Threshold Effect of Economic Growth Rate on Persistence Suicide

Tzu-Yi Yang
National Ilan University
Ssu-Han Chen (ssuhanchen19820517@gmail.com)
Ming Chi University of Technology
Yu-Ting Lan
National Ilan University
Yu-Tai Yang
Vanung University

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Tzu-Yi Yang, PhD.
Graduate Program of International Business Communication
Department of Foreign Languages and Literature
National Ilan University No. 1, Section 1, Shennong Rd.
Yilan City, Yilan County 260, Taiwan
E-mail: tyyang@niu.edu.tw
Tel:+886- 3-935-7400

Ssu-Han Chen, PhD. **
Department of Industrial Engineering and Management
Ming Chi University of Technology
No.84, Gungjuan Rd., Taishan Dist., New Taipei City 24301, Taiwan
E-mail: ssuhanchen19820517@gmail.com
Tel: +886-2- 29089899

Yu-Ting Lan, Master
Graduate Program of International Business Communication
Department of Foreign Languages and Literature
National Ilan University No. 1, Section 1, Shennong Rd.
Yilan City, Yilan County 260, Taiwan
E-mail: youtinglan24@gmail.com
Tel:+886- 3- 978389250

Yu-Tai Yang, PhD.
Department of Aeronautical and Opto-Mechatronic Engineering
Vanung University
No.1 Vanung Rd. ChungLi, Taoyuan 32061, Taiwan
E-mail: yaung5629@mail.vnu.edu.tw
Tel: +886-3-4515811

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* Grammatical and writing style errors in the original version have been corrected by our colleague who is a native English speaker.

** Corresponding author: Ssu-Han Chen is an associate professor of Department of Industrial Engineering and Management. Ming Chi University of Technology, Taiwan. E-mail: ssuhanchen@mail.mcut.edu.tw

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ABSTRACT

In this study, a Panel Smooth Transition Autoregression (PSTAR) model was introduced and the empirical results found nonlinear effects and heterogeneity of economic growth rate on the persistence of suicide rate, and can be summarized into three conclusions. First, the suicide rate has a persistent effect, and it varies over time depending on the transition variable within different threshold intervals. Second, the persistent effect will be manifested in different degrees by the change of the economic growth rate. With the increase of the lag period of the suicide rate, the effect of the influence will gradually decrease. Third, the marginal impact in the third year is much lower than the suicide rate in the first year.

Keywords: Panel Smooth Transition Autoregression (PSTAR) model; Suicide rate; GDP ; Nonlinear Threshold effect; Persistence effect
JEL Code: I12, I15, Q56

***Data Availability Statement:** The datasets generated during and/or analyzed during the current study are available from the corresponding author on reasonable request.

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1. Introduction

Taiwan has experienced significant economic, environmental, and social changes since the 1990s. Figure 1 displays Taiwan's economic growth rate and suicide rate from 1994 to 2020. From the figure, it can be positioned that the suicide rate in Taiwan has been on the rise since 1994, gradually decreased from 2006 to 2011, and then stabilized. On the flip side, in the part of economic growth rate, it is visible that there were two trough periods (negative growth) in 2001 and 2009, and the peak period occurred in 2010.

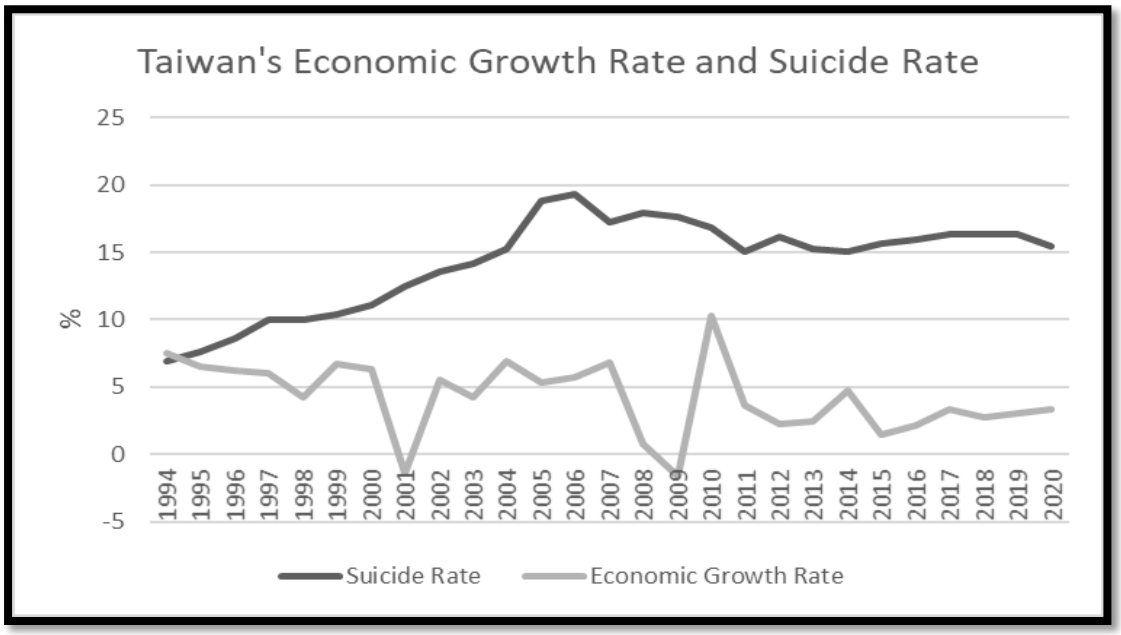

Figure 1 Trend chart of Taiwan's economic growth rate suicide rate from 1994 to 2020. Source: Suicide Rate- Statistics Division of Ministry of Health and Welfare (MOHW), Economic Growth Rate- Directorate General of Budget, Accounting and Statistics, Executive Yuan (DGBAS), and collated by this research.

If comparing the economic growth rate and the suicide rate in the same period, it can be determined that the suicide rate continued to rise during the decline of the economic growth rate from 1994 to 2001. Economic growth rates escalated from 2001 to 2002, fluctuated in 2002-2005 (declined in 2002-2003, increased in 2003-2004, and decreased again in 2004-2005) but suicide rates did not decline with the economic recovery over the same period of 2001-2002 and 2003-2004. On the contrary, it continues to rise and the so-called persistence arises. That is, the suicide rate is not reflected in the current period of the economic growth rate, but only after a period of time. Alternatively, comparing the economic growth rate with the suicide rate from 2005 to 2007, although the economic growth rate increased, the suicide rate also

increased from 2005 to 2006, and did not decrease until 2006 to 2007 (1 year persistence). A persistence appearance can also be located.

Furthermore, the subprime mortgage crisis occurred in the United States in 2007, which led to the soon after global financial crisis in 2008, resulting in a serious slip in Taiwan's GDP in 2007-2009, an increase in 2009-2010, and a decline in 2011-2012, suicide rates rose slightly over the same period in 2007-2008, but continued to decline in 2008-2011, before rising until 2011-2012 (3 year persistence). It is probable that Taiwan's economic system is relatively robust and its prosperity is not immediately affected by the international economic environment.

In 2012-2014, the economic growth rate increased, the suicide rate decreased, and in 2014-2015, the economic growth rate dropped, the suicide rate increased slightly, it can be brought to light that the economic growth rate and the suicide rate had an opposite correlation. However, the economic growth rate increased slightly in 2015-2017, decreased slightly in 2017-2018, and increased again in 2018-2020, while the suicide rate continued to increase during the same period, and only dropped in 2019-2020, and the persistence reappeared (4 year persistence). The persistence of economic growth rate on suicide rate and the connection between economic growth and decrease on suicide rate can be observed via figure 1.

The reason why Taiwan's economic growth rate has declined must be affected by changes in the internal or external economic environment. During the period from 1994 to 2001, events such as the Asian financial crisis in 1997-1998, the chi-chi earthquake in 1999, the dot-com bubble in 2000 and the September 11 attacks in the United States in 2001 occurred one after another. These events not only caused Taiwan's economic growth rate to drop, but also the suicide rate to jumped from 6.9% in 1994 to 12.5% in 2001. Because of the high suicide rate before the Asian financial crisis, it can be inferred that the suicide rate in Taiwan remained steady during the crisis period of 1997-1998, but commenced to ascend after the crisis (Chen et al., 2010; Chen, 2017).

The 2008 Global Financial Crisis triggered by the United States after the subprime mortgage crisis in 2007 had a huge impact on Taiwan's economy, far exceeding the Asian financial turmoil in 1997. Taiwan is a small open economy with limited domestic market demand, and its economic growth has always been driven by export growth. Therefore, it is extremely dependent on foreign trade and is inseparable to the world economy; in addition, the United States is Taiwan's third largest trading partner, thence in 2009 Taiwan's economy experienced negative growth again since 2001. The global financial crisis negatively impacted Taiwan on slowing industrial production and trade growth, as well as economic recession and heightened deflationary pressures. In response to the crisis, the Taiwan government implemented economic revitalization programs, and adopted measures such as loose monetary policy and tax reform, which

have effectively slowed down Taiwan's economic assault. Therefore, during this period, Taiwan's suicide rate had not been greatly affected, and even presented a declined appearance. The economic growth rate also resuscitated the following year (2010) and reached a peak of 10.25% (Guo, 2009; NDC, 2013; Wu et al., 2012; Chen, 2017).

After 2011, the recovery of major global economies such as the European Union was not as successful, and the volume of international trade stagnated due to reduced demand. In addition, the international division of labor had also undergone a certain degree of transformation. The return of manufacturing in the United States was not conducive to the recovery of the global economic prosperity, coupled with China's policy of focusing on domestic production of components and the rapid rise of the supply chain. Besides, Taiwan's exports were highly dependent on electronic information products, and it is also vulnerable to the impact of the international economic boom. All of the above reasons had a negative impact on the international competitiveness of Taiwan, which had always been an export-oriented economy, and caused the slowdown of Taiwan's economic growth after the global financial tsunami (only a brief recovery from 2013 to 2014) (CBC, 2015; Hsiao, 2018). Simultaneously, the suicide rate remains obstinately high.

As can be seen from Figure 1, the high suicide rate and low economic growth rate in recent years have become a hidden concern in modern Taiwan society that cannot be ignored. And such a situation deserves a more in-depth examination from the perspective of manpower (human resources) and economy. Because manpower is one of the inseparable elements of economic growth, which will be explained in more detail from the following paragraph.

Since Taiwan adopted an export-oriented policy in the 1960s, its economy has grown rapidly, creating an economic growth miracle. Figure 2 reveals Taiwan's GDP per capita from 1963 to 2020, from 7,545 yuan in 1963 to 838,191 yuan in 2020. Although there was a slight decrease in some period, an overall distinct growth phenomenon still can be observed.

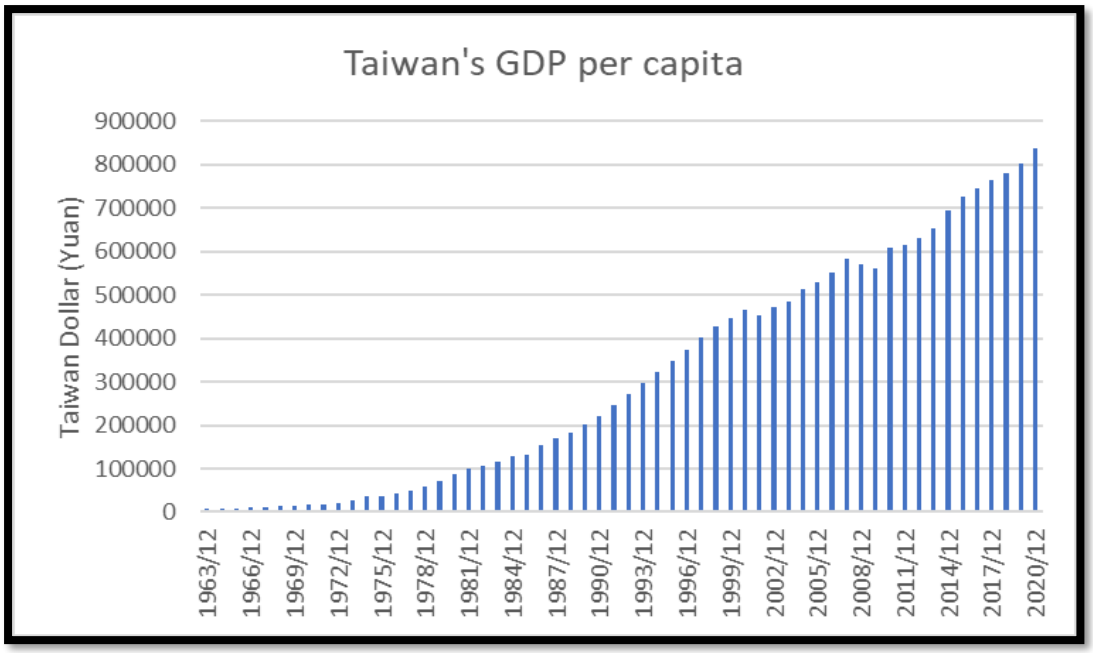

Figure 2 Taiwan's GDP per capita trend chart from 1963-2020. Source: Taiwan Economic Journal (TEJ).

Due to the long-term trade surplus, Taiwan accumulated a large amount of foreign exchange reserves in the 1980s, but it also caused the overall economic imbalance and income inequality to gradually be exacerbated. In response, the government proposed a new direction of economic liberalization and internationalization. Meanwhile, Taiwan established Hsinchu Science Park and began to develop technology-intensive industries such as electronics, information, and other industries (Wu, 2008; NDC, 2013). One of the most famous and successful examples is Taiwan Semiconductor Manufacturing Company (TSMC), which was established in 1987. Today, TSMC has become the world's largest professional integrated circuit manufacturing service company. In Taiwan, the semiconductor industry has been increasing year by year in terms of export volume, output value, and the proportion of Taiwan's GDP. The importance of the semiconductor industry to Taiwan's economic development and growth is self-evident (Liu, 2021).

These days, the semiconductor industry has distinctly become the lifeblood of Taiwan's economy. But don't forget that the development of technology-intensive industries requires a large amount of manpower. In other words, manpower is also an indispensable element in the process of economic growth. It is precisely because of the abundance of outstanding talents that Taiwan has been able break through the fierce competition in the global environment, to create a proud economic miracle that ranks among the Four Asian Tigers in Asia (Wu et al., 2012; Hsiao, 2018; Tang and Wu, 2020).

From the above-mentioned characterization, the importance of human resources to Taiwan's economy can be comprehended. In addition, not only the semiconductor

industry, but all industries need professional manpower. Conversely, if a country has a high suicide rate or the economic persistence factors causes suicide rates to continue to take effect, it most likely represents a shortage of manpower. Insufficient manpower will inevitably shake the economy of a country, because one of the elements of favorable economic development is the achievement of abundant professionals in various fields performing their duties. Otherwise, positive or negative economic growth is closely related to suicide rate, and can prove the structural changed relationship between economic growth, human resources and suicide rate. As a result, this study aims to clarify whether economic growth rate has a deferred effect on suicide rates.

After the Global Financial Crisis, Taiwan has faced problems such as insufficient investment momentum and the outflow of talents (NDC,2003). In addition, beneath the trend of globalization, if a global financial crisis occurs and the economic recession continues to spread, Taiwan will not be able to keep out of the affair. Whether the new type of global economic headwinds will increase people's suicide risk still needs to be closely watched (CDC, 2018). Therefore, the results of this study can provide a reference for relevant government departments, business managers and company line numbers under the return of human resource management white paper under economic stability.

2. Literature Review

2.1 Persistence Suicide, Suicide rate and Economic Growth Rate

Some scholars have explored the correlation between persistence suicide (suicide attempts) and economic aspects. Marcotte (2003) uses an extended utility maximization model, to study the relationship between economic factors such as health costs and income, and suicide attempts in the US from 1991-1992. It was found that future income has a positive effect on suicide attempt, and most affected by those with the worst suicide attempts. Since the economic bubble burst in 1990, along with deflation, Japan's economy has shown slow or even negative growth. Chen et al. (2014) employed the decomposition method to analyze the sudden and rapid rise in suicide rates in Japan in 1997-1998, and the accompanying high suicide attempt rates since 1998. A positive relationship between financial hardship (e.g., bankruptcy) and suicide attempts was found according to the decomposition method, especially for male attempted rates.

The above studies have confirmed the significant and positive impact of changes in the economic environment and factors on suicide attempts. In that way, is there also a relevance between suicide rates and economic growth rates? Yang (2010) used the multiple regression model, time series single root test and ARIMA transformation model to explore whether the overall economic-related variables have a more direct impact on the suicide rate, and the results showed that the overall economic decline led

to an increase in the suicide rate. There is also Chang (2009) who used tracking data (Panel data) regression analysis to study the relationship between economic and social factors and suicide rates among different unemployment groups in 23 counties and cities in Taiwan (excluding Jinma area) from 1997 to 2017. The relationship between the two, and the global economic recession in recent years has caused many businesses to close down, which in turn has led to an increase in suicide rates.

In the study exploring the relationship between economic growth rates and suicide rates abroad, Mann et al. (2017) used time-series and cross-sectional correlation research methods to know that economic recessions are usually associated with an increase in suicide rates, and clearly show that there is a complex relationship between the economy and suicide. And Yoo (2018) investigated the economic, social and modernization factors in 26 OECD countries to analyze the suicide rate. The research period was 2018 using regression analysis to study the suicide rate and its causes caused by economic, social and modernization factors. The final result shows that the economic change has a very important relationship with the suicide rate. When the economic change is greater, the suicide rate also changes.

Moreover, Cormier and Klerman (1985) employ time series analysis to explore the effect of economic fluctuations on suicide rates in Quebec, Canada, from 1966 to 1981, which the unemployment and suicide rates in Quebec rose in unison during this period. The determinant contains the unemployment rate and the male-female labor force participation. It is demonstrated that not only the changes in unemployment were found to be accompanied by a positive relationship with suicide rate, but also with the female suicide rate. Economic fluctuation has therefore been shown to be an important factor in the rise in suicide rates; Luo et al. (2011) using graphical analysis and nonparametric analysis to explore the impact of business cycles on suicide rates (differentiate between different age groups) in the United States from 1928-2007 and calculate the correlation coefficient between national unemployment rate and suicide rate. The results of the analysis show that the overall suicide rate generally increased during the recession and peaked during the Great Depression of 1929-1933. On the opposite end, suicide rates dropped significantly during economic expansions like World War II. Finally, it is concluded that the economic cycle has a positive impact on the suicide rate.

However, some scholars have pointed out that there is no substantial relationship between the economic growth rate and the suicide rate. For example, Cheng (2011) used spatial analysis to explore the economic growth rate from 2001 to 2003 and the suicide rate in Taiwan during the recession from 2007 to 2009. The purpose is to explore whether the influence of Taiwan's economic factors on the suicide rate will be different in different economic times. However, the experimental results point out that the hypothesis that the suicide rate increases due to economic recession is not valid. Yang

(1992) assumed that the suicide rate in the United States during the period 1940-84 was the result of the interplay of economic and social variables, and applied single equation regression to explore the suicide rates for total population and the four sex by race social groups. The result showed that suicide rates did not rise during economic booms or busts and the unemployment rate only significantly adversely affected the suicide rate of white males.

2.2 Nonlinear Model

Wu and Chang (2017) developed the Panel Smooth Transition Autoregression (PSTAR) model from the Panel Smooth Transition Regression (PSTR) model and used it to examine the nonlinear and persistent effects of monetary and fiscal policy on foreign direct investment (FDI) in 10 OECD countries. As suggested by Wu et al. (2017), the PSTAR model can be constructed by the following steps. First, identify the linear part of the smooth transition autoregressive model, where this part constitutes an autoregressive model whose dependent variable is of order p. The next step is to use a stepwise regression model to determine the optimal p for the lagged dependent variable. The final step is to replace the exogenous variables of the PSTR model with dependent variables with multiple period lags. In addition to the ability of the PSTR model to capture data heterogeneity and the advantages of accurately describing the individual and temporal effects of the model, this type of model can avoid the collinearity problem commonly found in linear structural models.

In addition, the model can provide useful information to improve the estimation validity of the model when researchers study situations with long lags in the dependent variable. Since this paper attempts to study the threshold effects of economic growth rate on persistence suicide, and the variable data of the model has time series characteristics, we choose to use the PSTAR model in our empirical analysis.

The variables in the empirical suicide rate model often have time series characteristics and heterogeneity, and due to the asymmetric relationship between the model variables, the suicide rate may show nonlinear characteristics, and traditional linear models may not be able to correctly estimate the suicide rate. Empirical results may suffer from estimation bias because empirical procedures used in linear models may ignore significant correlations between variables in the model, or because of heterogeneity that typically occurs when data structures have cross-sectional characteristics. Finally, since the variables in most empirical models of suicide rate tend to have time series characteristics and heterogeneity, and due to the asymmetric relationship between model variables, suicide rate may exhibit nonlinear characteristics, and traditional linear models may not be able to correctly estimate the suicide rate.

Aiming at the above problems, this paper attempts to construct a model of persistence suicide, and uses the stepwise regression method to estimate the characteristics of

persistence suicide. In addition, a newly developed non-linear regression analysis technique, the Panel Smooth Transition Autoregression (PSTAR) model, was used to test the persistence suicide rate of Taiwan. The model offers the advantage of capturing data heterogeneity and accurately describing individual and temporal effects in the model. At the same time, it can also address nonlinearity and heterogeneity in the data, while providing significantly better predictive power and recognition accuracy than traditional linear regression models.

3. Research Method

3.1 Research Data

In this study, the suicide rate lagged by period $t-1$ and $t-3$ (4 periods are taken) is applied as independent variables, expressed as S_{t-1} and S_{t-3} respectively, t represents time period. The current year suicide rate is the dependent variable, denoted as S_t. The data of independent and dependent variables are obtained from the Statistics Division of Ministry of Health and Welfare. Additionally, the GDP (economic growth) lagged by period $t-2$ as the transfer variable, delivered as G_{t-2}, sourced from Taiwan Economic Journal (TEJ). The data are annual data, and the research period is from 1994-2020. The relevant variables are organized as shown in Table 1.

Table 1 List of variables.

Variables	Variable Name	Symbol	Source
Dependent	Current Year $Suicide_t$	S_t	The Statistics Division of Ministry of Health and Welfare
Transfer	GDP Lag 2	G_{t-2}	Taiwan Economic Journal
Independent	Suicide Rate Lag1. Lag 3	$S_{t-1}.S_{t-3}$	The Statistics Division of Ministry of Health and Welfare

Note: The study period was 1994-2020.

Additionally, since the data regarding Taiwan's suicide rates in this study are divided into northern, central and southern parts, in line with Supreme Administrative Court (2021), the counties and cities in northern, central and southern Taiwan are presented in Table 2.

Table 2 The counties and cities in northern, central and southern Taiwan.

District	Counties and cities
North	Taipei City, New Taipei City, Taoyuan City, Hsinchu County, Hsinchu City, Keelung City, Yilan County, Hualien County, Kinmen County and Lienchiang

	County
Central	Miaoli County, Taichung City, Changhua County, Nantou County and Yunlin County
South	Chiayi County, Chiayi City, Tainan City, Kaohsiung City, Pingtung County, Taitung County and Penghu County

Source: Supreme Administrative Court (2021), and collated by this research.

3.2 Empirical Model

In this study, the main focus was on the investigation of the threshold effect of economic growth rate on persistence suicide in the period of 1994-2020. According to PSTR model proposed by González et al. (2005) and the suggestions from Wu et al. (2017), in this study, a PSTAR model was set up to estimate the threshold effect of economic growth rate on persistence suicide.

The advantage of PSTR model was that two linear regions were connected through nonlinear transfer function. In addition to more precise description on the time and individual effect from the sample data, the heterogeneity can also be acquired. Besides, the estimation way used in this method was quantitative to obtain the threshold value of a model, and this showed a strong contrast to the past way based on subjective judgment. As compared to traditional empirical model, PSTR model used a more objective way to decide the threshold transition. Finally, in addition to the modification of the issue of immediate occurrence of jumping proposed by Hansen (1999), in order to explain the transition threshold value occurred in the neighborhood of smooth transition threshold value, an additional transitional speed parameter was added in PSTR model. When time series feature or macroeconomics variable was adopted in the model, this model was absolutely suitable. The construction of PSTR model in this study was as follows:

$$y_{it} = \alpha_i + \beta_0 X_{it} + \omega\beta_1 X_{it} G(Z_{it}; \gamma; \mathrm{C}) + \mu_{it} \quad \text{..... (1)}$$

Wherein, i=1,2,…N was cross sectional suicide rate in northern Taiwan, middle Taiwan and southern Taiwan, t=1,2,…T was time, y_{it} represented the suicide rate(i) of the current period (t), and X_{it} was independent variable of time dependent dimension vector k. In this study, while setting up the past suicide rate model, stepwise regression model was also applied to find out optimal exogenous variable. α_i was the fixing effect of an individual, $G(Z_{it-d}; \gamma; \mathrm{C})$ was a transition function with value in the range from 0 to 1, Z_{it-d} was a transition variable of lagged by d period, which was also an exogenous variable; γ was transition speed variable for describing transition function in the model, and transition threshold value and residual were represented respectively by c and ε_{it}. In addition, lagged transition variable and the optimized current period

must be estimated through minimal value Bayesian information criterion (BIC) and Akaike information criterion (AIC). For the transition function of this model, suggestions of Granger & Teräsvirta (1993) and Terasvirta (1994) were followed and assigned as follows:

$$G(Z_{it-d};\gamma,\mathrm{C}) = \left\{1 + exp[-\gamma\prod_{j=1}^{m}](Z_{it} - \mathrm{C}_j)]\right\}^{-1} \ldots\ldots\ldots\ldots\ldots\ldots \quad (2)$$

or

$$G(Z_{it-d};\gamma,\mathrm{C}) = 1 + exp[-\gamma\prod_{j=1}^{m}(Z_{it} - \mathrm{C}_j)^2] \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots \quad (3)$$

Wherein location parameter dimension m was defined as C1≤C2≤... ≤Cm, and C= (C1, C2, …Cm) and γ>0. The slope of transition function was represented by γ value, in other words, the larger the γ value, the steeper (.) the slope of G. Especially when γ→∞ and the value of G (.) was convergent to 1, in fact, such situation represented: 1. Structural change occurred in single time point. 2. PSTR model will be simplified to PTR model. 3. The model will be roughly the same as the single point jump model proposed by Hansen (1999). Meanwhile, G (.), when γ→0, will approximate linear form, and this represented that PSTR model will not only be modified into fixing model with panel estimation capability, but also the single point structural change will be insignificant too. In order to catch the nonlinear form in the model, according to the empirical suggestions from González et al. (2005), generally speaking, it was enough only considering two forms of m=1 or m=2. When m=1, the data will be divided into two regions by transition threshold value, and it was a logical model (see formula 2); when m=2, the transition threshold value will divide the data into 3 regions, and it was an exponential model (see formula 3). Formula (4) represented a broad PSTR model:

$$y_{it} = \alpha_{0i} + \sum_{j=1}^{j}\beta_j X_{it-j} + \sum_{j=1}^{j}\beta'_j X_{it-j}Z_{it-d} + \tau_{it} \ldots\ldots\ldots\ldots\ldots \quad (4)$$

Transition function quantity in the model was represented by j=1, 2,...,r, and there were a total of (r+1) transition regions, in addition, the estimation result of formula (2) or (3) was used to decide the form of transition function.

Before constructing PSTAR model, in this study, not only the cross- sectional data of the past suicide rate regarding northern Taiwan, middle Taiwan and southern Taiwan were adopted, but also stepwise regression model was applied to find out the linear feature of suicide rate. In this study, based on the periodical feature of the variable data, it was estimated that the lagged period of j^{th} period was lagged by one period and lagged by three period. The auto-regression model of suicide rate was as shown in formula (5):

$$S_{it} = \alpha_{i0} + \sum_{j=1}^{j} \alpha_j S_{it-j} + u_{it} \text{.....(5)}$$

S_{it} and S_{it-j} represented respectively the suicide rate of t period and lagged by j period, and intercept and residual was respectively α_{i0} and u_{it}, and α_j was persistence coefficient of suicide rate. In this study, after evaluating the linear feature of suicide rate, GDP lagged by 2 period was selected as transition variable, which was used as the substitute of exogenous variable in PSTR model. Under the suggestion of Wu and Chang (2017), formula (5) was used for estimation, consequently, multiple lagged dependent variable was obtained. The PSTAR model of this study was defined as follows:

$$S_{it} = \beta_{i0} + \sum_{j=1}^{j} \beta_j S_{it-j} + \sum_{j=1}^{j} \beta_j' S_{it-j} G(GDP_{it-d}; \gamma, c) + \varepsilon_{it} \text{.....(6)}$$

Wherein $G\ (GDP_{it-d}; \gamma, c)$ was a transition function with value in the range from 0 to 1. GDP_{it-d} represented GDP lagged by d^{th} period. Moreover, the transition speed under two extreme conditions of model was described by transition parameter γ, and c was transition threshold value. The stable transition of suicide rate can be explained through transition function, and GDP might have lagged threshold effect on suicide rate. Therefore, after considering the features of data in this study, GDP lagged by 2 period instead of the present period GDP (GDP_{it}) was selected as transition variable $(GDP_{it-d}, d = 2)$. In addition, for the optimized lagged transition value, AIC and BIC estimation methods with minimal value were adopted for estimation; and ε_{it} was residual.

3.3 Model Specification and Test

In addition to deviation generated from estimation result due to unstable feature appeared in sample data, before using empirical model for estimation, cross sectional panel unit root test was used in advance to judge if sample data was stable time series. After confirming the stable feature, the model estimation method proposed by González et al. (2005) and Wu, Liu and Pan (2013) was adopted in this study. First, linearity test was conducted to confirm if suicide rate can satisfy nonlinear condition, if the model formed nonlinear panel model, it represented that linear null hypothesis[1] was rejected. Next, it was needed to estimate transition threshold value and confirm the heterogeneity of sample data to confirm the form of model and the transition parameter of transition function. Finally, after checking the form and quantity of model transition variable, nonlinear least square method and formula (6) were used to estimate the persistence effect and nonlinearity of GDP on suicide rate. Starting from the next section, test steps and processes will be described in detail.

When implementing empirical data analysis, considering that PSTR model was

not appropriate for estimation of data involving with homogeneous cross section, hence, in this study, the model was converted into general linear panel model. Therefore, before conducting model parameter estimation, homogeneity test was arranged in advance, and it was also proved that the model had nonlinear feature. This was similar to that the test represented null hypothesis of linear model, $H0$: r = 0. However, although the null hypothesis $H0$: r = 0 of the model did not have interference parameter (such as the issue of location parameter) and transition effect, yet it could still possibly stop the normal distribution of test statistical quantity. In order to test the linearity of formula (6), according to suggestion of González et al. (2005), while implementing homogeneity test, the expansion of first order Taylor $H0$: r = 0 was used in this study to replace the transition function $G(Z_{it-d};\gamma,c)$ of the model. Attached regression formula was as follows:

$$\delta_{it} = \theta_{i0} + \sum_{j=1}^{j} S_{it-j} + \sum_{j=1}^{j} \theta_j' S_{it-j} GDP_{it-d} + \tau_{it} \ldots\ldots\ldots\ldots\ldots\ldots (7)$$

Wherein the residual of formula (6) was represented by δ_{it}, θ_{i0} was intercept term, S_{it-j} was suicide rate lagged by j period, GDP_{it-d} was GDP lagged by d period. Linearity test mainly included the test of null hypothesis had concurrent value of 0, the asymmetric distribution will not be affected by the expansion of first order Taylor approximation value. Applying Wald (LM) test in the statistical quantity of X^2 or F was empirical test method to such hypothesis. LM test model was as shown in formula (8):

$$LM = TN\ (SSR_0 - SSR_1)/\ SSR_0$$
$$LM_F = \{[(SSR_0 - SSR_1)]/mk\}/\{[SSR_1/(TN - N - m\ (k+1))]\} \ldots (8)$$

Wherein SSR_0 was defined as the sum of square of residual in null hypothesis, in other words, the model was a linear panel model and had specific effect. SSR_1 was defined as the sum of square of residual in the substitute hypothesis, in other words, the model had m regions, wherein m was quantity of transition parameter. K was quantity of explanatory variable, and T was time, N was cross section suicide rate in northern Taiwan, central Taiwan and southern Taiwan. LM model included statistical quantity of different distribution of *F (mk, TN-N-m(k+1))* and $X^2(mk)$, and it also decided if the model had nonlinear feature (that is, whether the model data had homogeneity or not).

After finishing linearity test of the model, if nonlinear characteristic appeared in model test, it represented that the linear null hypothesis of the model was rejected, and the transition function of the model had at least one threshold transition variable. The next step was to test if other transition effects existed in empirical model and to estimate the quantity of transition function in the model and reasonable value of transition

threshold value. As long as the model had transition effect, it represented that the linear hypothesis of the model was rejected.

According to suggestions from González et al. (2005), while conducting the test of the number of threshold value, it was needed to use in advance a model with a transition function (r=1) for estimation; meanwhile, attached regression formula was accompanied to test null hypothesis ($H0: r = 1$) of two threshold values as corresponded to one threshold value, therefore, the quantity of transition parameter was confirmed. Suppose the test result did not reject the null hypothesis of one threshold value, then before the null hypothesis of attached threshold value cannot be rejected, the optimal quantity of threshold value should be continuously tested. In the meantime, the optimal quantity of threshold value in the model can be seen as r value in the model. After judging the quantity and form of transition variable and confirming the heterogeneity of sample data, nonlinear least square method was used to estimate the persistence effect and nonlinearity of economic growth rate on suicide rate.

4. Empirical Results

The main focus of this study was the threshold effect of economic growth rate on persistence suicide, and formula (7) was used to test the linearity and homogeneity of economic growth rate and suicide rate; from the empirical result, the continuous nonlinear effect and heterogeneity of economic growth rate on suicide rate was found, and respective descriptions will be conducted on them. This chapter will be divided into six parts: Descriptive statistics, nonlinear panel unit root test, Hausman test, linearity test, the optimal number of threshold regime test and empirical results of PSTAR model.

4.1 Descriptive Statistics

Table 3 showed the characteristics of variable GDP and suicide rate (S) within given time. The maximal value, minimal value, average value and standard deviation were all listed in each corresponding row of each variable.

Table 3 Descriptive statistics on Suicide Rate and GDP from 1994-2020.

	S	GDP
Max	19.20000	10.25000
Min	9.700000	-1.610000
Mean	15.39524	3.940952
STD	1.999869	2.868689
Observations	21	21

Note:

1. The variables S and GDP are the same as S_{it} and G_{it-2} in Table 3.1.
2. The sample period is 1994-2020.

From table 3, something can be seen. First, the scope of GDP ranged from maximal value (10.25000) to minimal value (-1.610000), which was broader than the maximal value (19.20000) to minimal value (9.700000) of S. Furthermore, the observation

values of two variables were all 21. Finally, the mean value of S and GDP was 15.39524 and 3.940952, and standard deviation was 1.999869 and 2.868689.

4.2 Nonlinear Panel Unit Root Test

In this stage, the Augmented Dickey Fuller (ADF) test was adopted to test if the variable had stable characteristic to avoid the appearance of deviation of hypothetical regression or empirical result. Specifically speaking, the null hypothesis H_0 and opposing hypothesis H_1 of nonlinear panel unit root test were as follows:

$\mathbf{H_0}$: With unit root

$\mathbf{H_1}$: Without unit root

If *p*- value of each variable was significant, it represented that the null hypothesis of H_0 was rejected and H_1 was accepted.

Table 4 Nonlinear panel unit root test

Variables	Augmented Dickey-Fuller test statistic	Break Date	Lag
S_{it}	-5.353581***	2010	4
S_{it-1}	-3.811376***	2017	4
S_{it-3}	-3.723717***	2003	4
G_{it-2}	-6.038587***	2011	4

Note:

1. *, ** and *** indicate significance at the 10%, 5% and 1% level, respectively.
2. S_{it} is the suicide rate of the current period, S_{it-1} and S_{it-3} represent the suicide rate lagged by 1 period and 3 period, respectively, and G_{it-2} is the GDP lagged by 2 period.

From the result of table 4, the obvious significances of all variables can be observed, and it also represented that null hypothesis H_0 was rejected and opposing hypothesis ‘‘without unit root” was accepted. This represented time series and cross-sectional variable among panel data showed stable status. In addition to this, the result allowed the carry-out of nonlinearity test of this study.

In this study, unit root test of structural breaking was further introduced to test that nonlinear structural series can still reach stable status during the conversion process as time went by. Figure 3 were respectively the unit root test figures of current period suicide rate (S_{it}), suicide rate lagged by one period (S_{it-1}), suicide rate lagged by three period (S_{it-3}) and GDP lagged by two period (G_{it-2}) in the period from 2001 to 2020. As shown in table 4 and figure 3, it represented that each variable was significant, and it showed that series structure had nonlinear structural conversion, and they will finally reach stability along with time.

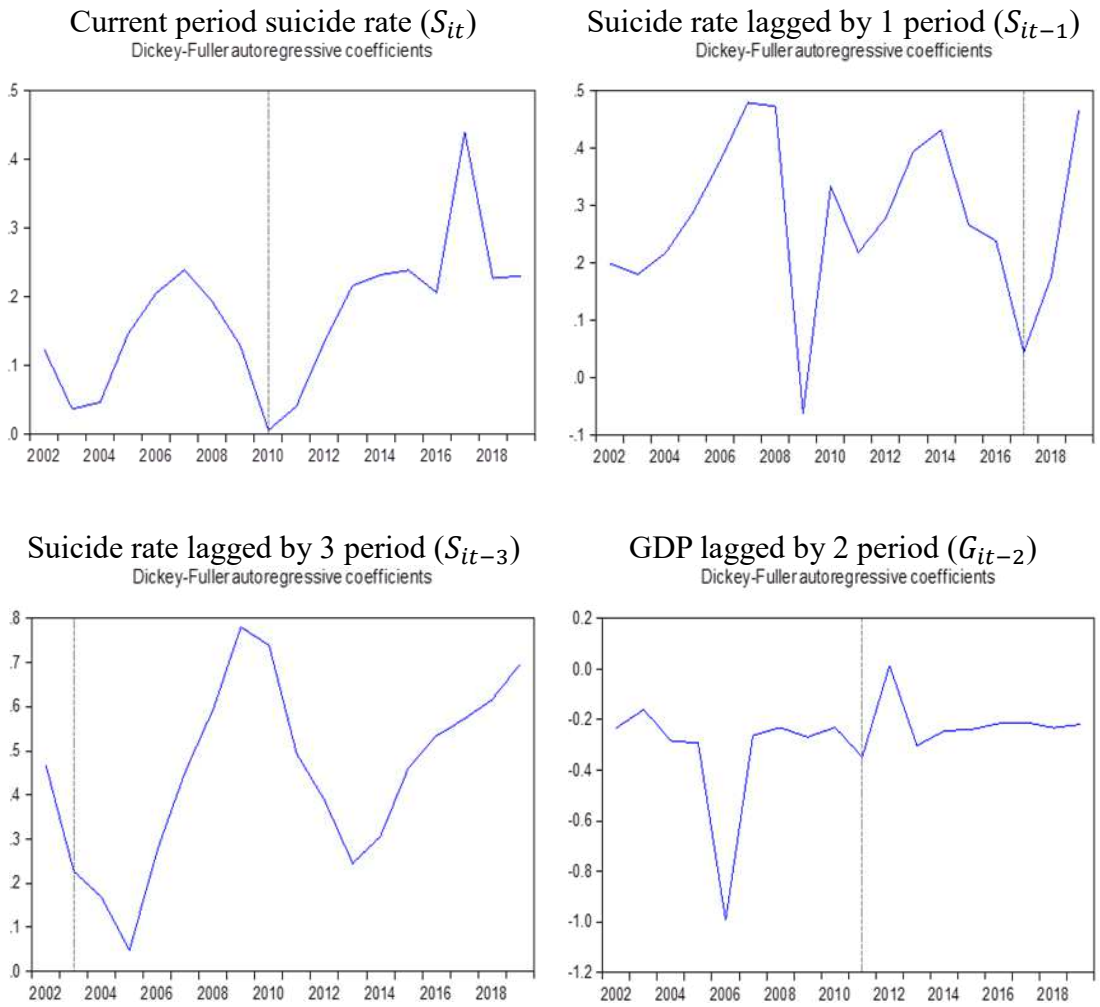

Figure 3 Unit root figure of current period suicide rate (S_{it}), suicide rate lagged by 1 period (S_{it-1}), suicide rate lagged by 3 period (S_{it-3}), and GDP lagged by 2 period (G_{it-2}).

Note: The sample period is 2001-2020.

4.3 Hausman Test

In order to prove the appropriateness of using PSTAR model to evaluate the persistence suicide, Hausman test was adopted in this study to test if the data was model of fixed effect or random effect. Null hypothesis H_0 and opposing hypothesis H_1 were as follows:

$\mathbf{H_0}$: Applicable to random effect model.

$\mathbf{H_1}$: Applicable to fixed effect model.

The result of Hausman test was as shown in table 5. Here p- value was not significant, null hypothesis of H_0 was accepted, therefore, the optimized method for estimating linear panel data model was random effect model.

Table 5 Hausman test.

Test data	Chi-Sq. Statistic	Chi-Sq. d. f.	*p-value*
Cross-section	1.798534	2	0.4069

random

4.4 Linearity Test

The results of nonlinear panel unit root test showed the stable characteristics of all variables. Therefore, continuous test of whether the model showed the nonlinear correlation between economic growth rate and suicide rate was reasonable. Based on the research of Wu, Liu and Pan (2013), attached regression formula (7) was used in this study to conduct linearity test, and the expansion of first order Taylor $H0$: $r = 0$ was used to replace the model's transition function $G(q_{it-d}; \gamma, c)$, and it was as shown in the following:

$$\delta_{it} = \theta_{i0} + \sum_{j=1}^{j} S_{it-1} + \sum_{j=3}^{j} S_{it-3}\, GDP_{it-2} + \tau_{it} \quad \text{.....(9)}$$

Wherein,

S_{it-1} was the suicide rate (i) lagged by time *(t-1)*, that is, it was the suicide rate lagged by 1 period.

S_{it-3} was the suicide rate (i) lagged by time *(t-3)*, that is, it was the suicide rate lagged by 3 period.

GDP_{it-2} was GDP lagged by time *(t-2)*, that is, it was GDP lagged by 2 period.

Null hypothesis and opposing hypothesis were described as follows:

$\mathbf{H_0}$: PSTAR model was a linear model.

$\mathbf{H_1}$: It was PSTAR model (nonlinear) with at least one transfer variable (r=1).

If r value of each variable was significant, it represented that null hypothesis of H_1 was accepted and that of H_0 was rejected. The data of linearity test was as shown in table 6.

Table 6 Linearity test.

Test statistic	Number of Location Parameters (m) m=1	Number of Location Parameters (m) m=2
Wald Tests (LM)	5.325(0.070)*	12.997(0.011)**
Fisher Tests (LMF)	2.678(0.077)*	3.379(0.016)**
LRT Tests (LRT)	5.564(0.006)***	14.556(0.006)***

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

Table 6 showed the results of Wald test, Fisher test and LRT test. The appearance of significance rejected linear null hypothesis under one transition variable, meanwhile, the test data also showed the visible nonlinear relationship between economic growth rate and suicide rate. Next, minimal values AIC and BIC had to be used to estimate the quantity of optimized threshold value.

4.5 The Optimal Number of Threshold Regime Test

Due to the existence of nonlinear relationship between economic growth rate and

suicide rate, the optimal number of threshold regime was further analyzed in this study. The null and opposing hypothesis was respectively as follows:

$\mathbf{H_0}$: PSTAR model was nonlinear model.

$\mathbf{H_1}$: PSTAR model was linear model.

Table 7 Test of no remaining nonlinearity.

Test statistic	Number of Location Parameters(m) m=1	Number of Location Parameters (m) m=2
Wald Tests (LM)	1.026(0.599)	-14.144(1.000)
Fisher Tests (LMF)	0.447(0.642)	-2.292(1.000)
LRT Tests (LRT)	1.035(0.596)	-12.760(1.000)

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

According to the estimation data of table 7, it can be seen that no matter the quantity of location parameter was 1 or 2, significance did not appear in the data, and this represented that the test data did not reject null hypothesis, and this proved again the nonlinearity of PSTAR model. In other words, the conclusion of optimized lagged period of either 1 or 2 can be obtained.

4.6 Empirical Results of PSTAR Model

After finishing the above-mentioned series of tests, finally, it was needed to use PSTAR model to estimate the influence of economic growth rate on suicide rate. This study has made real contribution to existed literature regarding that topic. First, PSTAR model was used to estimate the persistence of suicide rate, and that model can evaluate the influence of nonlinear and cross-sectional data on suicide rate, meanwhile, it also displayed effectively the dynamic smooth transition process of suicide rate. More importantly, these features not only had avoided the possible appearance of deviated result when using traditional linear model, but also had estimated precisely the change and persistence of suicide rate. In addition, this study will be used as one transition variable in the model to ensure if economic growth had deferred effect on suicide rate, simultaneously, the nonlinear effect of economic growth rate on suicide rate can be tested too.

After confirming that all the variables of empirical model can satisfy steady-state condition, stepwise regression model was used in this study to test the persistence of suicide rate. Next, based on the fact that empirical variable had periodical feature, test the lagged by one period and lagged by three period of length j^{th} period, and test standard was set up as 0.1.

Table 8 The estimation of persistence of suicide rates.

AR Model Variable Parameter	*P*	
	Coefficient	*P-value*
C	4.115748	5.797335(1.276540)***
S_{t-1}	0.582728	0.523289(0.100832)***
S_{t-3}	0.180266	0.140753(0.086259)**

Adjusted R-squared	0.667277

Note:

1. S_{t-j}, j=1,3 is the persistence of suicide rates.
2. *, ** and *** indicate significance at the 10%, 5% and 1% level, respectively.

From table 8, the significance of influence of suicide rate lagged by one period and lagged by three period on the current period of suicide rate can be seen, and it represented that the suicide rate of the current period was significantly affected by past suicide rate, and the persistence of suicide rate was 0.763 (0.583+0.180). In addition, although the non-existence of normal distribution in residual in null hypothesis was rejected by the significant residual estimation result of the model, yet the residual did not have series related null hypothesis was not rejected. According to the suggestions from Wu and Chang (2017), after confirming the optimized lagged period of persistence suicide, suicide rate lagged by one period and lagged by three period were used to replace exogenous variable in PSTR model. In addition, because the past GDP might have important deferred threshold effect on the current period of suicide rate, therefore, in this study, GDP lagged by two period was selected as transition variable in the model.

After the previous linearity and optimal number of threshold regime test, it was confirmed that 2 transition variables (r=2) and GDP lagged by two period parameters should be adopted in PSTAR model. Table 9 showed the estimation result of related parameters, and it showed the significant influence of the previous suicide rate on the current period suicide rate, and the persistence was 0.335. As compared to PSTAR model, linear model not only cannot estimate accurately the threshold value of economic growth rate on suicide rate, it was also difficult to express the change of suicide rate along with time and economic growth rate. That is, the structural change of suicide rate might be hidden in the estimation process of linear model. As a result, it was quite important to use nonlinear method to construct the model of persistence suicide.

Table 9 Estimated results of suicide rate.

Chosen Model Variable Parameter	PSTAR model *r=m=1; d=2*	Linear Model
γ	40.7953	-----
C	0.7811	5.797335(1.276540)***
β_1	0.8235(0.1982)***	0.523289(0.100832)***
β_1'	-0.3421(0.1861)*	-----
β_2	-0.2916(0.1751)*	0.140753(0.086259)
β_2'	0.4610(0.1949)**	-----
R^2	-----	0.545763
AIC	-3.319	0.8755
BIC	-3.213	1.0796
Persistence effect		0.335
$G(GDP_{it-d};\gamma,c)=0$	0.5319	
$G(GDP_{it-d};\gamma,c)=1$	0.6508	

Note: γ and C are the estimated transition parameter and threshold value. Parentheses ( ) are p-value. β_i and β_i',i=1,2 is the length of the lagged period of suicide rate. *, ** and *** indicate significance at the 10%, 5% and 1% level, respectively.

The threshold value c and transition parameter γ was respectively 0.7811 and 40.7953. The description and meaning were listed in detail as follows. In PSTAR model, under the situations of higher than and lower than threshold values, the relationship between economic growth rate and suicide rate showed the same trend in different intervals (0-1). The threshold value of GDP lagged by two period was 0.7811. Under two extreme situations, for $G(GDP_{it-2}; 40.7953,0.7811) = 0$ and $G(GDP_{it-2}; 40.7953,0.7811) = 1$, the effect was respectively 0.5319 and 0.6508. Therefore, no matter it was higher than or lower than the threshold value, the trend of positive relationship can always be observed. The negative values of AIC and BIC was sufficient to prove the appropriateness of PSTAR model.

This chapter had a main purpose of displaying linear model and comparing its result with PSTAR model. In linear model, the test statistical quantity of Hausman test was 0.4069, which was not significant. This result had supported the hypothesis that linear panel data should be estimated by empirical random effect model. From table 9, it can be obviously seen for the positive relationship of economic growth rate on suicide rate lagged by one period and lagged by three period, and the coefficients were respectively 0.523289 and 0.140753.

As compared to PSTAR model, the estimated result provided by linear model had some errors. Indeed, the effect of economic growth rate on suicide rate lagged by one period and lagged by three period was fixed at 0.523289 and 0.140753. However, in PSTAR model, the effect was evaluated according to whether the transition variable was higher or lower than the threshold value (0.7811). In addition, the effect of $G(GDP_{it-2}; 40.7953,0.7811) = 0$ and $G(GDP_{it-2}; 40.7953,0.7811) = 1$ was respectively 0.5319 and 0.6508. Thus, linear model cannot reflect accurately the relationship between economic growth rate and suicide rate as that of PSTAR model. When the given data set had cross sectional and cross-time features, it was more appropriate to select PSTAR model and to use threshold value to test the effect of economic growth rate on suicide rate.

According to the model of formula (6) of persistence suicide, suicide rate lagged by one period S_{t-1}, GDP lagged by two period G_{t-2} had transition effect on the current period suicide rate, and threshold value was 0.7811, and the smooth transition effect shown was changeable. The effect of suicide rate lagged by one period on the current period suicide rate will be dependent on the level of GDP lagged by two period, for the smooth transition effects of $G(S_{it-1}; 40.7953,0.7811) = 0$ and $(S_{it-1}; 40.7953,0.7811) = 1$ of S_{t-1}, for the two extreme situations shown in the

model, and for transition effects of 0 and 100%, they were respectively 0.8235 and 0.4814, that is, under linear effect, the marginal effect of suicide rate itself was 82.35%. Along with time change, the stay of GDP lagged by two period in the high threshold region will lead to marginal effect (0.8235, 0.4814) of suicide rate itself S_t, and this empirical part approximated the conforming to Herding Behavior [2] rule. That is, in the high threshold region, one unit of increase in suicide rate lagged by one period will trigger the increase of 48.14% of current period of suicide rate. According to the definition of transition variable, GDP lagged by two period represented that the threshold had reached 78.11%, under the situation that GDP was increased, suicide rate will decrease, therefore, economic growth will reduce the occurrence of suicide.

Under the influence of variable of suicide rate lagged by three period, the effect of suicide rate lagged by three period on the current period of suicide rate will be dependent on the level of GDP lagged by two period. The smooth transition effect of current period suicide rate was $G(S_{it}; 40.7953, 0.7811) = 0$ and $(S_{it}; 40.7953, 0.7811) = 1$, that is, for two extreme situations displayed by the model, they were respectively -0.2916 and 0.1694, in high economic (GDP) stage, suicide rate lagged by three period showed low level, maybe under the influence of adjustment effect of lagged by one period and under the time divergence effect, the S_t lagged by three period's persistence marginal effect will get reduced, but the reduced trend did not cause convergence of suicide rate, the possible reason might be in real society, the persistence of suicide rate did not finish its adjustment in the lagged by one period, however, there were still some people, while the economy was getting better, did not have related economic factors changed immediately due to turning good of the economy, and suicide rate lagged by three period showed large scale adjustment.

Therefore, suicide rate lagged by three period, when the economy had G_{t-2} continuous turning good, adjustment was seen in lagged by three period. Such lagged by three period was negative at low threshold value, however, it turned positive later on, and it was expected that this part will lead to, under continuous turning good of economy lagged by two period G_{t-2}, the reduction of suicide rate lagged by three period S_{t-3}, and under the continuous recession of economy lagged by two period G_{t-2}, the rise of suicide rate lagged by three period S_{t-3}.

5. Conclusion

In this study, aggregate data and panel smooth transition auto-regression (PSTAR) model were introduced, and suicide rate lagged by one period (S_{t-1}) and lagged by three period (S_{t-3}) were used as independent variables, and dependent variable was current period suicide rate (S_t), and GDP lagged by two period (G_{t-2}) was used as transition variable. The level of GDP can be seen as the index of economic growth and

economic recession, meanwhile, it can also be used for studying the change of persistence suicide under nonlinear model.

In this paper, the following three conclusions can be summarized, first, there was the existence of persistence effect for suicide rate, furthermore, it was changed along with transition variable in different threshold regions and it was changed along with time too. Such result was obviously different than the result evaluated by traditional linear model. Second, persistence effect will have performance of different levels depending on the change of economic growth rate, along with the increase of the lagged period of suicide rate, the effect will be gradually decreased. Third, the marginal effect shown by the third year was far lower than the effect of suicide rate of the first year, that is, in the future, in the growth momentum of economic growth rate lagged by two period, suicide rate can be significantly listed into the policy consideration of preventing suicide.

The economic policy result based on GDP as transition variable showed that at the moment of lagged by two period of economic development, maybe the behavior of incapability of self-discipline has already been buried in current period suicide rate to lead to the increase of suicide rate, along with divergence of time, the thought of suicide and suicide rate might decrease due to better economic situation and the influence of Herding Behavior, and after time deferred effect, it might diffuse to third year, the suicide decrease again, at this moment, maybe there were some people that do not have their economic situations changed due to the turning into good economic environment, and people started to realize what the real issue was, however, they cannot control their desires, consequently, they cannot solve the problems they want to solve smoothly, and suicide rate rose slightly again, therefore, the effect of insufficiency of self-discipline (Rabin, 2002) conformed to the research result, and it changed along with transition variables in different threshold regions and changed along with time too. And this result was significantly different with the result estimated by the traditional linear model.

From the research results, it was found that in different economic development situations in Taiwan, GDP index, relative to the increase or decrease of suicide rate, showed nonlinear effect, however, as time went by, the persistence suicide showed different consequence along with the change of GDP index, in the future researches, other economic indexes might be added into the empirical model, in addition to confirming if structural threshold effect will be generated on suicide rate along with different economic indexes, other test can be further conducted to see if nonlinear relationship can be generated due to the close correlation between suicide rate and economic factor. Hopefully, this research result can catch the attention and interest from the government and other scholars, and it was hoped that in the application or research of related topics in the future, echo and more influential power can be generated.

Declarations

***Ethics approval and consent to participate:** Not applicable

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The datasets generated during and/or analyzed during the current study are available from the corresponding author on reasonable request.

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Conception and design: Ssu-Han Chen, Yu-Tai Yang
Collection and assembly of data: Tzu-Yi Yang, Ssu-Han Chen
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