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THE IMPACT OF BROADBAND ADOPTION ON ECONOMIC GROWTH: AN ASSESSMENT IN SELECTED DEVELOPED AND DEVELOPING COUNTRIES

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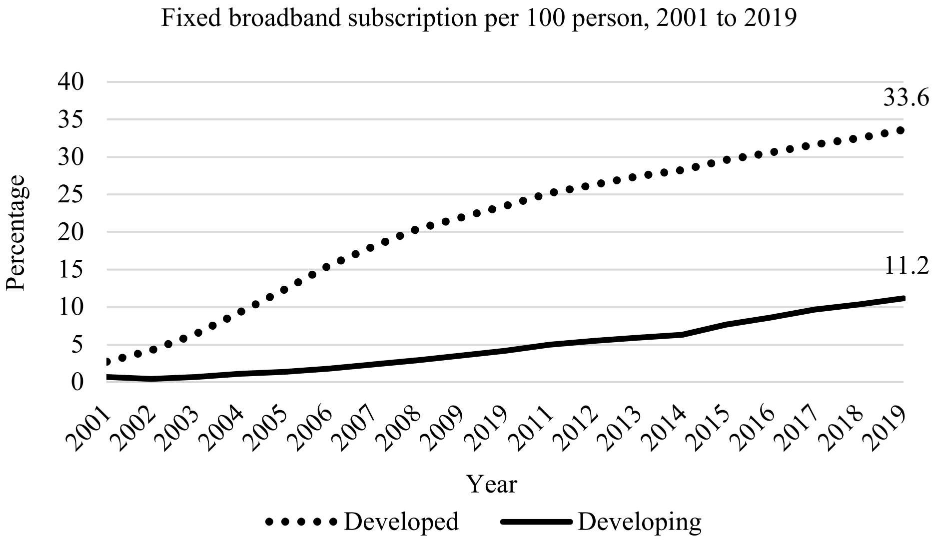
Broadband has emerged as an important infrastructure element to promote economic growth. This study aims to investigate and compare the relationship between broadband adoption and economic growth between developed and developing countries using panel data analysis. The empirical results signified that broadband adoption contributed positively to economic growth in both the developed and developing country groups. However, broadband's contribution towards economic growth was larger in the developed country group than in the developing country group. Also, several policy recommendations to improve the contribution of broadband adoption towards economic growth arose from the results of this study.

Keywords: Broadband Adoption, Economic Growth, Developed Countries, Developing Countries, Panel Data Analysis
JEL Classification: O30, O11, F62

1. INTRODUCTION

In the 1970s, the Internet was predominantly accessible only via dial-up using a traditional telephone line. As demand for internet access increased from both consumers and enterprises, the development of fixed high-speed data transmission technologies, such as DSL, ADSL and fibre, has surged (Crandall, 2005). As a result, broadband adoption, defined as the proportion of the population subscribing to broadband services to access the Internet, has soared worldwide. Nowadays, broadband adoption has emerged as an important element of nations' infrastructure for economic growth in developed and developing countries alike, impacting individuals, businesses, and communities. According to Qiang, Rossotto and Kimura (2009), increasing broadband access has supported firms, businesses, and organizations by lowering costs, raising productivity, encouraging technological innovation and eventually contributing to economic growth. In addition, broadband has led to drastic changes in the Information and Communications Technology (ICT) sector by enabling services, such as mobile applications, which have, in turn, influenced innovation in many other fields, including transport and health. Therefore, the impact of broadband adoption on nations' economies is a subject of rising interest.



Sources: ITU World Telecommunication / ICT Indicators database

Figure 1. Fixed Broadband Subscription in Developed and Developing Countries

Several studies have suggested that improved economic indicators have been seen in countries with high broadband adoption rates (see Alam, Sultana and Rayhan, 2019; Ng, Lye and Lim, 2013; Atif, Endres and Macdonald, 2012). Furthermore, previous studies have documented numerous reasons why rapid broadband diffusion has substantially impacted economic development. Based on Czernich et al. (2011), broadband lowers entry barriers to markets and offers greater market transparency, enhances productivity, increases market competition and ultimately promotes greater economic growth. Besides, in the global information technology report (Dutta and Mia, 2010), it was estimated that the global gross domestic product (GDP) would reach USD400 billion and create approximately ten million jobs annually when mobile broadband was brought into the developing world. According to the World Bank, a 10 per cent increase in broadband adoption increased GDP growth by 1.38 per cent in developing nations. Thus, closing the digital divide between developed and developing nations could significantly boost economic development. In addition, for developing countries to move towards a more developed status, higher broadband adoption rates and a more advanced ICT technology are required. In addition, the World Economic Forum (2016) noted that developing countries could move towards the developed world by increasing their broadband adoption rates. Hence, broadband adoption provides countries with an extremely valuable opportunity with which to improve their economic growth.

The World Bank revealed that broadband internet in developing countries is accessible by approximately 35 per cent of the population, in contrast to developed countries where around 80 per cent of the population has broadband internet access. As developing countries have lower rates of broadband internet access, their economic growth may not be as advanced as developed countries because lower rates of broadband internet access have hindered job creation and innovation in the ICT, engineering, and other sectors. Moreover, according to the ITU's, "Measuring the Information Society Report 2016", broadband adoption in developed countries is three times higher than in developing countries. In 2019, the broadband adoption rate of developed countries was 33.6%, but only 11.2% in developing countries (Figure 1). The disparity of broadband adoption between developed and developing countries has occurred due to the lack of available broadband connections in developing countries. The State of Broadband 2017 Report estimated that a huge disparity in broadband internet connection rates between developed and developing countries would occur. The report noted that the broadband internet connection rate in developed countries was around 84.4 per cent, while in developing countries, it was around 42.9 per cent.

All in all, broadband plays a vital role in today's economy, and it is a necessary tool for innovation and global growth. As the use of broadband technology has surged globally, the debate concerning the advantages of broadband has also increased. Czernich et al. (2011) argued that broadband could promote economic development in many ways, such as encouraging the sharing and exchange of knowledge, enhancing product innovation, and improving the coordination of different work activities. Similarly, many economists and policymakers have considered broadband as the best way to achieve a knowledge-based economy and stronger economic growth (Badran, El Sherbini and Ragab, 2007). For this reason, high broadband adoption rates have been one of the targets to achieve by developed and developing countries.

However, some scholars have disputed the contribution of broadband to global economic development and argued that the effect of broadband adoption on economic growth could be adverse. Katz and Koutroumpis (2012a) carried out a study on the economic impact of broadband adoption. They found no significant impact of the rate of fixed broadband penetration on economic growth in the Philippines. A similar study was also conducted in Senegal by Katz and Koutroumpis (2012b), the result found a negative impact of fixed broadband adoption on economic growth. In the case of the United States, the impact of broadband adoption has remained unclear due to insufficiently granular data. Most studies concerning the economic impact of broadband adoption in the United States have used data from the Federal Communications Commission (FCC). Microsoft and the United States Government Accountability Office have been criticized for overestimating the reach of broadband. As a result, researchers have not drawn definite conclusions regarding the economic impacts of broadband adoption in the United States.

Nonetheless, the FCC has recently resolved the data availability issue by applying a more precise data collection method, enabling the collection of more accurate geospatial broadband coverage data in the United States. However, for many low-to-medium income nations, such data are often simply not available in any form. This situation has led to doubtful findings on the impact of broadband on economic growth in low-to-medium income nations.

In addition, some researchers have argued that as developed countries have higher broadband adoption, the contribution of broadband to economic growth will be significantly greater in developed countries than that of developing countries. Based on some past studies, broadband contributes more towards economic growth in developing countries. According to Qiang, Rossotto and Kimura (2009), a 10 per cent rise in broadband penetration would raise the GDP growth of developing countries by 1.38 per cent but only 1.2 per cent in developed countries.

Given the above-mentioned contradictory views, this study examined this issue by investigating and comparing the relationship between broadband adoption and economic growth in selected groups of developed and developing countries using panel data between 2001-2019.

This study has contributed to the current body of literature in several ways. The majority of existing studies that have examined the contribution of broadband adoption on economic growth were restricted to developed economies. Therefore, this study attempts to fill the current gap in the literature concerning the importance and contribution of broadband adoption on economic growth in developing as well as developed countries. Besides, the outcome of this study might be a useful tool for policymakers to develop good broadband policies that will foster greater innovation in the ICT field, eventually leading to higher economic growth for both developed and developing countries. In addition, as more data becomes available, this study may contribute by providing more accurate insights on the impact of broadband adoption on economic growth in both developed and developing countries.

The remainder of this paper is organised as follows: Section 2 presents a review of the relevant literature concerning the adoption of broadband and economic growth; Section 3 illustrates the theoretical framework and the methodology used in this study; Section 4 discusses the empirical results, and Section 5 concludes the paper as well as providing policy recommendations.

2. LITERATURE REVIEW

Numerous previous studies have signified the important role of the adoption of broadband in improving economic growth, for example, Whitacre, Gallardo and Strover (2014), Atapattu (2010), Lee, Oh and Shim (2005) and Lee and Lee (2003). These researchers also stated that advanced broadband internet technology had a tremendous influence on many aspects of the economy.

Some well-documented academic literature has also suggested that broadband has positively contributed to economic growth in OECD countries. Atif, Endres and Macdonald (2012) found that broadband penetration had positively contributed to the economic growth per capita in 34 OECD countries. They determined that a 10 per cent rise in broadband penetration increased economic growth per worker by approximately 0.035 percentage points. Similarly, a study carried out by Czernich et al. (2011) suggested that a 10 per cent increase in broadband penetration improved per capita economic growth between 0.9 per cent to 1.5 per cent. Likewise, Bojnec and Ferto (2012) study covered 35 OECD countries and signified that increased broadband access led to increased GDP growth. Koutroumpis (2009) revealed that countries with lower broadband penetration experienced lower annual economic growth than countries with medium and high broadband penetration.

Besides, for European countries, like the OECD countries, most previous studies have suggested that increased broadband adoption significantly improved economic growth. Koutroumpis (2009) found that broadband adoption led to economic growth, where a 10-percentage point increase in broadband penetration led to a rise in GDP growth from 0.26 per cent to 0.85 per cent in 15 European countries. In addition, Gruber, Hätönen and Koutroumpis (2014) also performed similar research on data between 2005 and 2011. The results suggested that broadband adoption rates had substantial and positive effects on GDP growth.

Nevertheless, a study carried out by Ng, Lye and Lim (2013) examined the relationship between broadband penetration and economic growth in the ASEAN region from 1998 to 2011. The results revealed a positive relationship between broadband penetration and GDP growth. Similarly, Zaballos and Lopez-Rivas (2012) examined the economic impact of broadband adoption in the Latin American and the Caribbean (LAC) region. They stated that a 10 per cent rise in fixed broadband penetration increased the GDP per capita by 3.19 per cent. In addition, as indicated in World Bank report, Qiang, Rossotto and Kimura (2009) researched the impact of several ICTs, including fixed broadband, on the economic growth of 120 developed and developing countries between 1980 and 2006. Their findings concluded that a 10-percentage point rise in fixed broadband adoption increased GDP growth by 1.21 per cent in developed nations and 1.38 per cent in developing nations.

Badran (2012) found similar findings for Arab Countries; based on a study conducted on 22 developing countries in Arab nations between 1998 and 2008. The findings revealed that broadband adoption contributed positively to economic growth in the sampled Arab nations. Another study by Kolko (2012) examined the relationship between broadband expansion and economic growth in the United States from 1996 to 2006. The result suggested that broadband expansion and local economic growth had a positive relationship. However, the expansion was stronger in areas with low population density and within industries that involved greater usage of information technology.

However, it is noticeable that few past studies have revealed that broadband adoption had no significant impact on economic growth. Katz and Koutroumpis (2012a) investigated the impact of fixed and mobile broadband on the Philippines' economic growth between 2000 and 2010. The result suggested that there was no significant effect from fixed broadband penetration on economic growth. A similar study carried out by Katz and Koutroumpis (2012b) in Senegal, which covered the period 2004 to 2011, found that fixed broadband negatively impacted economic growth and that the impact of a simple 2G mobile phone penetration was more significant than fixed broadband penetration. Similarly, Thompson and Garbecz (2008) focused on the direct and indirect economic impact of broadband penetration at the state level in the United States. They found that evidence of the impact of broadband adoption on the GDP per capita was very limited. Likewise, Crandall, Lehr and Litan (2007) carried out a study on the effect of broadband adoption on economic growth at the state level in the United States and found that broadband adoption had no substantial effect on the GDP growth of states.

Previous studies have not reached a decisive outcome on the impact of broadband adoption on economic growth. Furthermore, there have only been a limited number of previous studies that have compared the impact of broadband adoption on economic growth between developed and developing countries. As such, this study is noteworthy as it has shed light on the impacts mentioned above.

3. METHODOLOGY AND DATA

3.1 Theoretical Framework

This study investigated and compared the relationship between broadband adoption and economic growth in a sample of countries categorized as developed and developing nations between 2001 and 2019. Hence this study employed the general and augmented production function framework by modelling aggregate economic outputs (Y) as a function of capital (CAP), labor (LBR) and broadband penetration ($BBAND$), as illustrated below:

$$Y = f(CAP, LBR, BBAND). \quad (1)$$

3.2. Data and Sources

This study adopted two output variables, namely real GDP ($GDP_{i,t}$) and the real GDP per capita ($GDPC_{i,t}$) as proxies for economic growth, as they reflect a country's economic performance in a specified period. Real GDP was chosen as an indicator of economic growth as it focuses on the macroeconomic level of countries. In contrast, the real GDP per capita served as an indicator of economic performance at the individual level. Besides, this study adopted gross capital formation as a proxy for capital. Capital formation is defined as the produced assets, including second-hand assets used to produce other goods and services. The labor force was chosen as a proxy for labor. The number of fixed-broadband subscriptions was employed as the proxy for broadband adoption. It reflects the population's access to high-speed internet through subscriptions to fixed broadband services in a specific area. The empirical model is as follows:

$$\ln Y_{i,t} = \beta_0 + \beta_1 \ln BBAND_{i,t} + \beta_2 \ln CAP_{it} + \beta_3 \ln LBR_{i,t} + \varepsilon_{i,t}. \quad (2)$$

All of the variables were transformed into natural logarithm form in the model estimation. The details of the variables are reported in Table 1.

Table 1. Data Description

Variable	Name	Description	Unit of Measurement
Dependent	$\ln GDP$	Real GDP	US Dollars at 2010 prices
	$\ln GDPC$	Real GDP per capita	US Dollars at 2010 prices
Independent	$\ln BBAND$	Fixed broadband subscriptions	Per 100 people
	$\ln CAP$	Gross capital formation	US Dollars at 2010 prices
	$\ln LBR$	Labor force	Total

In addition, to capture the persistence of the growth pattern (Vu, 2011), a lagged dependent variable was included in our dynamic model, as follows:

$$\ln Y_{i,t} = \alpha_0 + \alpha_1 \ln Y_{i,t-1} + \alpha_2 \ln BBAND_{i,t} + \alpha_3 \ln CAP_{it} + \alpha_4 \ln LBR_{i,t} + u_{i,t}. \quad (3)$$

For enhanced consistency, all of the data were collected from the World Bank Database. The sampled countries were classified into two groups: developed and developing countries based on the classification from the World Economic Outlook (updated in April 2020). Due to data limitations, this study only covered 33 developed countries and 38 developing countries. The list of the sampled countries is stated in Table 2.

Table 2. Developed and Developing Countries Selected in This Study

Development Status	Countries
Developed $N = 33$	Austria, Belgium, Canada, Cyprus, Czech Republic, Denmark, Estonia, Finland, France, Germany, Greece, Iceland, Ireland, Israel, Italy, Japan, Korea Rep., Latvia, Lithuania, Luxembourg, Macao SAR China, Malta, Netherlands, New Zealand, Norway, Portugal, Slovak Republic, Slovenia, Spain, Sweden, Switzerland, United Kingdom, United States
Developing $N = 38$	Algeria, Argentina, Armenia, Belarus, Belize, Bolivia, Brazil, Brunei Darussalam, Bulgaria, Chile, China, Colombia, Comoros, Costa Rica, Dominican Republic, Ecuador, Egypt Arab Rep., El Salvador, Gabon, Hungary, India, Iran Islamic Rep., Jordan, Kazakhstan, Malaysia, Mexico, Moldova, Morocco, Paraguay, Peru, Philippines, Poland, Senegal, South Africa, Sri Lanka, Turkey, Uruguay, Vietnam

Table 3 provides the means, standard deviation (overall), minimum and maximum values of all key variables for developed and developing countries.

Table 3. Descriptive Statistics

	Developed Countries				Developing Countries			
	Mean	Std Dev	Min	Max	Mean	Std Dev	Min	Max
$\ln GDP$	26.37	1.85	22.67	30.54	25.20	1.88	20.39	30.08
$\ln GDPC$	10.65	0.20	10.65	10.93	7.64	0.39	7.64	8.19
$\ln BBAND$	2.85	1.13	-2.81	3.85	0.34	2.43	-8.69	3.53
$\ln CAP$	24.87	1.87	20.83	29.02	23.78	1.94	18.74	29.26
$\ln LBR$	15.21	1.69	11.97	18.94	15.80	1.87	11.45	20.48

3.3. Panel Data Analysis

As this study investigated and compared the economic impact of broadband in developed and developing countries, this study adopted both static and dynamic panel data methods. For the static model, this study carried out both the Breusch Pagan Lagrange Multiplier Test and the Hausman Test to identify if the Pooled Ordinary Least Squares (Pooled OLS), fixed effects and random effects were the best models to treat the data. While for the dynamic model, the dynamic Generalised Method-of-Moments (GMM) estimator, proposed by Arellano and Bond (1991), was preferred, as it addressed the endogeneity issue that arises from the inclusion of the lagged dependent variable. In addition, several diagnostic checks were computed for both the static and dynamic models, as presented in subsection 3.3.3.

3.3.1. Breusch Pagan Lagrange Multiplier Test

The Breusch Pagan Lagrange Multiplier test was proposed by Breusch and Pagan (1980) to identify whether the Pooled OLS or random effects model is an appropriate model. This test is distributed as chi-squared with one degree of freedom under the null hypothesis. The hypotheses to be tested were as follows:

$H_0: \sigma_\lambda^2 = 0$ (Pooled ordinary least squares is preferred)
$H_1: \sigma_\lambda^2 \neq 0$ (Random effects model is preferred)

When the null hypothesis is not rejected, it can be concluded that the Pooled Ordinary Least Squares model is more appropriate. When the null hypothesis is rejected, it indicates that the random effects model is more appropriate.

3.3.2. Hausman Test

The Hausman test was proposed by Hausman (1978) to identify whether the random effects model or fixed effects model is more appropriate to be applied in a panel data study. The hypotheses to be tested were as follows:

H_0: $Cov(\lambda_i, x_{it}) = 0$ (Random effects model is preferred)
H_1: $Cov(\lambda_i, x_{it}) \neq 0$ (Fixed effects model is preferred)

If the null hypothesis is not rejected, it indicates that the random effects model is more appropriate. When the null hypothesis is rejected, it can be concluded that the alternative hypothesis is accepted, and the fixed effects model is more appropriate.

3.3.3. Diagnostic Checks

We carried out diagnostic checks on the static model by examining if; multicollinearity, heteroskedasticity and serial correlation problems existed to ensure that the empirical results were robust and reliable. Besides, this study computed two diagnostic checks for the dynamic model by testing the first and second-order serial correlation in the disturbances and performing the Sargan test to estimate the over-identification restrictions. The null hypothesis for each diagnostic check is listed in Table 4.

Table 4. Tests and Hypotheses

Tests	Null Hypothesis	Statistical Value
Breusch-Pagan LM	Pooled ordinary least square is preferred	$\bar{\chi}^2$-stat
Hausman	Random effect model is preferred	χ^2-stat
Multicollinearity	No multicollinearity	mean vif
Heteroskedasticity	No heteroscedasticity (variances are constant)	χ^2-stat
Serial Correlation	No serial correlation (autocorrelation)	F-stat
Sargan	All instruments are valid	χ^2-stat
1st order serial correlation	No first-order serial correlation	z-stat
2nd order serial correlation	No second-order serial correlation	z-stat

4. EMPIRICAL RESULTS AND DISCUSSION

This section reports the empirical results of estimating Equations (2) and (3) using the Pooled OLS model, fixed effects, random effects and dynamic GMM estimations. After that, diagnostic tests, including multicollinearity, heteroskedasticity, serial correlation and over-identification restrictions, were carried out to ensure the robustness and reliability of the empirical result.

4.1. Developed Countries

The relationship between broadband adoption and economic growth in developed countries was identified based on the Pooled OLS method, random effects and fixed effects models. After testing all of the models, the fixed effects model was suggested as the most appropriate to be employed in this study. However, as heteroskedasticity and serial correlation problems existed, the OLS model with heteroskedasticity and serial correlation was adopted, as it was the model best fitted for developed countries. Table 5 depicts the results of the five approaches: the Pooled OLS, random effect, fixed effect, the OLS model with heteroskedasticity and serial correlation, and dynamic GMM. The results of the Breusch Pagan LM, Hausman, and diagnostic tests, including multicollinearity, heteroskedasticity, serial correlation, and over-identification restrictions, are detailed in Table 6.

Table 5. Empirical Results of Developed Countries

	Model 1	Model 2	Model 3	Model 4	Model 5
	Pooled OLS	Fixed Effects	Random Effects	OLS with Hetero. and Serial Correlation	Dynamic GMM
Dependent variable: $\ln GDP$					
$CONS$	2.61 (0.15)*	7.16 (0.61)*	7.19 (0.27)*	7.16 (3.06)**	1.60 (0.19)*
$\ln GDP_{t-1}$	-	-	-	-	0.70 (0.01)*
$\ln BBAND$	0.03 (0.01)*	0.04 (0.00)*	0.04 (0.00)*	0.04 (0.01)*	0.01 (0.00)*
$\ln CAP$	0.88 (0.02)*	0.32 (0.01)*	0.36 (0.01)*	0.32 (0.03)*	0.13 (0.00)*
$\ln LBR$	0.12 (0.02)*	0.74 (0.05)*	0.67 (0.02)*	0.74 (0.24)*	0.21 (0.02)*
R^2	0.99	0.96	0.97	0.96	
Dependent variable: $\ln GDPC$					
$CONS$	2.02 (0.16)*	2.18 (0.67)*	5.78 (0.30)*	2.18 (3.47)	0.71 (0.15)*
$\ln GDPC_{t-1}$	-	-	-	-	0.74 (0.01)*
$\ln BBAND$	0.04 (0.01)*	0.05 (0.00)*	0.05 (0.00)*	0.05 (0.01)*	0.01 (0.00)*
$\ln CAP$	0.89 (0.02)*	0.34 (0.02)*	0.39 (0.02)*	0.34 (0.04)*	0.12 (0.00)*
$\ln LBR$	-0.90 (0.02)*	-0.02 (0.05)	-0.34 (0.03)*	-0.02 (0.27)	-0.06 (0.01)*
R^2	0.85	0.17	0.71	0.17	
Observations	627	627	627	627	561
Countries	33	33	33	33	33

Notes: Figures in the parentheses are t-statistics. *, ** and *** indicate the respective 1%, 5% and 10% significance levels.

Firstly, the Breusch Pagan Lagrange Multiplier test was carried out to decide the most appropriate model to employ in this study. Based on the table above, the p-value of the Breusch Pagan LM test was significant at the 1 per cent significance level. Thus, the random effects model was preferred over the Pooled OLS model. After that, the Hausman test was carried out to identify the most appropriate approach between the random effects and fixed effects models. The result showed that the fixed effects model was preferred over the random effects model, as the p-value was significant at the 1 per cent significance level, suggesting the rejection of the null hypothesis. In addition, the diagnostic tests including; multicollinearity, heteroskedasticity and serial correlation were carried out under the fixed effects model. The result showed that the fixed effects model was free from multicollinearity as the VIF value of 9.2 was less than 10.

Table 6. Model Selection Tests and Diagnostic Checks Results of Developed Countries

Dependent variable:	$\ln GDP$		$\ln GDPC$	
	Static	Dynamic	Static	Dynamic
Breusch-Pagan LM	1896.6 (0.00)*		2273.9 (0.00)*	
Hausman	108.6 (0.00)*		7.79 (0.05)***	
Multicollinearity	9.2		9.18	
Heteroskedasticity	31601.1 (0.00)*		130000 (0.00)*	
Serial Correlation	124.1 (0.00)*		100.0 (0.00)*	
Sargan		32.6 (0.00)*		32.8 (1.00)
1st order serial correlation		-2.6 (0.01)**		-2.48 (0.01)**
2nd order serial correlation		-2.0 (0.04)**		-2.12 (0.03)**

Notes: Figures in the parentheses are p-values. *, ** and *** indicate the respective 1%, 5% and 10% significance levels.

However, both heteroskedasticity and serial correlation problems existed in this study. The results showed that the p-values of heteroskedasticity and serial correlation were significant at the 1 per cent significance level, suggesting that heteroskedasticity and serial correlation problems existed. Heteroskedasticity problems occur when the range between the smallest and largest values of the data are too significant. For instance, the smallest value of the variable, $BBAND$, was 0.06, while the largest value was 46.99, causing an unequal variance, further leading to heteroskedasticity problems. In contrast, serial correlation may be due to data values that appear to be close together in time. For instance, the data value for $BBAND$ for Canada in 2015 was 36.4046, which was close to the value of 36.7933 in 2016.

As both heteroskedasticity and serial correlation problems existed, the OLS model with heteroskedasticity and serial correlation method proposed by Wooldridge (1989) was employed, as it best fitted the model. The results produced were robust and reliable. In addition, the R^2 of this model was 0.96, which was similar to the value of R^2 in the fixed effects model. Following the result estimated from the OLS heteroskedasticity and serial correlation method, the coefficient of $\ln BBAND$ was positive and remained significant at the 1 per cent significance level. Based on the empirical result, the coefficient of $\ln BBAND$ was 0.043, suggesting that a 10 per cent increase in broadband adoption would lead to a 0.43 per cent increase in the economic growth of developed countries. Thus, it was evident that broadband adoption was significant in spurring economic growth in developed countries. This finding aligned with past studies, such as Atif, Endres and Macdonald (2012) and Bojnec and Ferto (2012). Another empirical study carried out by Rohman and Bohlin (2012) found that broadband speed played a significant role in economic growth, especially in developed countries. In addition, the finding was also in line with the augmented production function framework. Nevertheless, both labor and capital imposed positive and significant impacts on the economic growth of developed countries. This finding was similar to Wang et al. (2011), as the authors signified that capital and labor played a significant role in spurring economic growth. Interestingly, the impact of labor imposed a greater effect on economic growth compared to capital. This outcome might have been since most developed countries face serious labor shortage problems.

The results of the dynamic GMM estimation in Model (5) shown in Table 5 indicate that our main conclusion on the positive relationship between broadband adoption and economic growth remained intact. The lagged dependent variable was positive and significant with a coefficient of 0.701. However, the Sargan Test in Table 6 rejected the null that all of the instruments were valid. The null of no first and second-order serial correlation was also rejected, indicating that a dynamic model was not an appropriate estimator in this case.

We re-estimated all of the estimations using the real GDP per capita as the dependent variable. The results were qualitatively very similar to those obtained using the real GDP as the dependent variable. Specifically, the estimation showed that $\ln BBAND$ and real GDP were significantly associated with a coefficient of 0.046, which lent further credence that their relationship was positive.

4.2. Developing Countries

Similar to the methods employed for the developed countries, the OLS model with heteroskedasticity and serial correlation was used to investigate the relationship between broadband adoption and economic growth in developing countries. Table 7 displays the results of five approaches, including Pooled OLS, random effects model, fixed effects model, OLS model with heteroskedasticity and serial correlation and the dynamic GMM estimator. In addition, the results of the Breusch Pagan Lagrange Multiplier test, Hausman test and diagnostic tests, such as multicollinearity, heteroskedasticity and serial correlation, are shown in Table 8.

Similarly, the Breusch Pagan Lagrange Multiplier test was carried out after both the Pooled OLS and random effects model were estimated. The result showed that the random effects model was more appropriate, as the p-value was significant at the 1 per cent level, which indicated that the null hypothesis was rejected. Besides that, the Hausman test was carried out after the fixed effects model was estimated. The result depicted that the fixed effects model was more appropriate, as the p-value was significant at the 1 per cent significance level, suggesting rejection of the null hypothesis.

In addition, diagnostic tests including multicollinearity, heteroskedasticity and serial correlation were carried out. The result of the multicollinearity test suggested that multicollinearity did not exist, as the VIF of 5.98 was less than 10. However, the results of the heteroskedasticity and serial correlation tests suggested that heteroskedasticity and serial correlation existed, as the p-value was significant at 0.01 level, suggesting that the null hypotheses for both the heteroskedasticity and serial correlation tests should be rejected. As mentioned earlier, heteroskedasticity occurs as the range between the smallest and largest value in the dataset is too great. Serial correlation occurs if the data values appear to be close together in time.

Table 7. Empirical Results of Developing Countries

	Model 1	Model 2	Model 3	Model 4	Model 5
	Pooled OLS	Fixed Effects	Random Effects	OLS with Hetero. and Serial Correlation	Dynamic GMM
Dependent variable: $\ln GDP$					
$CONS$	2.99 (0.17)*	12.00 (0.63)*	8.03 (0.32)*	12.00 (2.03)*	1.55 (0.12)*
$\ln GDP_{t-1}$	- -	-	-	-	0.85 (0.01)*
$\ln BBAND$	0.01 (0.00)	0.04 (0.00)*	0.03 (0.00)*	0.04 (0.01)*	0.00 (0.00)*
$\ln CAP$	0.86 (0.02)*	0.33 (0.02)*	0.38 (0.02)*	0.33 (0.07)*	0.07 (0.00)*
$\ln LBR$	0.11 (0.02)*	0.34 (0.04)*	0.52 (0.02)*	0.34 (0.13)**	0.04 (0.01)*
R^2	0.98	0.96	0.95	0.96	
Dependent variable: $\ln GDPC$					
$CONS$	1.86 (0.22)*	6.76 (0.64)*	6.35 (0.35)*	6.76 (2.21)*	0.71 (0.06)*
$\ln GDPC_{t-1}$	- -	-	-	-	0.86 (0.01)*
$\ln BBAND$	0.04 (0.01)*	0.04 (0.00)*	0.04 (0.00)*	0.04 (0.01)*	0.00 (0.00)**
$\ln CAP$	0.85 (0.02)*	0.31 (0.02)*	0.34 (0.02)*	0.31 (0.07)*	0.07 (0.00)*
$\ln LBR$	-0.86 (0.02)*	-0.35 (0.04)*	-0.38 (0.03)*	-0.35 (0.13)*	-0.07 (0.01)*
R^2	0.79	0.74	0.76	0.74	
Observations	722	722	722	722	646
Countries	38	38	38	38	38

Notes: Figures in the parentheses are t-statistics. *, ** and *** indicate the respective 1%, 5% and 10% significance levels.

To address the problems of heteroskedasticity and serial correlation, the OLS model with heteroskedasticity and serial correlation method, as proposed by Wooldridge (1989), was applied, similarly to developed countries' case. The R^2 of this model was 0.96, which implied that 96 per cent of the variation of the GDP was explained by the independent variable. Besides, the coefficient of $\ln BBAND$ was 0.039 and was significant at the 1 per cent significance level. Indicating that a 10 per cent increase in broadband adoption would lead to a 0.39 per cent increase in the GDP of the developing countries. Similarly to developed countries, broadband adoption significantly accelerated the economic growth of developing countries. Furthermore, the impact of broadband adoption was smaller in developing countries compared to that of developed countries. Apart from the above, both labor and capital were positive and significant towards the economic growth of developing countries, which was in line with the general production function framework. Labor imposed a greater impact on the economic growth of developing counties, as a significant number of developing countries are still focused on labor-intensive industries.

Table 8. Model Selection Tests and Diagnostic Checks Results of Developing Countries

Dependent variable:	$\ln GDP$		$\ln GDPC$	
	Static	Dynamic	Static	Dynamic
Breusch-Pagan LM	2508.1 (0.00)*		3244.5 (0.00)*	
Hausman	151.4 (0.00)*		121.0 (0.00)*	
Multicollinearity	5.98		5.98	
Heteroskedasticity	13530.5 (0.00)*		15912.7 (0.00)*	
Serial Correlation	148.8 (0.00)*		201.6 (0.00)*	
Sargan		405.0 (0.00)*		398.3 (0.00)*
1st order serial correlation		-3.6 (0.00)*		-3.6 (0.00)*
2nd order serial correlation		-2.3 (0.02)**		-2.4 (0.02)**

Notes: Figures in the parentheses are p-values. *, ** and *** indicate the respective 1%, 5% and 10% significance levels.

We also estimated the dynamic equation using the GMM estimator for developing countries, using a similar procedure to that employed for developed countries. The findings suggested that the relationship between broadband adoption and economic growth was statistically positive significant. Nevertheless, the diagnostic checks again indicated that the dynamic model was not an appropriate estimator in this case.

Lastly, we re-estimated the models using the real GDP per capita as the dependent variable, and the results are presented in Table 7. The results showed positive signs and the statistical significance of the key variables of broadband adoption and real GDP per capita for developing countries.

5. CONCLUSION AND POLICY RECOMMENDATIONS

5.1. Conclusion

The relationship between broadband adoption and economic growth in developed and developing countries has been discussed for decades. Economists have provided different insights regarding the relationship between broadband adoption and economic growth in developed and developing countries. Well-documented literature has provided evidence that broadband adoption has contributed positively to economic growth in both developed and developing countries. However, some studies have shown that broadband contributes more to the economic growth of developed countries than developing countries, while other studies have provided contradictory findings.

Given these contradictory views, this study investigated and compared the relationship between broadband adoption and economic growth in developed and developing countries from 2001 to 2019 using panel data analysis. Several tests were conducted to identify if the Pooled OLS, random effects or fixed effects models were best fitted to treat the data.

The results suggested that the OLS model with heteroskedasticity and serial correlation method was the best fit due to heteroskedasticity and serial correlation problems. The findings signified a positive relationship between broadband adoption and economic growth in developed and developing countries. These findings were in line with many previous studies. In addition, it was noted that broadband tended to contribute more towards the economic growth in developed countries than that of developing countries. According to an International Telecommunication Union (ITU) 2019 report, a similar finding was found, in which broadband adoption provided a greater contribution towards economic growth in developed countries. Advanced technologies make broadband affordable, and the active engagement of developed countries in promoting broadband adoption might be why broadband appears to have a stronger contribution to economic growth in such countries.

On the other hand, according to the UNCTAD Internet Broadband for an Inclusive Digital Society report (UNCTAD, 2015), the disparities between rural and urban areas of the developing countries in broadband development are huge and significant. The report showed that the development of broadband in developing countries is not comprehensive and equally developed. Many challenges, such as the lack of skilled human resources, financial pressure and the absence of effective broadband policies, are faced by developing countries in providing sufficient broadband infrastructure, thereby hindering the development of broadband in such countries (UNCTAD, 2015).

In a nutshell, this study found a positive relationship between broadband adoption and economic growth in developed and developing countries from 2001 to 2019. Also, the contribution of broadband to economic growth was stronger in developed countries than in developing countries

5.2. Policy Recommendations

Several policies can be implemented to improve the contribution of broadband towards economic development in both developed and developing countries. The use of broadband in different aspects, such as business and education, should be widely encouraged. This outcome could be implemented through an investment subsidy plan and tax relief incentives for broadband service providers. Such programs would lower the cost of providing broadband services and eventually lead to a higher number of broadband subscriptions that would eventually benefit the economy. More importantly, broadband use in businesses and e-commerce should be continually promoted so that broadband can continue to contribute directly to economic development. Furthermore, policymakers could provide free broadband access, especially in rural areas; thereby, spreading the benefits provided by broadband more widely, further contributing to economic development.

Besides, Research and Development (RandD) programs related to broadband should be encouraged to intensively tackle the challenges and opportunities related to expanding broadband access and adoption. Such programs would be particularly relevant for developing countries that lag behind developed countries in their broadband deployments. Extensive broadband RandD programs are crucial as they could increase the affordability of broadband and the speed of broadband deployments. Eventually, such programs will improve broadband accessibility, especially in underserved rural areas.

Furthermore, instead of focusing on the overall adoption of broadband, more specific policies should be considered to ensure the balanced development and adoption of broadband, as unbalanced development and adoption of broadband would further widen the already existing adoption gaps in particular regions. In other words, policymakers should ensure that broadband policies are comprehensive. Last but not least, as broadband technologies evolve, a mechanism to track the progress of particular policies or plans should be developed. Such a tracking mechanism would enable policymakers to keep up with ever-changing broadband technologies; thereby, keeping policies abreast of developments in broadband and eventually benefiting the whole economy.

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