Dynamic effect of economic growth on the persistence of suicide rates

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Abstract

Positive and negative economic growth is closely related to the suicide rate. To answer the question whether economic development has a dynamic impact on this rate, we used a panel smooth transition autoregressive model to evaluate the threshold effect of economic growth rate on the persistence of suicide. The research period was from 1994 to 2020, and the results show that the suicide rate had a persistent effect, which varied over time depending on the transition variable within different threshold intervals. However, the persistent effect was manifested in different degrees with the change in the economic growth rate and as the lag period of the suicide rate increased, the effect of the influence gradually decreased. We investigated different lag periods and noted that the impact on the suicide rate was the strongest in the first year after an economic change and then reduced to be only marginal after three years. This means that the growth momentum of the suicide rate within the first two years after a change in the economic growth rate, should be included in policy considerations of how to prevent suicides.

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Introduction

The economic growth rate and the rate of suicides have an overall strong association. However, this relationship seems not be direct but rather show a lag period. Scholars have explored the correlation between the persistence of suicides (including suicide attempts) and economic aspects, *e.g*., Marcotte (2003) used an extended utility maximization model to examine the relationship between economic factors such as health costs and income and suicide attempts in the United States from 1991 to 1992. He found that suicide attempts are more likely when future income may be positively affected by the attempt, conditional on survival. Since the economic bubble burst in 1990 ushering in deflation, Japan's economy has shown slow or negative growth. Chen *et al.* (2014) employed the decomposition method to analyze the sudden and rapid rise of the suicide rate in Japan in 1997–1998 and the accompanying high suicide attempt rate since 1998. A positive relationship was found between financial hardships (e.g., bankruptcy) and suicide attempts, especially among males. These two studies confirm the significant and positive impact of changes in the economic environment and factors on suicide attempts echoing the results published by Choi e*t al.* (2020) and Jung *et al.* (2020). However, does relevance exist also between the suicide rate and economic growth rate? Yang (2010) used a multiple regression model, time-series single root test and the ARIMA transformation model to explore whether economic-related variables have a direct impact on suicide rates, which showed that overall economic declines lead to an increase in suicide rates. Meanwhile, Chang (2009) employed tracking data (panel data) regression analysis to examine the relationship between economic and social factors and suicide rates among different unemployment groups in 23 counties and cities in Taiwan (excluding the Jinma area) from 1997 to 2017. They found that the global economic recession in the period that had caused many businesses to close also led to an increase in the suicide rate.

In a 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 determine whether economic recessions are typically associated with an increase in suicide rates and clearly showed that a complex relationship exists between the economy and suicide. Yoo (2018) applied regression analysis to investigate economic, social, and modernization factors of 26 OECD countries in relation to suicide rates. The results revealed that economic change is closely associated with the suicide rate, specifically when the economic change is substantial.

Cormier and Klerman (1985) performed time-series analysis to explore the effect of economic fluctuations on the suicide rate in Quebec, Canada, from 1966 to 1981, a time when the unemployment and suicide rates in this Canadian province rose in unison. The determinants included the unemployment rate and male–female participation in the labour force. Here, changes in unemployment were not only found to have a positive relationship with the general suicide rate, but particularly so in the female suicide rate. In addition, Luo *et al.* (2011) conducted graphical analysis and nonparametric analysis to explore the impact of business cycles on suicide rates (differentiated between different age groups) in the United States from 1928 to 2007 and calculated the correlation coefficient between the national unemployment rate and the suicide rate. Their analysis showed that the overall suicide rate generally increased during the recessions, such as the Great Depression of 1929-193, and dropping significantly during economic expansions, such as that resulting from World War II.

On the other hand there are also scholars who conclude that no significant relationship exists between the economic growth rate and suicide rate. For example, Cheng (2011) performed a spatial analysis in Taiwan to explore the potential role of the 2001-2003 economic upturn and the 2007-2009 recession for suicide rates. In this case, however, the experimental results did not validate the hypothesis of increased suicide rates owing to the recession. Yang (1992), assuming that the suicide rate in the United States during the 1940-1984 period was the result of the interplay between economic and social variables, applied simple linear regression to explore the suicide rate of the total population and four social groups with different gender and race determinants. The results indicated that suicide rates did not rise during economic booms or busts, and that the unemployment rate significantly only adversely affected the suicide rate of white males.

Taiwan has experienced significant economic, environmental, and social changes since the 1990s (Lyons, 2009). The suicide rate in Taiwan has been on the rise since 1994, although it decreased gradually from 2006 to 2011. At the same time, the economic growth rate did not change strongly but went throw two periods of negative growth in 2001 and 2009 and a peak period in 2010.

A comparison of the economic growth rate and suicide rate in Taiwan during the period from 1994 to 2020 shows that the suicide rate continued to rise during the decline of the economic growth up to 2001 (Figure 1). The growth rate escalated 2001-2002 after which it fluctuated for three years. However, the suicide rate did not decline with the economic recovery periods. On the contrary, it continued to increase giving rise to what is now called its persistence. That is, the suicide rate was not directly impacted by the ongoing period of economic growth rate but reflected after a lag period. Alternatively, the economic growth and the suicide rate first increased in unison from 2005 to 2006, after the suicide rate decreased in the following year, while the economy continued up (1-year persistence).

The subprime mortgage crisis that occurred in the United States in 2007, which led to global financial problems, resulted in a serious drop in Taiwan's gross domestic product (GDP) in 2007-2009 followed by an increase in 2009-2010 and another decline in 2011-2012. Meanwhile, the suicide rate rose slightly during 2007-2008 but declined in 2008-2011 before rising until 2011-2012 (*i.e.,* a 3-year persistence). Thus, Taiwan's economic system was sufficiently robust to resist immediate affection of its prosperity by the international economic environment. In 2012-2014, the economic growth rate increased while the suicide rate decreased, and in 2014-2015, it dropped while the suicide rate increased slightly. Although it can be deduced that the economic growth and the suicide rate had an opposite correlation in this period, this is not

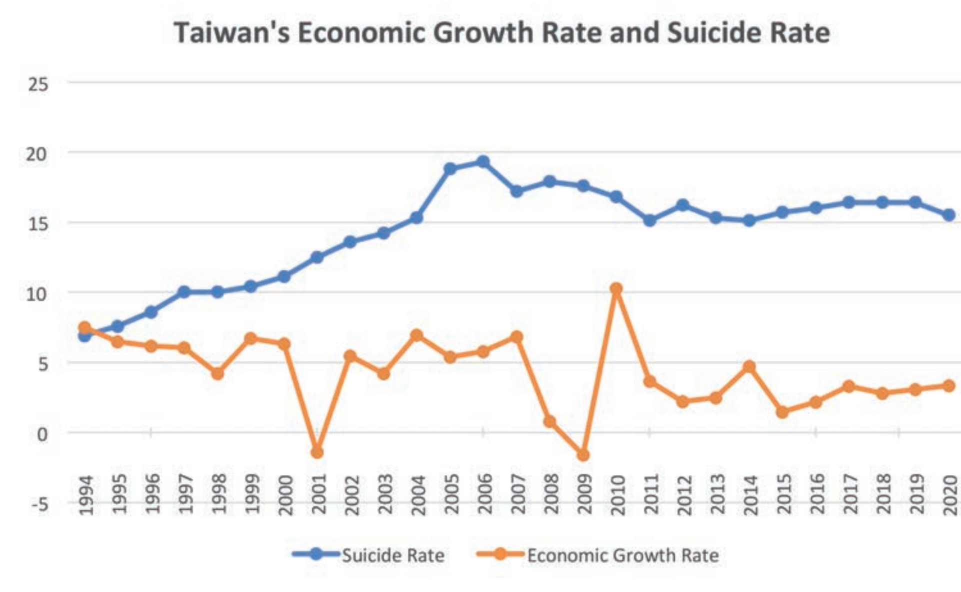

Figure 1. Taiwan's economic growth rate and suicide rate 1994-2020. Source of data: Suicide rate statistics: Division of Ministry of Health and Welfare; Economic growth rate: Directorate General of Budget, Accounting and Statistics.

always so. When the economic growth rate increased slightly in 2015-2017, decreased slightly in 2017-2018 and increased once again in 2018-2020, the suicide rate increased continuously and dropped only later (in 2019-2020). Thus, the reappearance of a lag was observed (in this case a 4-year persistence). This effect of the economic growth rate on the suicide rate and connection between economic growth and decrease in the suicide rate is obvious in Figure 1. The decline of Taiwan's economic growth may have been affected by changes in the internal or external economic environment. During the period of 1994-2001, financial problems occurred one after the other, e.g., the 1997-1998 Asian financial crisis, the 1999 Jiji earthquake in Taiwan, the 2000 dot-com bubble and the attacks on 11September 2001in the United States. These events not only caused Taiwan's economic growth to drop but also its suicide rate to jump from 6.9% in 1994 to 12.5% in 2001. Owing to the high suicide rate before the Asian financial crisis, it can be inferred that Taiwan's suicide rate remained steady during the crisis period of 1997-1998 but continued its ascent 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 impact of the Asian financial turmoil in 1997. Taiwan has a small economy and a limited domestic market demand, with growth to a large extent driven by export, which makes it highly dependent on foreign trade and thus inseparable from the world economy. In addition, since the United States is Taiwan's third largest trading partner, its economy nosedived both in 2001 and in 2009. Both industrial production and trade slowed amid economic recession and heightened deflationary pressure. In response to the crisis in 2009, the Taiwanese Government implemented economic revitalization programmes and adopted measures such as loose monetary policies and tax reforms, which effectively slowed the assault on the country's economy. Therefore, the suicide rate was not considerably affected and even exhibited a declining trend. According to the National Development Council (NDC), the economic growth recovered the following year (2010), reaching a peak exceeding10% (Chen, 2017; Guo, 2009; NDC, 2013; Wu *et al.*, 2012).

After 2011, the volume of international trade stagnated owing to reduced demands. In addition, the international division of labour underwent a certain degree of transformation. The return of manufacturing to the United States was not conducive to the recovery of global economic prosperity, coupled with the policy of the People's Republic of China focusing on domestic production of components leading to a rapid rise of the supply. Besides, Taiwan's exports are highly dependent on electronic information products and strongly impacted by the international rade. According to the Central Bank of the Republic of China (CBC), these factors exerted a negative impact on the international competitiveness of Taiwan causing adeceleration of the country's economic growth after the global 2007-2009 financial crisisthat only sawa brief recovery from 2013 to 2014 (CBC, 2015; Hsiao, 2018). Simultaneously, the suicide rate remained obstinately high.

After the global financial crisis, Taiwan faced problems such as inadequate investment momentum and outflow of talents (NDC, 2003). In addition, under the trend of globalization, Taiwan would be unable to remain uninvolved if a worldwide financial crisis occurs. Taiwan Centers for Disease Control and Prevention (CDC) has been concerned whether the new type of global economic headwinds would increase people's suicide risk (Taiwan CDC, 2018). Indeed, the economic persistence factors has caused the suicide rate to continue high and exert various effects that includes shortage of manpower. Insufficient manpower would inevitably shake the country's economy as both positive and negative economic growth rates are closely related to the suicide rate by influencing the structural relationship between economic growth, human resources and the suicide rate. Focusing on the above problems, this study aimed to clarify whether the economic growth rate has a deferred effect on the suicide rate and also investigate the threshold effect of the economic growth rate on persistence of suicide. This would be done by accurately describing individual and temporal effects while also addressing the nonlinearity and heterogeneity of the data, while demonstrating better predictive power and recognition accuracy than traditional linear regression models.

Materials and Methods

Background

Wu and Chang (2017) developed a panel-based smooth transition autoregression (PSTAR) model from the panel-based smooth transition regression (PSTR) model and used it to examine the nonlinear and persistent effects of monetary and fiscal policies on foreign direct investment in 10 countries belonging to the Organization for Economic Cooperation and Development (OECD). According these authors, the PSTAR model can be constructed by identifying the linear part of the smooth transition autoregressive model, which constitutes an autoregressive part whose dependent variable is the order of p, followed by a stepwise regression model to determine the optimal p for the lag period of the dependent variable. After this has been done, the exogenous variables of the PSTR model should be replaced with dependent variables with multiple period lags. In addition to its ability to capture data heterogeneity and the advantages of accurately describing its individual and temporal effects, the PSTR model avoids the collinearity problem commonly found in linear structural models. This model also provides useful information to improve estimation validity when examining situations with long lags of the dependent variable. As this study attempts to investigate the threshold effect of the economic growth rate on persistence of suicide and the variable data of the model have time-series characteristics, the PSTAR model was chosen for the empirical analysis.

The variables in empirical suicide rate models typically have time-series characteristics and heterogeneity, and owing 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 also suffer from estimation bias, because the empirical procedures used in linear models may ignore significant correlations between the variables in the model or because of heterogeneity, which typically emerges when the data structure has cross-sectional characteristics. Finally, as the variables in most suicide rate empirical models tend to have time-series characteristics and heterogeneity, and owing to the asymmetric relationship between the model variables, the suicide rate may exhibit nonlinear characteristics, and traditional linear models may not be able to correctly estimate the suicide rate.

Research data

In this study, the suicide rate with one and two years time lag were expressed as S_{t-1} and S_{t-2}, respectively, and employed as the independent variables, with the same-year suicide rate (S_t) used as the dependent variable. Information on the independent and dependent variables were obtained from the Statistics Division of the Ministry of Health and Welfare (MoH). The economic growth was obtained from the Taiwan Economic Journal (TEJ) (https://www.finasia.biz/) and used as the transfer variable with a two-year lag, expressed as G_{t-2}. The research period was 1994-2020 with the data employed were annual as shown in Table 1. The suicide rate data were divided into northern, central, and southern Taiwan in line with the administrative division of the country by the Supreme Administrative Court (2021), with the counties and cities as presented in Table 2.

Empirical model

The main focus of this study was the threshold effect of the economic growth rate on the persistence of suicide in the period of 1994-2020. This study used the PSTAR model, i.e. the original PSTR model proposed by González *et al.* (2005) including the additional suggestions of Wu and Chang (2017), to estimate the threshold effect of the economic growth rate (G) on the persistence of suicide(S) in Taiwan. An advantage of the PSTR model is that it connects two linear regions through a nonlinear transfer function. In addition to providing highly precise descriptions of the time and individual effects of the sample data, the model can capture heterogeneity. The estimation technique used to obtain the threshold value of the model is quantitative, which differs considerably from the traditional technique that is based on subjective judgment. Compared with traditional empirical models, the PSTR model uses a more objective way to decide the threshold transition. Finally, in addition to the modification of the issue of the immediate occurrence of jumping observed by Hansen (1999) to explain the transition threshold value in the neighbourhood of the smooth transition threshold value, an additional transitional speed parameter was added to the PSTR model. When a time-series feature or macroeconomic variable is adopted for this model, it becomes completely suitable. The PSTR model was constructed as follows:

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

where i (1,2…N) is the cross-sectional suicide rate; t (1,2…T) the time; y_{it} the suicide rate (i) in the current period (t); and X_{it} the independent variable of the time-dependent dimension vector k. A stepwise regression model was employed to find the optimal exogenous variable, where α_i equals the fixed effects of an individual; G (Z_{it-d}; g; C)a transition function with a value within the range from 0 to 1(where Z_{it-d} is the transition variable with a d-year lag period, which is also an exogenous variable); a transition speed variable for describing the transition function of the model; c the transition threshold value; and ε_{it} the residual. In addition, the lag period of the transition variable and the optimized period (the current year) must be estimated with the minimal-value Bayesian information criterion (BIC) and the Akaike information criterion (AIC). For the transition function of this model, the suggestions of Granger and Teräsvirta (1993, 1994) and Teräsvirta (1994) were followed and assigned as follows:

$$G(Z_{it-d};\gamma,C) = \left\{1 + exp[-\gamma\textstyle\prod_{j=1}^{m}](Z_{it} - C_j)]\right\}^{-1} \quad \text{(Eq.2)}$$

$$G(Z_{it-d};\gamma,C) = 1 + exp[-\gamma\textstyle\prod_{j=1}^{m}(Z_{it} - C_j)^2] \quad \text{(Eq.3)}$$

where the location parameter dimension m is defined as C1≤C2≤... ≤Cm, and C= (C1, C2…Cm) and the slope of the transition function γ (with γ>0); thus, the larger the value of γ, the steeper (.) the slope of G. When the transition parameter γ→∞ and the value of G (.) converge to 1, the situation becomes represented as follows: i) a structural change occurring at a single point in time; ii) the PSTR model collapses to the PTR model; and iii) the model becomes roughly the same as the single-point jump model proposed by Hansen (1999). Meanwhile, when γ means speed, it will rotate within 1-100% (0-1)→0, G (.), it approximates a linear form indicating the modification of PSTR into a fixed model with panel estimation capability that makes the single-point structural change insignificant. To capture the nonlinear form of the model according to the empirical suggestions of González *et al.* (2005), means that it would be adequate to consider only m=1 or m=2. When m=1, the data would be divided into two regions by the transition threshold

Table 1. List of variables.

Variable	Variable type	Symbol	Source
Current-year suicide rate	Dependent	S_t	Statistics Division, MoH
Two years GDP lag	Transfer	G_{t-2}	Taiwan Economic Journal (TEJ); Statistics Division, MoH
Suicide rate			
One year lag	Independent	S_{t-1}	-
Three years lag		S_{t-3}	

Data for the 1994-2020 study period; GDP, gross domestic product; MoH, Ministry of Health and Welfare.

Table 2. Counties and cities in Taiwan.

District	Counties and cities
Northern	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
Southern	Chiayi County, Chiayi City, Tainan City, Kaohsiung City, Pingtung County, Taitung County, and Penghu County

Source: Supreme Administrative Court (2021).

value, which is a logical model (Eq. 2). Meanwhile, when m=2, the transition threshold value would divide the data into three regions, which is an exponential model (Eq. 3). The broad PSTR model is represented as follows:

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

The number of transition functions in the model is represented by j=1, 2...r, and a total of (r+1) transition regions exist. In addition, the estimation results of Eq.2 or Eq. 3 were used to decide the form of the transition function. Before constructing the PSTAR model, the cross-sectional data of the past suicide rate in northern, central and southern Taiwan were adopted and the stepwise regression model employed to find the linear feature. Based on the periodical feature of the variable data, it was estimated that the j^{th} period had a1-year and a 3-year lag period. The autoregression model of the suicide rate is shown in the next equation:

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

were S_{it} and are is the rate in year t; and S_{it-j} the suicide rate with a j-year lag period; a_{i0} the intercept; u_{it} the residual; and a_j the suicide rate persistence coefficient. After the linear feature of the suicide rate had been evaluated, G with a lag period of two years (G_{t-2}) was selected as the transition variable and used as a substitute for the exogenous variable in the PSTR model. Based on the suggestion of Wu and Chang (2017), Eq. 5 was used for the estimation, and a dependent variable with multiple lag periods was consequently obtained. The PSTAR model in this study was defined as follows:

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

where G (GDP_{it-d}; γ, c) is a transition function with a value between 0 and 1; and GDP_{it-d} the GDP with a lag by d^{th} number of years. Moreover, the transition speed under the two extreme conditions of the model is described by the transition parameter γ, with c as the transition threshold value. GDP may have a threshold lag effect on the suicide rate and the stable transition of the suicide rate can be explained through this transition function. Therefore, after the features of the data in this study were considered, the GDP with a 2-year lag instead of the present-period GDP GDP_{it} was selected as the transition variable (GDP_{it-d}, d=2). In addition, for the optimized lag transition value, the AIC and BIC estimation methods with a minimal value were adopted for the estimation with ε_{it} as residual.

Model specification and testing

A cross-sectional panel unit root test was conducted in advance to judge the stability of the time series of sample data before the empirical model was used for the estimation. This was done owing to the emergence of an unstable feature in the sample data that could result in deviations generated by the estimation results, after stability had been confirmed, the model estimation method proposed by González *et al.* (2005) and Wu *et al.* (2013) was adopted. First, a linearity test was conducted to confirm whether the suicide rate can satisfy the nonlinear condition, *i.e.* the appearance of a nonlinear panel model indicating that the linear null hypothesis must be rejected. The null hypothesis (H_0) for the statistical test indicates error, while the alternative hypothesis (H_1) indicates a correct outcome. If a statistical test rejects H_0 even if it described the real situation, then the outcome would be a form-1 error. On the other hand, if the test result supports H_0, and the real situation would be described by H_1, the outcome would be a form-2 error. General practice is to keep the appearance of a form-1error at a certain level (that is, significant difference value or α value), it would be better to try to reduce the probability of the appearance a form-2 error. Next, the transition threshold value was estimated and the heterogeneity of the sample data confirmed to verify the form of the model and the transition parameter of the transition function. Finally, after checking the form and number of the model transition variable, the nonlinear least squares method and Eq. 6 were used to estimate the persistent effect and nonlinearity of the GDP on the suicide rate. The test steps and processes are described in detail in the subsequent section. When conducting the empirical data analysis, the PSTR model was considered to be inappropriate for data estimation involving a homogeneous cross-section; hence, the model was converted into a general linear panel model for this study. To prove that the model had a nonlinear feature, a homogeneity test was performed before the model parameter estimation. This test is similar to the one representing the H_0 of the linear model, *i.e.* r = 0. However, since this H_0 does not have an interference parameter (*e.g.*, with regard to location) and transition effect, it could inhibit the normal distribution of statistical quantity. To test the linearity of Eq.6, according to the suggestion of González *et al.* (2005), while implementing the homogeneity test, the expansion of the first-order Taylor polynomial (a linear approximation of the function) was conducted to replace the transition function $G(Z_{it-d}; \gamma, c)$ of the model. The attached regression formula is the following:

$$\delta_{it} = \theta_{i0} + \sum_{j=1}^{j} S_{it-j} + \sum_{j=1}^{j} \theta'_j S_{it-j} GDP_{it-d} + \tau_{it} \quad \text{(Eq.7)}$$

where δ_{it} is the residual of Eq. 6; θ_{i0} an intercept term; S_{it-j} the suicide rate with a lag of j years; and GDP_{it-d} the GDP with a lag of d years. The linearity test mainly includes the test of the H_0, with a concurrent value of 0, and the asymmetric distribution would not be affected by the expansion of the first-order Taylor approximation value. The Wald Lagrange multiplier (LM) test (an empirical test used to check whether any parameter restrictions are violated) in the statistical quantity of X^2 or F (see below). The LM test can be calculated by the following equations:

$$\begin{aligned} LM &= TN\,(SSR_0 - SSR_1)/\,SSR_0 \\ LM_F &= \{[(SSR_0 - SSR_1)]/mk\}/ \\ &\{[SSR_1/(TN - N - m\,(k+1))]\} \end{aligned} \quad \text{(Eq.8)}$$

where SSR_0 is the sum of the square of the residual in the H_0 (the model is thus a linear panel model with a specific effect), while SSR_1 is defined as the sum of the square of the residual in the substitute hypothesis, which means that the model has m regions, where m is the number of the transition parameter; k the number of the explanatory variable; T the time; and N the cross-section suicide rate in northern, central and southern Taiwan. The LM model includes the statistical number of the different distributions of F $(mk, TN\text{-}N\text{-}m(k+1))$ and $X^2(mk)$ and decides whether or not the model data exhibit homogeneity and whether there is a nonlinearity.If a nonlinear characteristic appears in the model test after the linearity test, then the linear H_0 must be rejected and the transition function of the model has at least one threshold transition variable. The next step involves testing whether or not other transition functions exist in the empirical model and estimating their number to arrive ata reasonable transition threshold value. As long as the model has a transition effect, the linear hypothesis of the model must be rejected. According to the suggestions of González *et al.* (2005), while conducting the test of the threshold value, a model with one transition function (r=1) should be used in advance of the estimation. Meanwhile, the attached regression formula was used to test the H_0 (r=1) for two threshold values, which therefore confirmed the number of the transition parameter. If the test results do not reject the H_0 for one threshold, the optimal threshold should be tested repeatedly until the $H_0$of this threshold cannot be rejected. The optimal threshold value of the model is given as r $(1 \ldots N)$. The nonlinear least squares method should be used to estimate the dynamic effect of economic growth on the persistence of suicide rate after the number and form of the transition variable are judged and the heterogeneity of the sample data has been confirmed.

Results

The main focus of this study was the threshold effect of the economic growth on the persistence of suicide. Eq.7 was used to test the linearity and homogeneity of the economic growth and suicide rate. From the empirical results, the heterogeneity and the continuous nonlinear effect of the economic growth on the suicide rate can be observed and their description provided.

Descriptive statistics

Table 3 shows the characteristics of the GDP and suicide rate variables within the given time, including the maximum value, minimum value, average value and standard deviation (SD), (Table 3).

Nonlinear panel unit root test

In this stage, the augmented Dickey-Fuller (ADF) test (used to test whether a given time series is stationary or not) was adopted to test whether or not the variables demonstrated stable characteristics to avoid deviation of the hypothetical regression or empirical results. The nonlinear panel unit root test differentiated between the H_0, *i.e.* finding of a unit root (H_0) and the opposing hypothesis (H_1), *i.e.* the absence of a unit root. If the p-value of each variable is statistically significant, then should be rejected and H_1 accepted. Table 4 underlines the obvious significance of all the variables. H_0 was rejected, and H_1 accepted; thus, the time-series and cross-sectional variables among the panel data exhibited a stable status. In addition, a unit root test for the structural breaking was further conducted to determine whether or not the nonlinear structural series can reach a stable status during the conversion process over time. Figure 2 presents the unit root test of for the different lag alternatives from 2001 to 2020. As shown in Table 4 and Figure 2, each variable was statistically significant, and the series structure underwent nonlinear structural conversion and should thus reach stability over time.

Hausman test

To prove the appropriateness of the use of the PSTAR model to evaluate the persistence of suicide, the Hausman test (used to differentiate between fixed effects and random effects in panel model analysis) was employed. Here the H_0 was defined as applicable to random-effects models and H_1 as applicable to fixed-effects models. Panel data models examine cross-sectional (group) and/or time-series (time) effects. These effects may be fixed and/or random. Fixed effects assume that individual group/time have different intercept in the regression equation, while random effects hypothesize that individual group/time have different disturbance. Therefore, we need to test our data is random or fixed. The results are shown in Table 5. The p-value was not significant, and H_0 was therefore accepted, which means that the linear panel data model was a random-effects model.

Linearity test

The results of the nonlinear panel unit root test showed stable

Table 3. Descriptive statistics of the suicide rate and GDP in 1994-2020.

	S	GDP
Maximum	19.20000	10.250000
Minimum	9.70000	-1.610000
Mean	15.39524	3.940952
Standard deviation	1.99987	2.868689
Observations	21	21

S, suicide rate; GDP, gross domestic product.

Table 4. Results of the nonlinear panel unit root test.

Variable	ADF test (outcome)	Break time (year)	Lag (years)
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

ADF, the augmented Dickie-Fuller test; S_{it}, the suicide rate in the current period; S_{it-1}, the suicide rate with a 1-year lag; S_{it-3}, the suicide rate with a 3-year lag; G_{it-2}, the GDP with a 2-year lag; ***statistical significance at the 1% level.

characteristics for all variables investigated. Therefore, the continuous test to determine whether the model showed the nonlinear correlation between the economic growth rate and suicide rate was deemed reasonable. Based on the research of Wu *et al.* (2013), the regression equation (Eq. 7) was used to conduct the linearity test, and the expansion of the first-order Taylor H_0: r=0 was used to replace the model's transition function $G(q_{it-d};\ \gamma,\ c)$, as follows:

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

where S_{it-1} is the suicide rate with 1-year lag period; S_{it-3} the suicide rate with a 3-year lag period; and GDP_{it-2} the GDP with a 2-year lag period. Here H_0 would indicate a linear PSTAR model, while H_1 would signify a PSTAR nonlinear model, with at least one transfer variable (r=1). If the r value of each variable is significant, would be accepted and rejected. The results of the linearity test are shown in Table 6. Table 6 presents the results of the confirmatory tests (Wald, Fisher and LRT). The appearance of the significance rejected the linear H_0 under one transition variable. Meanwhile, the

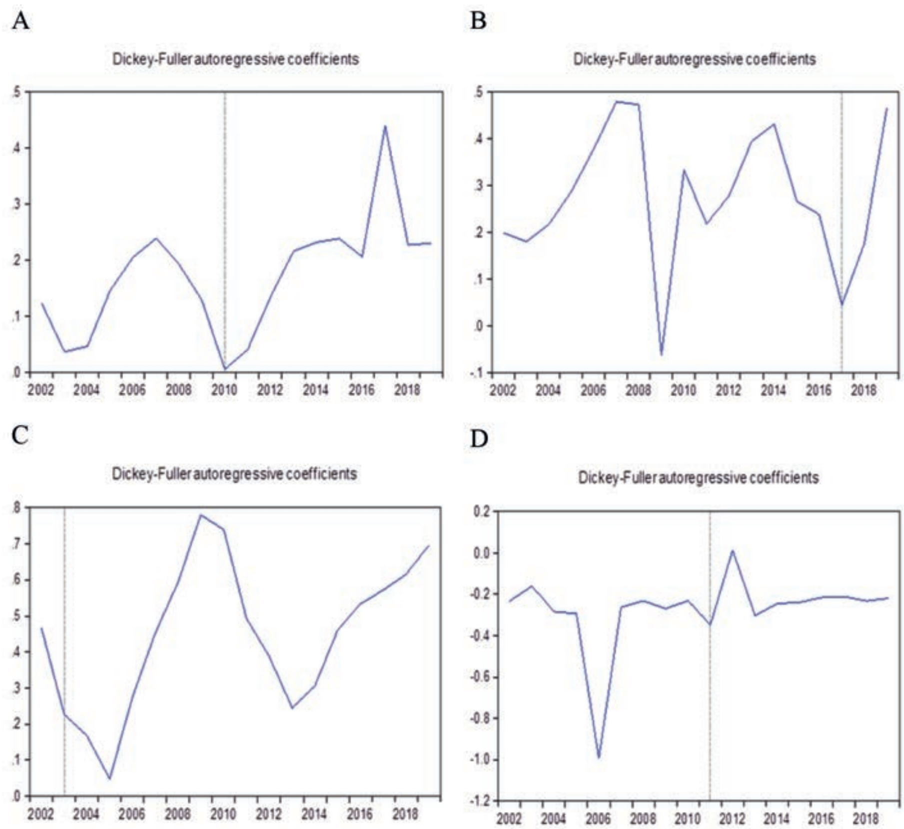

Figure 2. Unit root test of the current-period suicide ratein Taiwan 2001-2020. A=same-year suicide rate (S_{it}); B=Suicide rate with a 1-year lag (S_{it-1}); C=suicide rate with a 3-year lag period (S_{it-3}); D = GDP with a 2-year lag period (G_{it-2}).

Table 5. Hausman test.

Test data	Chi-square (outcome)	Chi-square DF	p
Cross-section random	1.798534	2	0.4069

DF, degrees of freedom

Table 6. Linearity test.

Confirmatory test	One location parameter (*m*=1)	Two location parameters (*m*=2)
LM	5.325(0.070)*	12.997(0.011)**
LMF	2.678(0.077)*	3.379(0.016)**
LRT	5.564(0.006)***	14.556(0.006)***

LM, Wald Lagrange multiplier (LM) test; LMF, the less extreme one-tailed mid-*p*-value function given by Fisher's exact test; LRT, likelihood ratio test; *statistical significance at the 10% level; **statistical significance at the 5% level; *** statistical significance at the 1% level.

test data also showed the visible nonlinear relationship between economic growth and the suicide rate, which demanded further analysis of the optimal threshold value using the H_0 (*i.e.* PSTAR model is a nonlinear model)and H_1=(*i.e.* PSTAR model is a linear model).

According to the estimation data in Table 7, it can be seen that regardless of whether the number of location parameters was 1 or 2, significance did not appear. Thus, the test data did not reject H_0, which once again proved the nonlinearity of the PSTAR model. In other words, it can be concluded that an optimized lag period of either 1 or 2 can be obtained.

Empirical results of PSTAR model

After confirming whether all the variables in the empirical model satisfied the steady-state condition, a stepwise regression model was used to test the persistence of suicide rate. Next, based on the fact that the empirical variables had a periodical feature, the 1-year lag period and the 3-year lag period with reference to the length of the j^{th} period, the test standard confidence intervalwas set at 0.1.From Table 8, the significance of the influence of the 1-year lag period and 3-year lag period on the same-year suicide rate can be seen, with a persistence amounting to 0.763 (0.583+0.180). Thus, current suicide rates are clearly affected by past suicide rates. In addition, though the nonexistence of a normal distribution in the residual in the null hypothesis was rejected by the significant residual estimation results of the model, the residual did not have a series-related null hypothesis and was therefore not rejected. According to the suggestions of Wu and Chang (2017), after confirming the optimized lag period of the suicide persistence, the 1-year and the 3-year lag periods of the suicide rate were used to replace the exogenous variable in the PSTR model. In addition, because the past GDP may have an important deferred threshold effect on the same-year suicide rate, GDP with a 2-year lag period was selected as the transition variable in the model.

After the previous linearity and optimal threshold value regime tests, it was confirmed that two transition variables (r=2) and the 2-year lag GDP period should be adopted in the PSTAR model. Table 9 presents the estimates of the related parameters significant

Table 7. Test for any remaining nonlinearity.

Confirmatory test	One location parameter (*m*=1)	Two location parameters (*m*=2)
LM	1.026(0.599)	-14.144(1.000)
LMF	0.447(0.642)	-2.292(1.000)
LRT	1.035(0.596)	-12.760(1.000)

LM, Wald Lagrange multiplier (LM) test; LMF, the less extreme one-tailed mid-*p*-value function given by Fisher's exact test; LRT, likelihood ratio test; *statistical significance at the 10% level; **statistical significance at the 5% level; *** statistical significance at the 1% level.

Table 8. Estimation of persistence of the suicide rate.

AR model variable Parameter	Coefficient	p
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)**
adj R^2	0.667277	-

S_{t-j}, j, 1,3 is the persistence of suicide rate;adj R^2, adjusted R-squared; *statistical significance at the 10% level; **statistical significance at the 5% level; *** statistical significance at the 1% level.

Table 9. Estimated results of suicide rate.

Chosen variable parameter for the model	PSTAR model r=m=1; d=2 (p)	Linear model (p)
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)*	-----
$\beta 2$	-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
Persisting effect	-	0.335
G(GDPit-d; γ, c) = 0	0.5319	-
G(GDPit-d; γ, c) = 1	0.6508	-

γ is the estimated transition parameter; C, the threshold value; *m*, the location parameter dimension; β_1 and β_1' and β_2' and β_2' = the mean of the data mean before and after transformation; $G(GDP_{it-d}; \gamma, c)$ see explanation under Empirical model, Eq. 3; i =the length of the lag period of the suicide rate; AIC, Akaike information criterion; BIC, Bayesian information criterion; *statistical significance at the 10% level; **statistical significance at the 5% level; *** statistical significance at the 1% level.

influence of previous suicide rates on the current suicide rate resulting in a persistence of 0.335. Compared with the PSTAR model, the linear model was not only unable to accurately estimate the threshold value of the economic growth on the suicide rate but also to express the change in the suicide rate along the economic growth over time. Thus, the structural change in the suicide rate may be hidden in the estimation process of the linear model. This result emphasizes the importance of using the nonlinear method to estimate the degree of suicide persistence.

The threshold value c and transition parameter g were 0.7811 and 40.7953, respectively. The description and meaning are explained in detail in Table 9. With respect to higher or lower than the threshold values in the PSTAR model, the relationship between economic growth and the suicide rate showed the same trend in different intervals (0-1). The threshold value of the GDP 2-year lag period was 0.7811. In the two extreme situations, for $G(GDP_{it-2;}$ 407953, 0.7811) and $G(GDP_{it-2;}$ 407953, 0.7811) = 1, the effect was 0.5319 and 0.6508, respectively. Therefore, regardless of whether it was higher than or lower than the threshold value, a consistent trend of a positive relationship was observed. The presence of negative values of both AIC and BIC is sufficient to prove the appropriateness of the PSTAR model.

The main objective of this section was to present the linear model and compare its results with those of the PSTAR model. In the linear model, the test statistical value of the Hausman test was 0.4069, which was not significant. This result supported the hypothesis that linear panel data should be estimated by an empirical random-effects model. The positive relationship between the economic growth and the 1-year and 3-year lag periods of the suicide rate, the coefficient was 0.523289 and 0.140753, respectively (Table 9).

Discussion

After the aforementioned series of tests, the PSTAR model was used to estimate the influence of the economic growth on the suicide rate. This model was first used to estimate the persistence of the suicide rate evaluating the influence of the nonlinear and cross-sectional data. The PSTAR model effectively displayed the dynamic smooth transition process of the suicide rate. Importantly, it was not only possible to avoid the deviated results that often appear when using the traditional linear model but also to estimate the precise change in, and persistence of the suicide rate. In addition, when testing the nonlinear effects, only one transition variable was needed to determine whether economic growth had a deferred effect on the suicide rate.

Compared with the PSTAR model, the estimated results provided by the linear model had some errors. The effect of the economic growth on the 1-year and 3-year lag periods of the suicide rate was fixed at 0.523289 and 0.140753, respectively. However, in the 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 $G(GDP_{it-2;}$ 407953, 0.7811) = 0 and $G(GDP_{it-2;}$ 407953, 0.7811) = 1 resulted in the values 0.5319 and 0.6508, respectively. Thus, the linear model was unable to reflect the relationship between the economic growth and the suicide rate as accurately as the PSTAR model. When the given dataset exhibits cross-sectional and cross-time features, selecting the PSTAR model would be appropriate as well as using the threshold value to test this effect.

According to Eq. 6, the suicide rate showed a 1-year lag period (S_{t-1}), while the 2-year GDP lag period had a transition effect on the same-year suicide rate. The threshold value was 0.7811 and the smooth transition effect was changeable. The effect of the 1-year lag period of the suicide rate on the same-year suicide rate would be dependent on the level of the 2-year GDP lag period for the smooth transition effect of $G(S_{t-1;}$ 407953, 0.7811) = 0 and ($S_{t-1;}$ 407953, 0.7811) = 1 on S_{t-1}. For the two extreme situations in the model, and for the transition effects of 0 and 100%, the threshold value was 0.8235 and 0.4814, respectively. That is, under the linear effect, the effect of the suicide rate was 82.4%. Along with the time change, the 2-year GDP lag period in the high-threshold region led to marginal effects (0.8235 and 0.4814) of the suicide rate, and this empirical part approximately conformed to the herding behaviour rule. According to Robert Shiller's research, herding behaviour refers to the tendency to follow a larger group rather than making independent decisions. He sees herding as driven by social or psychological factors, such as a desire for social conformity or a fear of missing out on potential gains. Uncertainty plays a role for herding because people generally face two restraining conditions, complete certainty or complete uncertainty, and they only tend towards herding when the restraint conditions are uncertain because this presents a situation when herding can increase psychological satisfaction.

That is, in the high-threshold region, one unit of increase in the 1-year lag period of the suicide rate triggered a 48.1% increase of the same-year suicide rate. According to the definition of the transition variable, the 2-year GDP lag period indicated that the threshold reached 78.1%. When the GDP increased, the suicide rate decreased; it can therefore be stated that economic growth reduces the occurrence of suicides.

Under the influence of the variable of the suicide rate with a 3-year lag period, its effect on the same-year suicide rate was dependent on the level of the 2-year GDP lag period. The smooth transition effect of the current-period suicide rate was $G(S_{it;}$ 407953, 0.7811) = 0 and ($S_{t-1;}$ 407953, 0.7811) = 1, that is, the two extreme situations displayed by the model were–0.2916 and 0.1694 at the high-GDP stage, and the 3-year lag period of the suicide rate showed a low level. Under the influence of the adjustment effect of the 1-year lag, and under the time divergence effect, the persistent marginal effect of the 3-year lag of the suicide rate decreased, but the reduced trend did not cause convergence. A possible reason for this outcome may be that the persistence of suicide rate does not complete its adjustment in the 1-year lag period in this particular society. However, for some people, related economic factors did not change immediately during the recovery of the economy. Thus, the 3-year suicide rate lag showed a large-scale adjustment.

Therefore, when the economy experienced G_{t-2} continuous improvement, adjustment was seen after a lag of 3 years. Such a lag was negative at a low threshold value but subsequently became positive and expected to lead to a reduction in the 3-year suicide rate lag period (S_{t-3}) under the continuous improvement of the economy with a 2-year GDP lag (G_{t-2})and a rise in the 3-year suicide rate lagunder the continuous recession of the economy after a lag of two years).

The economic policy results, based on the GDP as a transition variable, showed that for a 2-year lag period of economic development, the inability to practice self-discipline might be become buried in the current-period suicide rate, leading to an increase in the suicide rate. Along with the divergence of time, the thought of suicide and the suicide rate may decrease owing to an improved economic situation and the influence of herding behaviour. After the time-deferred effect, it may diffuse in the third year, and the suicide rate may decrease once again. At this time, some people may not have experienced a change in their economic situation from the improvement of the economic environment, and others may have begun to realize the actual issue but were unable to control their desires. They may not have been able to solve their problems smoothly, thereby causing the suicide rate to increase slightly once again. The effect of inadequate self-discipline (Rabin, 2002) conformed to the research results and changed along with the transition variable in the different threshold regions and with time. This result differed significantly from the result estimated by the traditional linear model.

From the research results, it was found that in different economic development situations in Taiwan, the GDP index, relative to the increase or decrease in the suicide rate, showed a nonlinear effect. However, over time, the persistence of suicide showed different consequences along with the change in the GDP index. Suicide is preventable and a phenomenon worthy of further investigation is whether the the suicide rate will continue to ferment when the economic situation continues into the second year. However, when the economy is a continuous source of suicide pressure, the quantitative results of this study would lead to failure to improve the economic conditions in the second year if collection and compiling of relevant data on the first suicide attempt could not prevent recurrence of suicide. Secondly, if the government-related social welfare units can improve the situation, or multi-service social innovation can corral the aspects of process, service and resources and strengthen the connection and care with people and families, it is very possible that the results of this innovative research would generate valuable impact and satisfactory results.

In future studies, other economic indices may be added to the empirical model in addition to confirming whether the structural threshold effect on the suicide rate will be generated by the different economic indices. Other tests can be conducted to determine whether the nonlinear relationship can be achieved owing to the close correlation between the suicide rate and economic factors. Hopefully, the research results will catch the attention and interest of other scholars and in the application or research of related topics in the future, replications and influential power can be generated.

Conclusions

In this study, aggregate data and the PSTAR model were introduced for the study of how and why the suicide rate changes. The suicide rate was used with 1-year and 3-year lag periods as independent variables, with the same-year suicide rate as the dependent variable and the GDP with a 2-year lag period as the transition variable. The GDP level is an index, whose change between economic growth and economic recession can be used to examine the change in persistence of suicide by a nonlinear model. Three conclusions were drawn: i) the suicide rate, which changed along with the transition variable in different threshold regions and with time, had a persistent effect, a result different from that evaluated by the traditional linear model; ii) the level of persistence differed depending on the change in the economic growth rate and as the lag period of the suicide rate increased, the effect decreased gradually; and iii) the marginal effect of the suicide rate observed in the third year was far lower than that seen in the first year. The overall deduction must then be that the suicide rate is significantly affected after a 2-year lag period after a (relatively) long-term economic change has occurred. This should be listed as a policy consideration for preventing suicides in the future,

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