis of panel data, time series data and survey data were employed in this research, the results are unlikely to be invariant across the spectrum of other econometric and statistical specifications. Finally, this research did not undertake an in-depth assessment of the quantitative extent of digital divide in the studied countries and had to rely on the available literature and on some descriptive statistics from its survey data. The reason for this is that no unique quantitative measure of digital divide is currently available, as it is increasingly becoming a multidimensional and complex issue resulting in continuous debate on the topic.

## 7.5 DIRECTIONS FOR FUTURE RESEARCH

Based on the findings of the positive relationship between Internet use and economic output from papers one and two, respectively, it was recommended in both papers that future studies should explore the Internet's other indirect effects on the economy, especially those that are highly potential but are still unexplored. One potential area of such investigation is to examine how the Internet is impacting on the service sector of economies. One of the most glaring changes currently sweeping the world economies is a shift from the manufacturing sector to the service sector.

This direction for future research is likely to be reinforced by the fact that the Internet industry itself is a service sector that is emerging as one of the potential growth drivers for many countries, including Australia.

Another potential area for investigation could be to study the Internet's effect on the share market of various economies. The performance of the share market is increasingly becoming an important parameter for macroeconomic stability of a country and the Internet as a powerful tool for information communication has a potential role in this sector. Health and education are two key areas where the Internet has significant potential to contribute in both developed and developing countries. In-depth investigations of the Internet's role in such areas are likely to provide insightful directions for the policymakers of these countries.

Due to different forms of digital divide emerging so quickly, research on these recent forms of divide has become very difficult. To date, most of the empirical research on digital divide has focused on socioeconomic variables such as age, gender, income and education. Since digital divide may be caused by differences in ability to use the Internet, skill divide is one of the most recent forms of digital divide which is likely to continue to haunt the digital landscape in the future also, an e-skill index may be developed from the various forms of Internet use at the regional level. Researchers can statistically examine how differences in such skills impact Internet use. Such investigation is expected to reflect, to some extent, the skill divide at the regional level. A comparison of such a relationship between regions is likely to provide strong policy implications for countries like Australia and other OECD countries as well.

As macro data on multiple indicators of social capital is almost impossible to obtain, social capital studies at a macro level (paper three and paper four) do not seem to be potentially very useful. The construction of social capital variable with five of its theoretically valid and statistically tested dimensions with the application of summated scale method on survey data is an innovation of this thesis. This quantitative measure of social capital is expected to provide an insightful direction to future researchers who would be keen to undertake investigations in the area of social capital for other regions. Findings from such regional studies may also provide strong direction for the national policies on digital divide and the Internet for the relevant countries.

The findings from papers six, seven, eight and nine suggest that OECD countries are environmentally sustainable despite experiencing a rise in their electricity consumption due to growth in Internet use. Therefore, investigations into the environmental effects of the Internet in other contexts may be useful from energy future perspective. Such investigations are expected to further enable countries to explore the potential of the Internet for achieving energy efficiency.

This research focused only on OECD countries, but it is recommended that future studies also focus on developing countries. It is argued that in many of these countries, Internet diffusion is faster than in developed countries. It may be important to investigate how and whether the Internet is playing a role to reduce poverty in these countries. Also, there may be scope for investigations in developing countries to see how or whether the Internet is positively impacting their economies at the micro level by facilitating microfinance, microcredit, and SMEs, among others which may contribute towards reduction of poverty.

This study recommends future studies that focus not only on the potential positive effects of the Internet but also on certain negative effects. The number of cybercrimes, such as hacking, piracy, copyright violation and trespassing, is continuously increasing. Such crimes sometimes may prove to be very expensive for individuals as well as for a country. Nevertheless, the increasing number of pornographic and other vulgar sites may gradually cause serious moral degradation, especially among the younger generation. These sites may eventually detract them from family life and are likely to deteriorate their social, moral and family values. These apparently intangible effects may look benign at the moment but may prove to be quite harmful in the long run. Therefore, future research should focus on such issues with a view to assessing the extent of their impacts.

Finally, it would be interesting to explore the effect of the Internet on sustainable development by assessing the combined effects of economic growth, social capital and environment thorough one single model instead of the four models this study employed. To accomplish this, this study proposes the application of Canonical Correlation and/or Multivariate Analysis of Variance (MANOVA) techniques.

## 7.6 CONCLUDING REMARKS

The central aim of this thesis was to assess the effects of the Internet on sustainable development through its three key pillars economic, social and environmental effects. To accomplish this, three objectives and four research questions are developed. A total of nine papers are produced to address four research questions to analyse the effects of the Internet on economic growth, social capital, electricity consumption and $CO_2$ emissions. OECD macro panel data, Australian time series macro data, and quantitative survey data from the WDR of Queensland, Australia, were analysed. PMG regression technique and the ARDL model were applied for the analysis in all four contexts (four research questions) for panel data and time series data, respectively, and the multivariate OLS regression technique was applied to analyse quantitative survey data.

Paper one and paper two analysed the effects of the Internet on economic growth for OECD countries and for Australia, and the effect was found to be positive. Papers three, four and five analysed the effects of the Internet on social capital which was found to be negative for OECD countries and for Australia. However, it was positive for regional Australia. Papers six and seven examine Internet's effect on electricity consumption in OECD countries in general, and for Australia. The effect of Internet use on electricity consumption was found to be positive for both OECD countries and for Australia in papers six and seven. Papers eight and nine investigated the effect of Internet use on $CO_2$ emissions in OECD countries and in Australia. In both cases, this effect was found to be insignificant.

Overall, the positive economic growth effect of the Internet highlights its important role in economies around the globe. The negative social capital effect of the Internet at the macro level (papers three and four) was attributed to the use of one single indicator of social capital, which is debated in the literature. The study found that the Internet has a positive social capital effect in the WDR when it used multiple indicators for social capital measurement. The positive effect of the Internet on electricity consumption was expected, while the insignificant emissions effect was also expected for two reasons. First, a rather insignificant share of total electricity is used for Internet-related needs; second, the Internet may be blessed with emissions abatement potential through 'Internet for green' and 'green Internet' schemes, which are already being promoted in many of these countries. Finally, this thesis unveils that the growth in the use of the Internet does contribute towards sustainable development especially in the context of the OECD countries.

This thesis provides recommendations for further investigations into the effect of the Internet on other areas of the economy which are currently unexplored and/or underexplored. Specifically, it is recommended that future research focus on the service sector and the share market, among others, and investigate the role of the Internet in poverty alleviation in the context of developing countries. More regional studies are also recommended to assess the Internet's effect on social capital, which will likely give direction towards dealing with the digital divide in regional areas. Further investigation into the environmental effects of the Internet are recommended for other regions and other parts of the world, as this may enable countries to tap into the potential of the Internet to help with achieving environmental sustainability. It may also be interesting to explore in future the combined effects of all three key parameters (economic growth, social capital and environmental effects) of sustainable development that this study examined separately.