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Time Series Analysis for the Dynamic Relationship between an Enterprise's Business Growth and Carbon Emission in Taiwan

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Abstract: Since the Paris Agreement came into effect in 2016, governments worldwide have established goals for future carbon emission reduction. Enterprises and governments have begun to pay attention to the management of carbon emission. This study explored the dynamic relationship between business growth and carbon emission performance by constructing and using a time series model to predict the trend of carbon emission. The time series method (ADF unit root test, cointegration test and VAR model etc.) was adopted to investigate 805 companies listed on the Taiwan Stock Exchange from 2012 to 2017 as the sample of this study. The carbon emission performance variables include: total carbon emission, annual increase of carbon emission, and annual increase rate of carbon emission. The business growth variables include: growth rate, stability of growth, and years of establishment. The results showed a long-term dynamic relationship between business growth and carbon emission performance. Therefore, using the time series method can assist enterprises in developing green strategies, strengthen carbon emission prediction and management capacities, reduce operating costs and risks, and actively achieve the ideal of sustainable development.

Keywords: business growth; carbon emission; carbon credit trading; time series analysis

1. Introduction

Carbon emission has affected the environment, ecology, economics, society, and human health. After becoming aware of the severity of this problem, governments worldwide have begun collaborating and developing relevant control regulations to prevent societal, environmental, and economic damage caused by climate change. In 1992, the United States convened an Earth Summit in Brazil which passed the United Nations Framework Convention on Climate Change for controlling the amount of artificially produced carbon emission. In 1997, the United Nations developed the Kyoto Protocol to serve as a basis for carbon emission management and reduction. Additionally, in 2016, the Paris Agreement replaced the Kyoto Protocol and required participating entities to review their carbon emission goals every five years.

Enterprises need to follow the global climate change convention, use low-pollution equipment, and improve R&D technology to lower the operational risks faced by carbon reduction [1]. How to use industrial development policies to reduce greenhouse gas emissions, create green business opportunities and competitiveness was pointed out, and this has become the industry's highest priority for sustainable management [2]. Expansion in the scale of an enterprise's production and increased labor force are the key factors for the increase of greenhouse gas emissions [3]. Low-carbon industrial policy can contribute to both environmental and social sustainability [4].

The greenhouse gas emissions generated by continuous economic growth have caused stress to the environment, and it was necessary to formulate an efficient energy portfolio policy [5]. The correlation between environmental and financial performance was studied and analyzed in Japan from 2004 to 2008 [6]. The data of CO_2 emissions and business performance of 89 international companies from 2006 to 2009 were analyzed [7]. Time series model was used to predict greenhouse gas emissions from fossil energy consumption, and China's GDP growth rate and the rate of change in carbon emissions from fossil energy was researched [8]. The increase in regulations for carbon and waste management are forcing firms to consider their supply chains from ecological and social objectives [9].

The climate is a determinant of most economic activities worldwide [10,11]. The weather can decide economic prosperity or depression. Regardless of whether observations are being made from a global perspective or from the perspective of individual countries, the climate exerts a strong influence on businesses, stock markets, and economic development. However, scientists have become concerned that industrial and economic developments may have affected the climate; therefore, effective control measures must be adopted in a timely manner [12]. Developing long-term goals and strategies for carbon emission reduction can enhance the competitiveness of businesses and reduce their expenditure on measures for protecting the environment [13]. Businesses should include the environmental costs incurred by business operation and policies of sustainable management in their financial statements to reflect actual profits [14].

Environmental issues will be inseparable from corporate financial accounting in the future [15]. Therefore, companies need to generate business operations in their financial statements. The environmental costs, sustainable business policies and other information should be disclosed, so that the financial situation is in line with the current state of the economy. The current accounting system has no complete norms, so environmental accounting (green accounting) was jointly proposed by the industry, government, and academia to understand companies' internal and external environmental costs. Through procedures such as identification, measurement and analysis, the consumption and benefits of the company's environmental capital can be reflected [16].

William Nordhaus, winner of the 2018 Nobel Prize in Economics, pioneered the research field of climate economics. Climate change, energy conservation, and the reduction of carbon emission have received worldwide attention. Nordhaus indicated in his research that climate change limits economic development. During the process of economic development, damage inflicted on the natural environment is a "negative externality." [17]. Nordhaus considered that the costs derived from negative externalities should be deducted from profits to obtain reasonable and realistic profits; in other words, negative externalities must be internalized. Therefore, Nordhaus proposed measures such as carbon emission rights trading or carbon tax to allow CO_2 generators to take on the responsibility for carbon emission, prompting governments and businesses to internalize external environmental costs [18].

At present, in order to solve the problem of externalities derived from corporate greenhouse gas emission, governments have applied "carbon pricing" to the international carbon emission trading market mechanism and also formulate carbon tax regulations to reduce greenhouse gas emission and achieve optimal pollution levels. Governments planning to move towards "carbon emission trading" or a "carbon tax" model in the future may change the business model if the regulations are implemented [19,20]. Therefore, it will be a challenge for enterprises to continue to operate and profit. The use of carbon pricing can be used as the basis for apportioning carbon costs per unit of product, which will have an impact on the cost accounting system for product cost attribution. Enterprises should set long-term reduction targets and follow the regulations to disclose carbon emission information in their financial statements.

With the rise of environmental awareness and the government's industrial development policy, enterprises have to cooperate with the laws and regulations in accordance with regulatory policy adjustments and corporate social responsibility requirements. Therefore, enterprises should build a low-energy and low-pollution operating system to enhance operational management efficiency and eliminate waste of resources, reduce energy consumption, upgrade technical equipment, develop renewable energy applications, and achieve long-term objectives. As a consequence, corporate carbon emission reduction has become an inevitable trend.

Sustainable development of the global economy is closely associated with environmental resources. Under regulations for energy conservation and carbon emission reduction, businesses should establish effective mechanisms for carbon emission management. The Carbon Disclosure 2017 Project Report indicated that approximately 1400 companies have adopted or will adopt internal carbon pricing. As the mechanisms for carbon emission reduction have become increasingly comprehensive, businesses should increase their capacity for carbon emission prediction and management. However, similar to how the organizational structure, management strategies, and performance of businesses change over time in accordance with their stage of growth, carbon emissions also vary. Therefore, this study adopted the carbon emission data disclosed by financial statements to construct a time series model to investigate the dynamic relationship between business growth and future carbon emission. The results are expected to supplement research on carbon emission reduction and management mechanisms as well as serve as a reference for businesses in developing effective carbon emission reduction strategies.

2. Literature Review

2.1. Development of Carbon Emission Reduction Mechanisms

From an economic perspective, it was emphasized that as long as property rights exist, a reasonable price can be negotiated on the market [21]. If pollution emissions are regarded as property rights, then society can trade pollution emissions on the market. Coase's theory was applied to the control and prevention of air and water pollution [22,23]. Similarly, carbon emission rights can also be traded. First of all, the total quantity control and trading system of carbon emission should be established. Transfers between emitting sources and emitting sources that have not reached their emission quota should also be allowed. With changes in demand and supply, carbon pricing will be generated, thereby introducing the market mechanism for solving the problems of global warming and sustainable development.

The Kyoto Protocol not only stipulates legally binding goals of carbon emission reduction and a cap for total emission but also allows the trading of CO_2 emission, the most prominent of all greenhouse gases, at the unit of CO_2 equivalent per ton. Three types of carbon emission reduction mechanisms have been developed. The first is joint implementation, referring to joint efforts in carbon emission reduction between developed countries. The second is the clean development mechanism, in which developed countries help developing countries meet their goals in carbon emission reduction by providing funds or technology. The third is emission trading, in which businesses or countries whose carbon emission exceeds their emission allowances can purchase allowances from other countries to set off their excess carbon emission. Vice versa, businesses or countries whose carbon emission is lower than their emission allowances can sell the remainder of their allowances. At present, the European Union Emission Trading System is the most active carbon trading market worldwide.

2.2. Predicting Performance in Carbon Emission According to Their Business Growth

Business growth can manifest in quantity, such as increases in output, revenue, and scale, as well as in quality, such as enhancement in production technology and efficiency [24,25]. Company size and employee number are significantly and positively correlated with revenue growth rate [26]. Using average business growth rate indices such as revenue, total asset growth, and increases in employee number to evaluate business growth may more accurately reflect the actual business growth [27]. The standard deviation of mean business growth rate can serve as a proxy variable of stable growth [28]. The standard deviation of the 3-year business growth rate was adopted as a proxy variable of stable growth [29], reporting that corporate governance exerts a moderating effect. Business growth is primarily subject to the influence of external factors, including economic outlook, political situation, trade agreements between countries, and exchange rate variations. However, internal and nonsystematic factors, such as deterioration in business managers' ability, reduction in output and product yield, aging of the production facility, and failure to improve production technology, can also have direct effects on business growth. In summary, business growth can be evaluated according to total asset growth rate, revenue growth rate, and employee growth rate, whereas the stability of business growth can be determined according to total asset growth rate, revenue growth rate, and standard deviation of mean employee growth rate.

Many studies have been conducted on the relationship between business growth and greenhouse gas emission. For example, the greenhouse gas emission data of companies within a supply chain was investigated, reporting that the data were positively correlated with a business's profitability [30]. Panel data was adopted to analyze the carbon emission data of 89 multinational corporations, revealing a correlation between business growth and variations in carbon emission [7]. Production scaling and growth of the labor force were identified as key factors that lead to increases in carbon emission [3]. Nonlinear grey multivariable models were adopted to predict China's carbon emission generated from fossil energy consumption, discovering that economic growth led to increased carbon emission [8]. Cointegration analysis was employed to explore the relationship between Malaysia's economy and carbon emission, revealing a stable long-term relationship among variables in the carbon emission model [31]. Based on the foregoing, the following hypothesis was formulated:

Hypothesis 1. *An enterprise's business growth has a stable and dynamic long-term relationship with its carbon emission performance in Taiwan.*

3. Methodology

This study employed the time series method to construct a forecast model for helping enterprises manage their carbon emission, reduce their expenditure on environmental protection measures, and fulfill their social responsibilities. Listed companies in Taiwan that have disclosed their carbon emission data and are certified by accountants at Taiwan Market Observation Post System were investigated. These companies investigated included high-tech, electronics, finance, department stores, and other manufacturing and service industries. Companies with incomplete data were excluded to avoid data bias. A total of 805 companies were chosen for this study and their business growth data retrieved from the Taiwan Economic Journal (TEJ) database offers the most timely updates on all the countries in Asia. The research period spans from 2012 to 2017.

3.1. Time Series Analysis

This study adopted the time series method for analysis. Through data collection across a single fixed time point, this method enables the observation of changes in different time points as well as the identification of dynamic relationship among time series variables and can be used to conduct forecasts based on historical data. In other words, past and present phenomena can indicate current and future development trends. Time series data are the observed values of variables obtained over time. Compared with cross-sectional data, time series data are organized sequentially according to the time at which they are recorded instead of being collected through random sampling. Furthermore, their order often conceals key information; for example, past events may influence future events, and a specific event that does not arouse immediate responses may have a delayed effect that can be observed at a later time. The time series analysis of this study includes: an Augmented Dickey-Fuller unit root test and Johansen cointegration test. According to Granger's representation theorem, if a cointegration relationship exists, then a corresponding dynamic error correction representative equation must exist. The changing relationship can be expressed by the vector error correction (VEC) model. The vector autoregressions (VAR) model is adopted to test the short-term dynamic relationship.

3.1.1. Unit Root Test

When performing a time series data analysis, a prerequisite is that the data must be stationary; only then can the data satisfy the hypothetical conditions of the statistics. Unit root tests can be used to test the constancy of the time series data. If a unit root is observed in a variable, then the said variable has a nonstationary times series. The Dickey-Fuller test was used to verify whether variables are stationary, and the residual term is white noise but often exhibited a significant self-correlation [32]. To resolve this problem, the addition of a lag operator for the difference of the independent variable to the right side of the original regression equation was proposed [33]. Their method is referred to as the augmented Dickey–Fuller (ADF) test and is the most widely adopted approach among the developed unit root tests. Before conducting the unit root test, the optimal number of lag periods must be determined. If the selected number of lag periods is excessively large, then the degree of freedom as well as the explanatory power will decrease. However, if the selected number of lag periods is too small, then the residual term cannot produce white noise, which leads to error in the estimated result. The selection of the optimal number of lag periods has a substantial influence on the research results. The Akaike information criterion (AIC) is the most commonly adopted standard for determining the optimal number of lag periods [34].

3.1.2. Cointegration Test

When an individual time series variable is nonstationary, the time series is restored to a long-term stable state if cointegration exists among the variables. Cointegration was defined as follows: If a time series variable can become stationary after undergoing dth-order difference, then this variable has $I(d)$ order of integration, and one set of vectors $Y_t = (Y_{1t}, Y_{2t}, \ldots Y_{nt})$ exists among the variables [35]. In other words, if two nonstationary variables can become stationary after forming a linear combination, then the two variables exhibit cointegration and maintain long-term stability and equilibrium. The use of maximum likelihood estimation (MLE) was proposed to test the cointegration vector [36], which can be used for determining the cointegration relationship among time series variables. Specifically, Johansen applies MLE to the Gaussian vector autoregressive model to derive an MLE equation. The theoretical foundation and actual tests are detailed as follows:

Assume the variable to be tested is Y_t and that its autoregressive equation modelVAR (k) is expressed as

$$Y_t = \mu + \prod_1 Y_{t-1} + \prod_2 Y_{t-2} + \ldots + \prod_k Y_{t-k} + \varepsilon_t \tag{1}$$

where Y_t is the coefficient matrix of $\prod_t = (n \times n)$, a dependent vector with n elements; $\varepsilon_t \sim iid(0, \Sigma_\varepsilon)$; and μ equals the constant vector of n × 1.

The VAR (k) of (1) after applying the first-order difference is

$$\Delta Y_t = \mu + \Gamma_1 \Delta Y_{t-1} + \Gamma_2 \Delta Y_{t-2} + \ldots + \Gamma_{k-1} \Delta Y_{t-k-1} + \Pi Y_{t-k} + \varepsilon_t \tag{2}$$

where $\Gamma_i = \sum_{j=1}^{i} \Pi_j - I, i = 1, 2, \ldots, k-1$, $\Pi = \sum_{j=1}^{k} \Pi_j - I$ and ΠY_{t-k} is the error correction term. ΠY_{t-k} represents the effect that the disequilibrium in the previous period has on the adjustment of the current period. This effect leads to the restoration of the long-term relationship in the system that is lost after applying the first-order difference. Π is the linear combination of all lag item coefficients and is referred to as the impact matrix. Its rank determines whether a cointegration vector exists between Y_{t-1} *and* Y_{t-k}; that is, the number of cointegration vectors can be identified according to rank. On the basis of the Π matrix characteristics, Johansen proposes using the trace test and maximum eigenvalue test to identify the cointegration vector and coefficient of cointegration. The null and opposite hypotheses are proposed as follows:

The null Hypothesis H_0: rank (Π) = r, with r cointegration vectors (i.e., r cointegration relationships at most).

The opposite Hypothesis H_1: rank (Π) = r + 1, with r + 1 cointegration vectors at most (i.e., having r + 1 cointegration relationships at most).

3.1.3. Vector Error Correction Model

If cointegration exists among variables of a multivariate model, then information can be missing when performing a VAR, resulting in estimation bias. To solve this problem, a VEC model based on cointegration was proposed to retrieve the long-term information missed during the difference operation by adding the error correction term from the previous period to the VAR model [35]. Thus, short-term adjustments of variables and long-term deviations from stability can both be reduced. Granger's representation theorem denotes that when cointegration is observed between variables, a corresponding VEC model must exist. Similarly, when two series exhibit cointegration, a VEC model can certainly be constructed to test the long-term equilibrium among variables. The model is estimated as follows:

$$Y_t = \beta_0 + \beta_1 X_t + u_t \tag{3}$$

$$e_t = \hat{Y}_t - \hat{\beta}_0 - \hat{\beta}_1 X_t \tag{4}$$

$$\Delta Y_t = \alpha + \sum_{i=1}^{n} \beta_i \Delta X_{t-i} + \sum_{i=1}^{n} \gamma_i \Delta Y_{t-i} + \lambda e_{t-1} + v_t \tag{5}$$

where e_{t-1} is long-term deviation from stability and λ is the coefficient of the error correction term, representing the adjustment speed of the long-term equilibrium error term. Significance of the coefficient of the error correction term indicates a notable error elimination effect, whereas nonsignificance indicates a poor adjustment effect. λe_{t-1} is the error correction term; it can indicate the disequilibrium between the actual and ideal values of each period, thereby enabling the short-term dynamic model to retain the long-term information between variables.

3.1.4. Vector Autoregressions Model

In a time series model, analysis was conducted using linear regression equations, which entailed the assumption of a causal relationship among variables. In ordinary regression equations, dependent variables were influenced by independent variables. However, in a macroeconometric model, dependent variables cannot be distinguished from independent variables; moreover, variables can either have interactions or have no causal relationships. To overcome this limitation, the VAR model which comprises multiple variables and multiple regression equations was proposed [37]. In this model, all variables are considered dependent variables and the optimal lag period of a variable is selected as the explanatory variable to allow the lag operator of the variable to include all relevant information. The generalized VAR model is proposed as follows:

$$Y_t = \alpha - \sum_{i=1}^{n} \beta_i Y_{t-i} + \varepsilon_t \tag{6}$$

where Y_t comprises the dependent variable vector of $(n \times 1)$, exhibiting a linear random process of joint-variation constancy. Y_{t-i} is the $(n \times 1)$ dependent variable vector consisting of the ith lag period of vector Y_t; α is the constant vector of $(n \times 1)$; β_i is the parameter matrix of $(n \times n)$ and can be viewed as having a conduction function; ε_t denotes the residual vector of $(n \times 1)$, which can be regarded as innovations; and Σ is the covariate matrix of $(n \times n)$.

3.2. Empirical Model

The cointegration model of business growth and their carbon emission performance was constructed as

$$\begin{aligned} &Y(TGHG, GHGG, GHGGR)_t = \alpha + \beta_1 Growth_t + \\ &\beta_2 GrowthSD_t + \beta_3 Age_t + \varepsilon_t \end{aligned} \tag{7}$$

The VEC model of business growth and their carbon emission performance was constructed as

$$\begin{gathered}\Delta Y(TGHG, GHGG, GHGGR)_{i,t} = \alpha + \beta \sum_{j=1}^{n} \Delta Y(TGHG, GHGG, GHGGR)_{i,t-j} \\ + \gamma_1 \sum_{j=1}^{n} \Delta Growth_{i,t-j} + \gamma_2 \sum_{j=1}^{n} \Delta GrowthSD_{i,t-j} + \gamma_3 \sum_{j=1}^{n} \Delta Age_{i,t-j} + \lambda CE_{t-1}\end{gathered} \quad (8)$$

where *CE* is the error correction term.

The VAR model of a business growth and its carbon emission performance was constructed as

$$\begin{gathered}\Delta Y(TGHG, GHGG, GHGGR)_{i,t} = \alpha + \beta \sum_{j=1}^{n} \Delta Y(TGHG, GHGG, GHGGR)_{i,t-j} \\ + \gamma_1 \sum_{j=1}^{n} \Delta Growth_{i,t-j} + \gamma_2 \sum_{j=1}^{n} \Delta GrowthSD_{i,t-j} + \gamma_3 \sum_{j=1}^{n} \Delta Age_{i,t-j}\end{gathered} \quad (9)$$

4. Results

4.1. Sample Description and Descriptive Statistics

In the present study, the statistical software Econometric Views was employed for data analysis; specifically, the time series function for panel data analysis was used. Table 1 presents variable descriptions and the results of descriptive statistics.

Table 1. Descriptive statistics and variable descriptions.

Variables	Mean	Maximum	Minimum	Standard Deviation	Definition
TGHG	910,494.612	30,147,226	22	3,471,130	Total carbon emission (ton); with natural logarithm taken
GHGG	15,447.235	1,897,893	−1,236,140	179,329.829	Annual increase of carbon emission (ton); with natural logarithm taken
GHGGR	4.041	884.991	−83.393	41.33	Annual increase rate of carbon emission (%)
Growth	2.692	107.228	−41.273	11.814	Growth rate (%) [1]
GrowthSD	8.854	98.263	0.212	9.595	Stability of growth [2]
Age	30.375	70	4	14.182	Years of establishment (year)

[1] Mean values of total asset growth rate, revenue growth rate, and employee growth rate [29]. [2] Standard deviation of the 3-year growth rate [29].

4.2. ADF Unit Root Test

The results of the ADF unit root test indicated that the raw values of all variables do not achieve a significance level of 1% (Table 2), revealing all variables that reject a unit root to be in stationary time series. Therefore, the data that did not undergo difference operation are adopted for time series analysis. Subsequently, MLE is adopted to perform a cointegration test [36].

4.3. Johansen Cointegration Test

MLE is conducted in this study to eliminate the autocorrelation of residual terms. Before conducting the cointegration test, AIC is adopted to determine the optimal number of lag periods. The smallest AIC value is selected as the optimal number of lag periods for cointegration (Table 3). All selected numbers of lag periods are 1. Under the linear trend assumption of variable cointegration, a trace statistic and a maximum eigenvalue test are conducted to determine the number of cointegration vectors. Table 4 presents the results of the cointegration test between an enterprise's business growth and its carbon emission performance. Business growth dynamics and carbon emission performance are verified to exhibit cointegration, suggesting stable equilibrium in long-term dynamics and therefore indicating that business growth can serve as a reference variable for predicting carbon emission performance. Table 5 presents a standardized combination of equations based on cointegration test results. Decreases in the stability of business growth lead to increases in growth rate, and enterprises that have been established for a relatively long period of time exhibit positive increases in the annual increase as well as annual increase rate of carbon emission.

Table 2. ADF unit root test (raw values).

Carbon Emission Performance			
Variables	**TGHG**	***GHGG***	**GHGGR**
Intercept	−6.152 ***	−10.215 ***	−16.158 ***
Trend and intercept	−9.827 ***	−10.262 ***	−16.141 ***
Business Growth Variable			
Variables	Growth	Growth SD	Age
Intercept	−22.251 ***	−20.554 ***	−4.698 ***
Trend and intercept	−22.382 ***	−20.831 ***	−6.075 ***

(1) *** indicates statistical significance at the 1% level. (2) Significance levels of the *intercept* are 10%, 5%, and 1%, and the critical values are −2.57, −2.86, and −3.44. 3. The significance levels of *trend and intercept* are 10%, 5%, and 1%, and the critical values are −3.13, −3.41, and −3.97.

Table 3. Cointegration test for the optimal number of lag periods.

	Criteria	**Lag 1**	**Lag 2**	**Lag 3**	**Lag 4**
Business growth and total carbon emission	AIC	25.658 *	25.66	25.696	25.712
Business growth and annual increase of carbon emission	AIC	28.596 *	28.625	28.65	28.656
Business growth and annual increase rate of carbon emission	AIC	32.01 *	32.039	32.038	32.058

* indicates minimum AIC and the optimal number of lag periods.

Table 4. Results of the cointegration test between an enterprise's business growth and its carbon emission performance.

Trace Statistic				
TGHG	**GHGG**	**GHGGR**	**5% Critical Value**	**H0**
577.428 **	692.247 **	709.508 **	54.079	$r \leqq 0$
322.782 **	448.415 **	448.795 **	35.192	$r \leqq 1$
137.129 **	233.916 **	232.392 **	20.261	$r \leqq 2$
44.968 **	48.945 **	49.576 **	9.164	$r \leqq 3$
Maximum Eigenvalue Test				
TGHG	**GHGG**	**GHGGR**	**5% Critical Value**	**H0**
254.645 **	243.832 **	260.713 **	28.588	r ≦ 0
185.653 **	214.498 **	216.403 **	22.299	r ≦ 1
92.16 **	184.971 **	182.815 **	15.892	r ≦ 2
44.968 **	48.945 **	49.576 **	9.164	r ≦ 3

** indicates statistical significance at the 5% level.

Table 5. Standardized cointegration equations of an enterprise's business growth and its carbon emission performance.

Variables	TGHG	GHGG	GHGGR
α	27.749 ** (9.02)	−263.822 ** (−6.313)	−42.861 ** (−5.385)
Growth	−1.82 (−1.405)	24.476 ** (13.851)	4.716 ** (14.059)
GrowthSD	−0.84 (−1.505)	10.931 ** (5.271)	1.045 ** (2.646)
AGE	−0.176 (1.25)	3.421 ** (3.208)	0.835 ** (4.115)

** indicates statistical significance at the 5% level.

4.4. *Vector Error Correction (VEC) Model Analysis*

Table 6 presents the VEC analysis results. The annual increase in amount and rate of carbon emission obtained relatively large adjustment coefficients of the error correction term. When the annual increase rate and enterprise's business growth deviate from the cointegration equation of long-term equilibrium, the annual increase rate is adjusted by 27% in the short term, signifying a return to long-term equilibrium, whereas the annual increase is adjusted by an increase of 0.4%. Regarding the short-term and mid-term dynamic adjustments of long-term equilibrium for business growth and carbon emission performance in the VEC model, the total amount of carbon emission is affected by the stability of growth in the previous period; the annual increase of carbon emission is affected by the annual increase of carbon emission and years of establishment in the previous period; and the annual rate of increase of carbon emission is affected by the annual rate of increase and the growth rate in the previous period.

Table 6. VEC analysis of an enterprise's business growth and carbon emission performance.

TGHG		GHGG		GHGGR	
Variables	**Coefficient**	**Variables**	**Coefficient**	**Variables**	**Coefficient**
α	−0.013 (−0.182)	α	−0.009 (−0.026)	α	0.014 (0.007)
ΔTGHG (−1)	−0.019 (−0.47)	ΔGHGG (−1)	−0.397 ** (−10.656)	ΔGHGGR (−1)	−0.395 ** (−10.034)
ΔGrowth (−1)	−0.013 (−1.927)	ΔGrowth (−1)	0.0001 (0.001)	ΔGrowth (−1)	−0.863 ** (−5.066)
ΔGrowthSD (−1)	0.016 ** (2.228)	ΔGrowthSD (−1)	0.063 (1.805)	ΔGrowthSD (−1)	−0.015 (−0.085)
ΔAGE (−1)	−0.005 (−0.561)	ΔAGE (−1)	−0.094 ** (−1.999)	ΔAGE (−1)	−0.024 (−0.101)
CE (−1)	0.0002 (0.054)	CE (−1)	0.004 ** (2.89)	CE (−1)	−0.27 ** (−6.819)
Adj.R^2	0.005	Adj.R^2	0.174	Adj.R^2	0.342
F-stat	1.664	F-stat	26.944	F-stat	64.796

** indicates statistical significance at the 5% level.

4.5. *Vector Autoregressions (VAR) Analysis*

We adopted the VAR model to investigate the short-term dynamic relationship between an enterprise's business growth and its carbon emission performance; the results are presented in Table 7. The total amount of carbon emission is affected by the total amount of carbon emission in the previous period, the stability of growth, and years of establishment in the short term; the annual increase in carbon emission is affected by the short-term annual increase in carbon emission during the previous period; and the amount of carbon emission is affected by the annual rate of increase in the previous period and years of establishment in the short term.

Table 7. VAR analysis of an enterprise's business growth and carbon emission performance.

TGHG		GHGG		GHGGR	
Variables	**Coefficient**	**Variables**	**Coefficient**	**Variables**	**Coefficient**
α	1.865 ** (6.129)	α	0.171 (0.205)	α	−2.651 (−0.595)
ΔTGHG (−1)	0.773 ** (29.115)	ΔGHGG (−1)	0.192 ** (4.722)	ΔGHGGR (−1)	−0.014 (−0.366)
ΔGrowth (−1)	−0.011 (−1.759)	ΔGrowth (−1)	−0.032 (−1.089)	ΔGrowth (−1)	0.051 (0.327)
ΔGrowthSD (−1)	0.021 ** (2.611)	ΔGrowthSD (−1)	0.007 (0.205)	ΔGrowthSD (−1)	−0.124 (−0.648)
ΔAGE (−1)	0.019 ** (1.971)	ΔAGE (−1)	0.008 (0.364)	ΔAGE (−1)	0.253 ** (2.116)
Adj.R^2	0.609	Adj.R^2	0.029	Adj.R^2	0.002
F-stat	240.105	F-stat	5.707	F-stat	1.319

** indicates statistical significance at the 5% level.

5. Conclusions

Under the Paris Agreement, consensus has been reached worldwide regarding the need for developing carbon emission reduction strategies and the potential benefits of carbon neutrality. Enterprises can save their emission allowances by implementing emission reduction measures and selling their remaining allowances on the carbon trading market to obtain additional income. If an enterprise's carbon emission reduction measures fail, then it must purchase carbon credits to compensate for its excess emission, resulting in increased operating costs and risks. Therefore, enterprises should establish an effective forecasting model to obtain an estimate of their carbon emission. The purpose of this research is to explore the dynamic correlation between an enterprise's business growth and carbon emission performance, and to construct a time series model to predict the growth of an enterprise's carbon emission. This research will help enterprises to strengthen their own carbon emission forecasting and management capabilities to achieve the goal of carbon neutrality through the carbon exchange.

The results from this study indicated stable cointegration between an enterprise's business growth and carbon emission performance. An enterprise's business growth can serve as a reference variable for predicting carbon emission performance. In terms of VEC analysis, when the annual rate of increase in carbon emission reduces excessively compared with the long-term trend, substantial adjustments may be made in the short term, leading to fluctuations and instability. VAR analysis reveals that the total amount of carbon emission is affected by the total amount of carbon emission in the previous period, the stability of growth, and years of establishment in the short term, and that the annual rate of increase in carbon emission is affected by the years of establishment in the previous period.

According to the research results, there are two benefits to reducing carbon emissions by enterprises. First, since the risk of climate change has a considerable influence on business operations, enterprises need to check and identify the carbon emissions produced by different internal production activities, and consider environmental costs among the items included in the operating costs. Then, when the price of the carbon rights trading market fluctuates, enterprises can achieve the goal of reducing emissions through the management of carbon emission, and minimize the impact of environmental costs on corporate profits and shareholders' equity. Second, in accordance with the amendments to the provisions of the company law, enterprises should disclose their greenhouse gas emissions in their financial reports, so that stakeholders can better understand the enterprise's investment in energy saving and carbon reduction activities. This will help to enhance the company's image and sustainable development, fulfill its social responsibility and obligation, promote the positive transformation of enterprises and stimulate the development of green industries.

This study investigated the relationship between an enterprise's business growth and its carbon emission performance, thereby supplementing the deficiency in existing literature on enterprises' carbon emission. This study also constructed a forecast model using the time series method to help enterprises manage their carbon emission and achieve carbon neutrality.

This paper still has some limitations. First, this study identifies an enterprise's operating dynamics from variables such as business growth rate; however, other items on financial statements may also have comparable value for predicting carbon emission performance. Future researchers are advised to conduct analysis using different variables for the enhancement of prediction accuracy. Second, the present research spans six years, from 2012 to 2017. The results can be interpreted as being attributable to other short-term factors; future researchers can extend the research period in order to evaluate this possibility. The disclosure of carbon emission data is currently voluntary, and numerous enterprises have not revealed their carbon emission data. Therefore, sample size is one of the limitations of this study. Legal regulations should be imposed to render the disclosure of carbon emission data compulsory, thus allowing future researchers to conduct in-depth investigations with larger sample sizes.

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