Solow model with technological progress: An empirical study of economic growth in Vietnam through ARDL approach

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Abstract

This study aims to clarify the relationship between technological progress and economic growth in Vietnam. This investigation used annual data from the World Bank related to Vietnam from 1985 to 2019 and applied the approach of autoregressive distributed lag to evaluate the impact of technological progress on economic growth in Vietnam in the short and long term. The regression equation constructed in this investigation came from the analysis of the Cobb-Doulag equation and the Solow model. The results of the study showed that GDP per capita is affected by the variables of technological progress in the short and long term, which means that technological progress affects economic growth in Vietnam. This study also contributes to the area of economic growth research in Vietnam with important evidence-based results on the impact of technological progress on GDP per capita, and the findings of this study have several implications for the understanding of the role of technological progress in economic development. The current study is still limited to small sample sizes and does not cover all indicators for analysis; however, it provides the foundation for future investigations with larger sample sizes, and other elements of technological progress are modified and applied in specific fields.

Keywords: *Vietnam, economic growth, Solow model, ARDL approach, and technological progress.*

1. Introduction

The Solow model can be understood as an exogenous growth model, which is the economic model of long-term economic growth based on the background of neoclassical economic theory. The model studies and analyses capital accumulation, labor or population growth, and productivity, which depend on technological progress. The Solow model of technological progress focuses on the theoretical model related to technological change in economic development; it has been widely applied to analyze macroeconomic phenomena of many various fields in the world.

Significantly, the trend of science and technology development is now considered a factor that directly influences labor productivity, replaces human power with machinery and equipment to decrease labor intensity, and increases the value of the product. Technological progress is considered the best way to create useful products and services with scarce resources. Vietnam is a developing country in the development stage, but there are so many difficulties due to the limited labor force and capital for economic growth. Thus, the nation would like to expand its economy, which needs to enhance labor productivity related to technological progress. They should be popularly applied to achieve more effective business activities, which are significant factors contributing to economic development in the country.

Many previous studies have been conducted on economic growth based on the Solow model. For instance, Solow's (1957) study researched technical change factors in the aggregate production function, and Schilirò (2017) emphasized that technological progress is considered an exogenous factor for economic growth. He also refers to Solow's contribution to theoretical development, which has expanded the technical structure of growth theory (Schilirò, 2017). According to the study by Sredojević et al. (2016), they pointed out the critical factors for technological progress, including knowledge, R&D, and education; therefore, the endogenous paradigm theoretically eliminates the failures of neoclassical theory because the trend of economic growth will be zero if there are no technological shocks. Furthermore, Gardoňová (2016) extended some results of previous studies with analysis and concepts based on the Solow model in her research, such as the limitation of natural resources in economic growth related to production factors with technological progress, and the expensive production tools can be replaced by cheaper technical aspects; therefore, the results of her study showed the usefulness of natural resources along with specialized progress rates, which affect exploit expenditure and handling of natural resources. The research of Ramanayake (2020) indicated the Solow model's disadvantage, which does not interpret the influence of human importance on technology; still, his study result shows that the long-term growth rates are increased by a technological policy in the Solow model, and policy shifts derive technological impacts. In the context of Vietnam, the research of Ngoc (2008) measured the impact of capital formation, labor, and technological progress on Vietnam's economic growth during 1975-2005 by using the Cobb-Douglas production function. Nguyen and Trinh used the autoregressive distributed lag model (ARDL) to analyze the impact of public investment in Vietnam on economic development and private investment during 1990-2016 (Nguyen and Trinh, 2018). Kumar applied the ARDL approach to examine the influence of ICT, international tourism, and financial growth on economic development in Vietnam during 1980-2010 from short-term to long-term (Kumar, 2014). The study by Canh (2019) also combined the Solow model and I/O tables for factor analysis that affect economic growth in Ho Chi Minh City, and Soejoto et al. (2017) analyzed the regression of some variables including labor, investment, human resources natural resources, and technology, with the results being all variables that are statistically significant with economic growth in Vietnam except for natural resources.

However, these studies with macroeconomic data were actually inappropriate and may not reflect the latest macroeconomic situation. Therefore, an empirical study in Vietnam related to the Solow model with technological progress is still necessary for this period; moreover, the development of technology must be associated with useful patents and inventions. The objective of this research is to concentrate on issues of technological progress that affect economic growth. This investigation makes a significant contribution to the research area associated with the influence of technological progress on economic growth derived from factors such as the number of patent applications, the number of trademark applications, the idea of patents per capita, and the idea of patents per hour. The rest of this paper is structured as follows: Chapter 2 reviews the theories of previous involved studies; Chapter 3 considers the research methodology including data, research model, and econometric methods; Chapter 4 analyzes the study results; Chapter 5 discusses the study; the last chapter concludes the study.

2. Literature Review

The Solow model can be defined as an exogenous growth model that is the economic model of long-term economic growth based on the background of neoclassical economic theory. Meanwhile, the trend of science and technology development is now considered a factor that directly influences labor productivity, replaces human power with machinery and equipment to decrease labor intensity, and increases product value. Technological progress can be seen as the best way to create services and products which are more productive, the most important activities of technological progress comprise R&D such as technology improvement and creation.

In fact, many researchers have addressed empirical studies of economic growth based on the Solow model and other related research methodologies. Solow's (1957) study researched technical change factors in the aggregate production function, and Schilirò emphasized that technological progress is considered an exogenous factor for economic growth. He also refers to Solow's contribution to theoretical development, which has expanded the technical structure of growth theory (Schilirò, 2017). The study by Khan and Majeed pointed out an important role of information and communication technologies (ICTs) and e-government, which affect economic growth. Their empirical study was based on the survey of eight economics in South Asia using estimation techniques such as two-stage least squares (2SLS) and generalized method of moments (GMM), which indicated that there is a positive effect between economic growth and ICTs, e-government (Khan and Majeed, 2019). The 2018 paper by Aydin and his colleagues is known for its in-depth analysis of the association with total factor productivity (TFP), ICT capital service, R&D expenditure, and auxiliary variables such as labor quantity and quality, non-ICT capital service. In their study results, they found that TFP positively affects ICT capital services in the long term; however, both ICT capital services and R&D expenditures impact TFP in the short term. Furthermore, the study also showed that there is a positive effect of TFP on the auxiliary variables in the short term. In particular, the research emphasized the significant importance of R&D investment in developing countries compared to developed nations; As a result, the study findings helped developing countries that promote more R&D investment to succeed in economic growth (Aydin et al., 2018). According to the study of Sredojević and colleagues, they concluded that technology change is an important element of economic growth when it is considered as a significant component of neoclassical theory, endogenous approach, and evolutionary growth theory. They also demonstrated the critical factors for technological progress in their study, including knowledge, R&D, and education; therefore, the endogenous paradigm theoretically eliminates the failures of the neoclassical theory because the trend of economic growth will be zero if there are no technology shocks (Sredojević et al., 2016). In addition, in 2016, Gardoňová (2016) extended some previous study results with analysis and concepts based on the Solow model in her research, such as the limitation of natural resources on economic growth related to production factors with technological progress, and the expensive production tools can be replaced by cheaper technical aspects; therefore, her study results showed the usefulness of natural resources along with specialized progress rates, which affect exploit expenditure and the handling of natural resources. Results reported by Ramanayake (2020) indicated that the Solow model's disadvantage, which does not interpret the influence of human importance on technology; still, his study result shows that the long-term growth rates are increased by a technological policy in the Solow model, and policy shifts derive technological impacts.

In their 2006 paper, Frankema and Lindblad compared the economic growth between Thailand and Indonesia association with technological progress in the long term during the 1960s as well, and their study estimated the long term of TFP with the difference among the two nations in policy, import of capital goods, foreign direct investment, and R&D expenditure. The study specified that legal policies and institutional frameworks are backgrounds for technological progress, so it explained the reason that there are different results of economic growth although the initial economic growth situation among the two countries is similar in the long term (Frankema and Lindblad, 2006). Furthermore, Irawan analyzed the effect of information and communications technology on economic growth in ASIAN countries, the research focused and analyzed the input-output (I-O) table from ASIAN members such as Indonesia, Singapore, Malaysia, and Thailand. The study result argued that ICT improvement can make more developed nations have more beneficial than less developed nations, but the influence of ICT on the economy belongs to the concentration of ICT applications and the framework of the ICT sector (Irawan, 2014). An analysis of Das and Upadhyay also conducted a growth model based on panel data of fifteen Asian countries between the early 1970s and 2014, and then the study focuses on estimating the time series data every year in Malaysia with the same duration. Two research models in their study indicated that there is a positive relationship between human capital and output growth or development related to total factor productivity (Das and

Upadhyay, 2019). The investigation by Ahmed and Ridzuan (2013) was related to ICT and economic development based on panel data between 1975 and 2006 of ASEAN5+3, including Malaysia, Thailand, Singapore, Indonesia, Philippines, Japan, Korea, and China; The study explored that GDP is significantly affected by investment in labor, capital ,and telecommunications.

In particular, several researchers have studied economic growth in the context of Vietnam as well. In 2008, Ngoc measured the impact of capital formation, labor, and technological progress on Vietnam's economic growth during 1975-2005 by using the Cobb-Douglas production function. Her findings revealed that technological progress is precisely unavailable in economic growth, while studying, there is only capital accumulation contributed to economic growth from 84% to 89% for the duration of 1975-2005, which compared to 85% and 90% in the time of 1986-2005 (Ngoc, 2008). In their work, Nguyen and Trinh used the ARDL approach to analyze the impact of public investment in Vietnam on economic development and private investment during 1990-2016. Their findings proved that economic growth is affected by public investment in the survey period following an inverted U shape, but it occurs with a significant influence in the second year and an insignificant influence in the long term. Furthermore, other investments from FDI, private companies, and government companies positively affect economic development in the short term. The government capital stock also positively impacts economic growth in the short and long term (Nguyen and Trinh, 2018). Furthermore, Canh's research combined the Solow model and I/O tables for factor analysis affecting economic growth in Ho Chi Minh City between 2006 and 2015. Her detection points to the economy of Ho Chi Minh City, which plays an important role in the country's economy with the size and growth of the economy (Canh, 2019). The study by Soejoto and fellow workers offered an analysis of the regression to discover the effect of Solow variables, including labor, investment, human resources, natural resources, and technology, on economic growth in Southeast Asia. The results of the researchers contributed to our understanding of the Solow variables, which have a significant influence on economic growth per country. The economic growth of Indonesia and Brunei is significantly affected by investment, human resources, and labor. Meanwhile, Thailand and the Philippines are variables such as investment, natural resources, and labor; however, Malaysia includes investment, technology, and human resources compared to technology, natural resources, and labor in Cambodia. In particular, all variables are statistically significant for economic growth in Vietnam, except for the variable on natural resources (Soejoto et al., 2017). In a 2014 study, Kumar applied the ARDL approach to examine the influence of ICT, international tourism, and financial growth on economic development in Vietnam during 1980-2010 from short-term to long-term. The outcome showed that tourism has a positive impact in the short term, but ICT and financial growth have a significant effect in the long term (Kumar, 2014). Similarly, Kumar and colleagues also detected the relationship between ICT, remittances, and output per worker in Vietnam during 1980-2012 by using the augmented Solow model and ARDL approach. The study's consequence performed that worker output is essentially affected by ICT in the short term and long term; furthermore, the elasticity coefficient of remittance is still a positive effect in the long term although the significant level does not belong to from 1 to 10%, the outcome is a negative effect in the short term (Kumar and Vu, 2014). A recent study by Nguyen and friends recognized the impact of factors such as technology absorption ability, internal R&D productivity of interior R&D, and exterior infrastructure difficulties on technology negotiation worth following the approach to technology demand in the Vietnam technology market. The findings showed that firms absorpt higher technology ability, as a result, they have the advantages of the inbound and outbound market with the trend of higher technology demand in the technology market; conversely, the productivity of firms of interior R&D moves toward higher exterior technology demand, and companies have exterior infrastructure difficulties that interfere with the technology demand approach (Nguyen et al., 2020).

To our knowledge, reviewing the above studies, it can be seen that no one has studied so far the Solow model with the trend of technological progress in the context of Vietnam in recent years related to the number of patent applications, the number of trademark applications, the idea of patent per capita, and the idea of patent per hour because the development of technology must be associated with patents and inventions. In fact, many previous investigations on economic growth can be reviewed, including the analysis of Nguyen and Trinh (2018), which only explored the effect of public investment, private investment, FDI, private firms, and government firms on economic growth in Vietnam. Another study showed an outstanding value for the economy of Ho Chi Minh City, but the result of the study cannot illustrate the Vietnam economy (Canh, 2019), while the study by Soejoto et al. (2017) showed the Solow variables, including labor, investment, human resources, and technology that have a momentous effect on economic growth in Vietnam. The research was especially proved by Ngoc (2008) that economic growth was not based on technological progress, it only depended on capital accumulation, which contributed more than 80% to Vietnam's economic growth. From analyzed above, therefore, the research hypothesis is proposed in this study as follows:

Research hypothesis (H1): There is a positive relationship between technological progress and economic growth in Vietnam.

3. Methodology

3.1 Research framework

This study focuses on a theory called endogenous growth theory that explains the technological progress in the Solow model. Based on the production equation of Cobb and Douglas (1928), Solow (1956) describes the economic growth model equation with two inputs that are capital (K), labor (L), and Y is the output as follows:

$$Y = F(K,L) \quad (1)$$

From the above equation (1), Solow continues to extend it to technological progress as exogenous (Solow, 1956; Solow, 1957; Mankiw et al., 1992; Mankiw, 2015; Schilirò, 2017; Ramanayake, 2020). Therefore, a new equation is given by (2) at time t with A being the level of technology (Solow, 1956; Solow, 1957; Mankiw et al., 1992; Gardoňová, 2016).

$$Y(t) = A(t)F(K,L) \quad (2)$$

On the basis of the growth of Solow model (2), Lucas (1988) expands the Cobb-Douglas production function to technological progress with the special form.

$$Y(t) = A(t)K(t)^{\alpha}L(t)^{1-\alpha} \qquad 0 < \alpha < 1 \quad (3)$$

To divide equation (3) by labor (L), the equation result is rewritten as

$$\frac{Y(t)}{L(t)} = \frac{A(t)K(t)^{\alpha}L(t)^{1-\alpha}}{L(t)} \quad (4)$$

Equation (4) can be written per capita as (5)

$$y(t) = A(t)k(t)^{\alpha}L(t)^{1-\alpha} \quad (5)$$

Where y is output per capita ($y(t) = \frac{Y(t)}{L(t)}$) and k is capital per capita ($k(t)=\frac{K(t)}{L(t)}$), equation (5) continues to take the logarithm on both sides; as a result, the new equation is shown by (6)

$$\ln y(t) = \ln A(t) + \alpha \ln k(t) + (1-\alpha)\ln L(t) \quad (6)$$

From the above analysis, this research considered and offered the level of technology (A) that is an endogenous variable due to technological progress that affects economic growth in the current trend, so a new research model was presented with the variables proposed in the following equation (7) as follows:

$$\ln Y1_t = \ln X1_t + \ln X2_t + \ln X3_t + \ln X4_t + \ln X5_t + \ln X6_t + u_t \quad (7)$$

Where:

GDP per capita (Y1) represents the output per capita (y). The level of technology (A) is suggested by factors such as the number of patent applications (X1), the number of trademark applications (X2), the idea of patents per capita (X3), and the idea of patents per hour (X4). Capital per capita (k) is X5 (Investment per capita), and labor (L) is identified by X6 (School enrollment), u is the error term, and t is the year between 1985 and 2019.

3.2 Data

All variables are clarified by the World Bank (2021a) in Equation (7). This investigation also used annual data from the World Bank (World Bank, 2021b and 2021c) related to Vietnam during 1990-2019. The data was taken by logarithm before statistical calculation; however, there were still three variables with data that are not available, and they were modified and calculated to analyze the research model following the definition of Kasim(2018) and World Bank (2021a) as follows: $X3=\frac{X1}{\text{Population}}$, $X4=\frac{X1}{\text{Total hours in year}}$ and $X5=\frac{\text{Total investment to GDP}}{\text{Population}}\times \text{GDP}$.

3.3 Estimation method

This research conducted is based on the autoregressive distributed lag (ARDL) proposed by Pesaran and other researchers (Pesaran and Pesaran, 1997; Pesaran and Shin,1999; Pesaran et al., 2001) to analyse the long-term relationship and dynamic interaction between variables. In particular, research by Nguyen and Trinh (2018) also showed that ARDL's benefits compared to other co-integration approaches are more statistically significant when the sample size is small, in contrast to the Johansen co-integration method, a large sample size; furthermore, if the variables' data are not sure of stationary, non-stationary and mixed stationary at level I (1) or I (0), the ARDL approach is a good solution for practical research. This technique can explore the relationship between a dependent variable and independent variables in the short and long run within the ARDL model with a single multivariate equation. The regressors of other cointegration methods are demanded, the lagged durations that are the same, but the variables must be dissimilar and optimal lagged duration in the ARDL framework following the Akaike information criterion (AIC) or Schwartz Bayesian criterion (SBC). Hence, equation (7) was reformed according to the ARDL approach as follows:

$$\begin{aligned} D\ln Y1_t &= \beta_0 + \beta_1 \ln Y1_{t-1} + \beta_2 \ln X1_{t-1} + \beta_3 \ln X2_{t-1} + \beta_4 \ln X3_{t-1} + \beta_5 \ln X4_{t-1} + \beta_6 \ln X5_{t-1} + \beta_7 \ln X6_{t-1} \\ &+ \sum_{j=1}^{n} \delta_{1j} D\ln Y1_{t-j} + \sum_{j=0}^{n} \delta_{2j} D\ln X1_{t-j} + \sum_{j=0}^{n} \delta_{3j} D\ln X2_{t-j} + \sum_{j=0}^{n} \delta_{4j} D\ln X3_{t-j} + \sum_{j=0}^{n} \delta_{5j} D\ln X4_{t-j} \\ &+ \sum_{j=0}^{n} \delta_{6j} D\ln X5_{t-j} + \sum_{j=0}^{n} \delta_{7j} D\ln X6_{t-j} + \varepsilon_t \quad (8) \end{aligned}$$

Where β1, β2, β3, β4, β5, β6, and β7 are long-term multipliers, n is a lag number, β0 is the drift and εt is the white noise error. In addition, the estimated error correction model needs to build the short-term dynamic parameters along with the long-term estimation; thus, the equation of error correction model was identified as follows.

$$\begin{aligned} D\ln Y1_t &= \delta_0 + \sum_{j=1}^{n} \delta_{1j} D\ln Y1_{t-j} + \sum_{j=0}^{n} \delta_{2j} D\ln X1_{t-j} + \sum_{j=0}^{n} \delta_{3j} D\ln X2_{t-j} + \sum_{j=0}^{n} \delta_{4j} D\ln X3_{t-j} \\ &+ \sum_{j=0}^{n} \delta_{5j} D\ln X4_{t-j} + \sum_{j=0}^{n} \delta_{6j} D\ln X5_{t-j} + \sum_{j=0}^{n} \delta_{7j} D\ln X6_{t-j} + \lambda EC_{t-1} + \sigma_t \quad (9) \end{aligned}$$

Where the short-term dynamic coefficients are denoted by δ1, δ2, δ3, δ4, δ5, δ6, and δ7, which adjust the model to equilibrium, λ is an adjusted speed and EC includes the residuals achieved from equation (8). The procedure of ARDL analysis performs tests including bound test, identification of the lagged duration by using AIC or SBC, estimation of the ARDL model with the identified lagged period, and impacted calculation of ECM in the short term based on ARDL approach with cointegration. Reliability is also examined by tests such as the normality test, the Breusch-Godfrey serial correlation LM test, the heteroskedasticity test, Ramsey RESET test, cumulative sum of recursive residuals, and the cumulative sum of squares of recursive residuals test.

4. Research results

4.1 Unit root test with augmented dickey-fuller

Variables	ADF test statistic	P-value	Test critical values			Result	Order
			1%	5%	10%		
LnY1	-0.597	0.857	-3.646	-2.954	-2.615	Nonstationary	
D(LnY1)	-4.418***	0.0014	-3.646	-2.954	-2.615	Stationary	I(1)
LnX1	-4.475***	0.0011	-3.639	-2.951	-2.614	Stationary	I(0)
LnX2	-0.191	0.930	-3.639	-2.951	-2.614	Nonstationary	
D(LnX2)	-5.662***	0.0001	-3.689	-2.971	-2.625	Stationary	I(1)
LnX3	-5.194***	0.0002	-3.639	-2.951	-2.614	Stationary	I(0)
LnX4	-4.616	0.0008	-3.639	-2.951	-2.614	Stationary	I(0)
LnX5	-1.338	0.6000	-3.639	-2.951	-2.614	Nonstationary	
D(LnX5)	-4.102	0.0032	-3.653	-2.957	-2.617	Stationary	I(1)
LnX6	-0.859	0.7889	-3.639	-2.951	-2.614	Nonstationary	
D(LnX6)	-3.809***	0.0066	-3.646	-2.954	-2.615	Stationary	I(1)
Notes: D() denotes the first-order difference with an abbreviation I(1). Significance is statistical at 10% (*), 5% (**), 1% (***).							

Table 1: Results of the unit root test with augmented dickey-fuller (ADF)
Source: Authors' computation using Eview 10

In Table 1, the logarithm data series were examined stationary using the augmented dickey-fuller test in the unit root test. The result reveals that LnX1, LnX3, and LnX4 were stationary at level I(0), while LnY1, LnX2, LnX5, and LnX6 were the first-order difference at level I(1). Therefore, the procedure of the ARDL approach is capable of using cointegration I(1) or I(0) in the practical study and it is also suitable for the referred studies from other researchers (Pesaran and Shin, 1996; Kumar, 2014; Kumar and Vu, 2014; Nguyen and Trinh, 2018).

4.2 Bound Test

Next, to identify the effect of variables in the long term, this study combines equation (8) with the bound test to explore the long-term impact on the results as detailed in Table 2.

From equation (8), the setting of null hypothesis (H0) is $\beta1 = \beta2 = \beta3 = \beta4 = \beta5 = \beta6 = \beta7 = 0$, which means that there is no co-integration relationship between variables. The alternative hypothesis (H1) is $\beta1 \neq 0$, $\beta2 \neq 0$, $\beta3 \neq 0$, $\beta4 \neq 0$ which means, $\beta5 \neq 0$, $\beta6 \neq 0$, $\beta7 \neq 0$ that means there is a cointegration relationship among variables.

Results of Bound test									
k	F-statistic	99%		97.5%		95%		90%	
		I(0)	I(1)	I(0)	I(1)	I(0)	I(1)	I(0)	I(1)
6	131.16	2.88	3.99	2.55	3.67	2.27	3.28	1.99	2.94

Table 2: Results of the bound test
Source: Authors' computation using Eview 10

Table 2 shows that all the values of the bound test were less than the value of F-statistics, so it was statistically significant by 5% and the null hypothesis was rejected. The alternative hypothesis was accepted, and there is a cointegration relationship between variables, which means there is a long-term relationship between variables.

4.3 Estimation of the ARDL approach

Lag	AIC	SC	HQ
0	-1.262984	-0.942354	-1.156704
1	-11.56148	-8.996438	-10.71124
2	-18.31268*	-13.50323*	-16.71848*

Table 3: Lag order selection criteria.
Source: Authors' computation by using Eview 10.

The lag number n can be selected as a maximum value, that is, 7 in equation (8). Based on the criteria of AIC or BSC, Table 3 illustrates that the value of AIC and SC also obtained a minimum value in lag 2. The next table reveals the result of the ARDL approach with the selected lag in Table 3 along with the dependent variable LNY1.

Variable	Coefficient	Std. Error	t-Statistic	Probability
LNY1(-1)	0.499***	0.086945	5.743620	0.0000
LNX1	-0.053442	0.166529	-0.320914	0.7520
LNX1(-1)	-16.223***	3.492638	-4.644967	0.0002
LNX1(-2)	-73.867***	5.579898	-13.23810	0.0000
LNX2	-0.017790	0.071755	-0.247921	0.8070
LNX2(-1)	0.006228	0.092434	0.067376	0.9470
LNX2(-2)	0.224***	0.059956	3.738237	0.0015
LNX3	-2.100***	0.463374	-4.532356	0.0003
LNX4	2.333***	0.523484	4.457714	0.0003
LNX4(-1)	16.280***	3.453657	4.713966	0.0002
LNX4(-2)	73.758***	5.599962	13.17125	0.0000
LNX5	0.006546	0.032011	0.204500	0.8403
LNX5(-1)	-0.150***	0.017759	-8.488704	0.0000
LNX6	-0.041687	0.053792	-0.774978	0.4484
C	803.343***	72.14036	11.13584	0.0000
R-square	0.999452	Mean dependent var	6.411093	
Adjusted R-squared	0.999027	S.D. dependent var	1.001849	
S.E. of regression	0.031256	Akaike info criterion	-3.790243	
Sum squared resid	0.017585	Schwarz criterion	-3.110012	
Log likelihood	77.53901	Hannan-Quinn criter.	-3.561366	
F-statistic	2347.018	Durbin-Watson stat	2.053901	
Prob(F-statistic)	0.000***			
Notes: Significance is statistical at 10% (*), 5% (**), 1% (***).				

Table 4: Estimating the ARDL approach with dependent variable LNY1 at the selected lag
Source: Authors' computation using Eview 10

The optimal lagged period of the ARDL approach was ARDL(1, 2, 2, 0, 2, 1, 0) in Table 4, the probability of the ARDL model was statistically significant by 1% and affected GDP per capita in the two-year delay. Adjusted R-squares were also larger than 99%, which means that the change of dependent variable is based on more than 99% of independent variables. The following table indicates the estimation of the coefficients in the long run of the ARDL approach.

Variable	Coefficient	Std. Error	t-Statistic	Probability
LNX1	-180.06***	28.87548	-6.235916	0.0000
LNX2	0.424***	0.054194	7.834980	0.0000
LNX3	-4.195***	0.431901	-9.713237	0.0000
LNX4	184.51***	28.97129	6.368951	0.0000
LNX5	-0.288***	0.057024	-5.051379	0.0001
LNX6	-0.083	0.099853	-0.833938	0.4152
C	1604.70***	261.4982	6.136575	0.0000
Notes: Significance is statistical at 10% (*), 5% (**), 1% (***).				

Table 5: Estimating the Long-Run Coefficients of ARDL Approach
Source: Authors' computation using Eview 10

Table 5 demonstrates the estimation of long-term coefficients with ARDL(1, 2, 2, 0, 2, 1, 0), all variables were statistically significant by 1%; however, the school enrollment variable was not statistically significant because the p-value was greater than 5%. The number of trademark applications and the idea of patents per hour had a positive influence on GDP per capita in the long term; conversely, the number of patent applications, the idea of patents per capita and investment per capita were in an inverse relationship with GDP per capita in the long term. The subsequent table estimates the short-term impact by using ECM.

Variable	Coefficient	Std. Error	t-Statistic	Probability
D(LNX1)	-0.053442	0.125826	-0.424727	0.6761
D(LNX1(-1))	73.867***	1.604082	46.04954	0.0000
D(LNX2)	-0.017790	0.032300	-0.550766	0.5886
D(LNX2(-1))	-0.224***	0.024518	-9.141442	0.0000
D(LNX4)	2.333***	0.144882	16.10651	0.0000
D(LNX4(-1))	-73.758***	1.606285	-45.91867	0.0000
D(LNX5)	0.006546	0.009047	0.723602	0.4786
CointEq(-1)	-0.500***	0.013114	-38.17550	0.0000
ECM = LNY1 - (-180.56 x LNX1 + 0.42 x LNX2 - 4.19 x LNX3 + 184.51 x LNX4 - 0.28 x LNX5 - 0.08 x LNX6).				
Notes: Significance is statistical at 10% (*), 5% (**), 1% (***).				

Table 6: Estimation of the short-term impact using ECM

Source: Authors' computation using Eview 10

The short-term impact of ECM on ARDL(1, 2, 2, 0, 2, 1, 0) is estimated in Table 6 with the coefficient result of ECM being negative and statistically significant by 1%, which means that there is a model correction regarding long-term equilibrium. The results imply that there was a strong positive relationship between the number of patent applications and GDP per capita in the short run, whereas the number of trademark applications had a weak negative impact. The idea of patents per hour affects GDP per capita both positively and negatively in the short term, but the negative influence is stronger than the positive influence. In particular, the investment per capita was not statistically significant because the p-value was greater than 5%, which means that it did not affect GDP per capita in the short term. The following table and figures prove the reliability of the ARDL approach by using diagnostic tests.

No.	Tests	Results of diagnostic tests			
		Jaque-Bera	**F-Statistic**	**Probability**	**Conclude**
1	Normality test	2.7497		0.2528	Standard distribution
2	Breusch-Godfrey serial correlation LM test		1.743769	0.2065	No autocorrelation
3	Heteroskedasticity test		0.3954	0.9581	No heteroskedasticity
4	Ramsey RESET Test		0.1055	0.7493	Standard model
Notes: Significance is statistical at 10% (*), 5% (**), 1% (***).					

Table 7: Results of diagnostic tests
Source: Authors' computation using Eview 10

The results of the diagnostic tests in Table 7 confirm that the ARDL approach is reliable because all p-values were greater than 5%, which means that the model was the standard distribution, nonautocorrelation, nonheteroskedasticity and standard model. Furthermore, Figure 1 shows that both the cumulative sum of recursive residuals and the cumulative sum of squares of recursive residuals were within the range of significance at level 5%, which means that the residuals of the ARDL approach are suitable and stable.

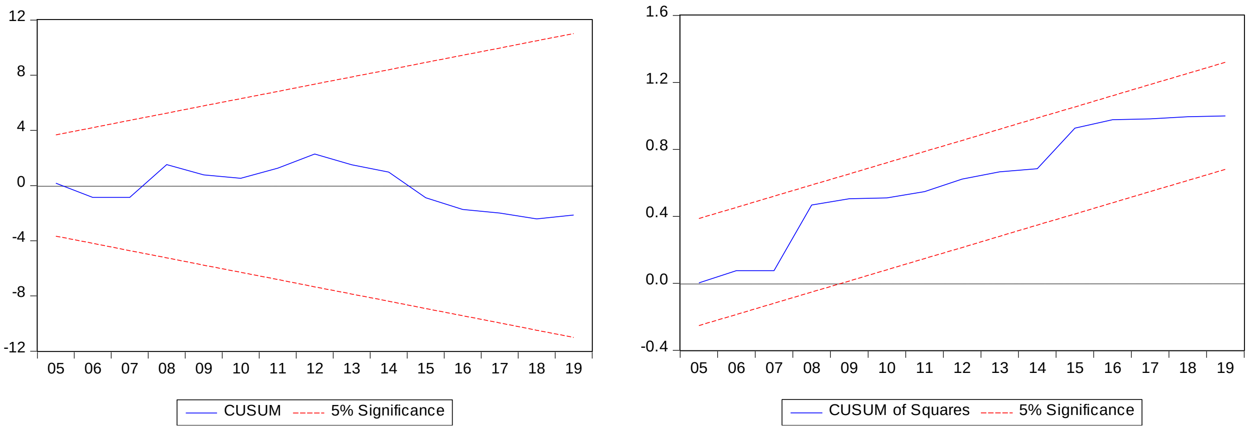

Figure 1. Cumulative sum of recursive residuals and cumulative sum of squares of recursive residuals test
Source: Authors' computation using Eview 10

5. Discussion

This research analyzed the issues of technological progress that affect economic growth with a research model, which was constructed from the Cobb-Doulag equation following the Solow model with technological progress through the ARDL approach. The established regression equation was estimated with the collected data during 1985-2019. Interestingly, four (GDP per capita, number of trademark applications, investment per capita, and school enrollment) of the seven variables (GDP per capita, number of patent applications, number of trademark applications, idea of patents per capita, idea of patents per hour, investment per capita, and school enrollment) were the first-order differences, this is the first significant condition of stationary data series for testing; especially, the study results of Bound test revealed that variables have a long-term relationship. The findings proved that the number of trademark applications, the idea of patents per hour, the number of patent applications, the idea of patents per capita, and investment per capita affect GDP per capita in the long run, while there are three variables affecting GDP per capita in the short run, such as the number of patent applications and the number of trademark applications, the idea of patents per hour. There is no relationship between school enrollment and GDP per capita in the long-run and short-run; both the idea of patents per capita and investment per capita do not also affect GDP per capita in the short run. The results of this study showed that GDP per capita is affected by variables depending on technological progress in the Solow model; as a result, the research hypothesis (H1) is accepted, which means that there is a relationship between technological progress and economic growth in Vietnam, however, these results are not in line with the study of Ngoc (2008), who found that economic growth was not based on technological progress, it only depended on capital accumulation.

6. Conclusions

In summary, the aim of this article was to analyze whether there is a relationship between technological progress and economic growth in Vietnam between 1985 and 2019 through the ARDL approach. Especially, all variables related to technological progress, for instance, the number of patent applications and the idea of patents per hour, have a negative impact on GDP per capita in the long-term, in contrast to the number of trademark applications and the idea of patents per hour positively affect GDP per capita, in which the number of patent applications and the idea of patents per hour dramatically affect GDP per capita. In the short term, the number of patent applications has a dramatically positive influence on GDP per capita compared to the number of trademark applications, which has a slightly negative impact; particularly, the idea of patents per hour affects GDP per capita both positively and negatively in the short term, but the negative influence is stronger than the positive influence. This study also contributes to the area of economic growth research in Vietnam with important evidence-based results on the impact of technological progress on GDP per capita. The findings of this study have several implications for the reader's understanding of the role of technological progress in economic development because patents and trademarks play an important role in economic growth and are tools that contribute to the strength of each company and country. They are also factors to create innovation and improve R&D activities, technology delivery, as well as attract inbound and outbound investment, although the number of patent and trademark applications in Vietnam is still lower than in other nations. The current study is still limited to small sample size and is not covered with all indicators related to technological progress for analysis such as the number of scientific and technical journal articles, the expense of R&D, and so on. However, this study provides the backbone for future research, which should investigate the larger sample size and other elements of technological progress are modified and applied in specific fields as well.

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