Associate Professor Wang Tsung-LI, PhD
E-mail: wsteven@stu.edu.tw
Department of Market Management
Shu-Te University of Taiwan
Associate Professor Lin Hung-PIN, PhD
E-mail: lhp0606@stu.edu.tw
Department of Leisure & Tourism Management
Shu-Te University of Taiwan
Associate Professor Sung Yu-CHI, PhD
E-mail: yuchi@stu.edu.tw
Department of Leisure & Tourism Management
Shu-Te University of Taiwan

THE DYNAMIC ANALYSIS AMONG ENERGY CONSUMPTION, TOURIST EXPANSION AND ECONOMIC GROWTH ON CARBON DIOXIDE EMISSIONS

Abstract. *This study constructs both short and long run theoretic and empirical dynamic model by using the co-integration and causality tests among energy consumption, tourist expansion, economic growth, and CO_2 emissions. The following main findings were obtained: (1) the dynamic theoretical result shows that the effect of long run energy consumption and tourism expansion is greater than short run when CO_2 emissions increases. (2) A short-run unidirectional causality exists from CO_2 emissions to inbound tourist arrivals, and energy consumption. (3) A feedback causality relationship between economic growth and inbound tourist arrivals suggests that compared to outbound travelers, inbound tourist arrivals have a greater impact on economic growth. (4) A unidirectional causality running from economic growth to both CO_2 emissions and inbound tourist arrivals indicates a growth-led hypothesis between them. (5) A short-run unidirectional causality from energy consumption to CO_2 emissions, tourism expansion, and economic growth exists, along with a feedback causality relationship between energy consumption and CO_2 emissions both in the short and long run. This implies that any conservation policies regarding tourism and energy programs may not only decrease CO_2 emissions but also deter economic growth. Thus, suitable policies associated with cleaner energy programs in tourism activities and transportation are required to balance the conflicts between emissions and economic growth.*

Keywords*: Co-integration; Economic Growth; Tourism Expansion; Inbound Tourist Arrivals; Granger Causality.*

JEL Classification: C12; O11; Q43; Z32

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1. Introduction

Over the past few decades, global warming and climate change have become significant environmental threats for the modern era, and issues related to greenhouse gases (GHGs) are heavily debated among researchers, governments, and policy makers. Introduced in 1996, the Integrated Pollution Prevention and Control (IPPC) Directive indicated that as the main sources of anthropogenic GHGs, carbon dioxide (CO_2) emissions are responsible for more than 60% of the green houses effect, which has contributed to the upsurge in global temperatures and climate change (Ozturk and Acaravci, 2010). As a high-income developing country, Taiwan is recognized as one of the four Asian Tigers due to its economic miracle over the last three decades. Similar to other developing countries, energy consumption in Taiwan not only stimulates economic growth but also raises emissions. Its per capita emission has reached 4.6 ton of oil equivalent (toe), which is 60% higher than the European average (2.9 toe in 2009). This is still growing faster than most other advanced economies. According to a report by the Environmental Protection Administration (EPA) in 2019, energy consumption resulted in 258.72 million metric tons of carbon emissions and Taiwan ranked 5th in terms of the level of per capita carbon emissions, ahead of Japan (6th) and China (10th).

The environmental Kuznet curve (EKC) hypothesis suggested by Grossman and Krueger (1995) has been widely used in the literature to explain environmental deterioration. The EKC designates a positive relationship between a country's economic performance and its level of CO_2 emissions. By integrating energy consumption with the EKC, Alam et al. (2011) and Gökha (2022) revealed that energy use is a crucial factor in CO_2 emissions and suggested that conserving energy consumption may be a way of managing the emissions problem. Lotfalipour et al. (2010) suggested that due to the significant relationship among CO_2 emissions, energy consumption, and economic growth, the reduction of energy consumption at the expense of economic growth may not be a desirable outcome. How to formulate appropriate policies that maintain a balance among those involving factors has therefore become a crucial topic for government and policy makers.

Several empirical studies have attempted to unravel factors that determine the level of emissions to generate favorable policies to improve environmental quality. However, tourism expansion has been noticeably overlooked in emissions models. There is an increasing and generally accepted belief that tourism expansion, as a substitutive form of export, not only accumulates foreign reserves but also provides job opportunities and extra sources of income, and hence, promotes economic growth (Balaguer and Cantavella, 2002). According to the World Travel and Tourism Council's latest annual research in 2019, the direct, indirect, and induced impact of travel and tourism contributed US$ 8.9 trillion to global GDP, comprised 10.3% of global GDP, created 330 million jobs, and provided one in ten jobs around the world. However, beyond the positive impact on economic and employment performance, tourism activities have posed a severe challenge for the environment. Significant challenges in tourism expansion may arise from its contribution to environmental degradation and climate responsiveness. Such expansion is itself both a possible victim of global warming and a contributor, accounting for considerable amounts of carbon emissions. It currently accounts for over 5.5% of total emissions and CO_2 emissions from global tourism activities are predicted to increase by 30% by 2035 (Othman et al., 2012). As the representative country, Taiwan appears to be an interesting case. Despite experiencing impressive progress in tourism expansion and emissions over the last three decades, the country is fast becoming a source of rising trends of tourism and emissions. Transportation related to tourism activities has contributed a record figure of 1.38 mega tons, or 92% of the pollutant emission loads of carbon monoxide, carbon dioxide, and hydrocarbons in 2012 (EPA, 2012).

The importance of tourism expansion as a factor of economic growth has grown and numerous studies have examined the causality relationship between tourism expansion and economic performance. However, many tourism researchers are yet to take the linkage between tourism and environmental degradation sufficiently seriously. We attempt to fill this gap by adding energy consumption as a potential determinant of environmental degradation. Furthermore, we distinguish tourism expansion from inbound tourist arrivals and outbound travelers to investigate the dynamic interactions of energy consumption, tourism expansion, and economic growth with emissions.

The main purpose of this study is to investigate the short and long run causality between energy consumption, tourism expansion, economic growth, and CO_2 emissions in Taiwan for the period 1980–2019 on the basis of the theoretical model we constructed. The contribution of this research is twofold. First, we integrate the pollution (CO_2 emissions) growth and tourism expansion into a single framework. This enables us to examine the negative impacts of tourism (pollution) with its apparently positive impact (economic growth) in the assimilated framework, while also considering the influential variable of energy consumption. Second, most of the existing literature on tourism-led causality analysis uses the sum of the data of international tourist arrivals. However, the influence of major tourism expansion on the country's economic performance may be ignored, leading to ambiguous empirical results. To improve the empirical reliability of our findings, we distribute tourism expansion to inbound tourist arrivals and outbound traveler receipts to shirk the problem of empirical homogeneity. Third, the latest data in this study were from 2019, prior to the COVID-19 pandemic. Thus, the empirical results may provide clues for extended research, especially since Taiwan is recognized as a country in which COVID-19 has had a relatively small impact. The remainder of this paper proceeds as follows. Section 2 conducts the short and long run theoretical model dynamically, and Section 3 and 4 analyze the data, methodology, and causality results. The empirical findings and policy implications are provided in section 5.

2. Theoretical l analysis

2.1 Model

Assuming that the economy system consists of a representative household and a government, and the government collects an income tax from the household to finance the tourism expansion (inbound and outbound tourism arrivals in domestic country). The home country's objective for the representative household is to maximize the discounted sum of future instantaneous utility function

$$Max \int_0^\infty U(E, M, CO_2)\, e^{-\rho t} dt \,, \tag{1}$$

where ρ is the subjective discount rates, E denotes the household's energy consumption. M and CO_2 are tourism expansion and CO_2 emissions stocks, respectively. Here, we follow Van der Ploeg and Zeeuw (1990) and assume that the instantaneous utility function is specified as the separable energy consumption, tourism, and CO_2 emissions stocks,

$$U(E, M, CO_2) = u(E) + \phi(M, CO_2) \,, \tag{2}$$

where $u_E > 0$, $u_{EE} < 0$, $\phi_M > 0$, $\phi_{CO_2} < 0$, $\phi_{MM} < 0$, $\phi_{CO_2 CO_2} > 0$. In Eq. (2), we have positive utility from energy consumption, E (i.e $u_E > 0$). $\phi_M > 0$ means that tourism expansion is beneficial to the household and $\phi_{CO_2} < 0$ implies the CO_2 emissions has negative effect on household's utility.

The accumulation of tourism expansion is

$$\dot{M} = \theta g - \delta M \,, \tag{3}$$

where g is the government spending, θ is the parameter for the tourism expansion stock depended by the government spending. For simplicity, we define θ as government's funding rate in the following analysis. δ is the depreciation rate of the tourism expansion. The economic performance y is produced to use a stock of productive capital k followed by a diminishing return

$$y = f(k)\,; \qquad f^{'} > 0, f^{''} < 0 \,, \tag{4}$$

, and the government collects its income tax revenue to finance the spending from the tourism expansion

$$\tau f(k) = g \,. \tag{5}$$

From Eqs. (4) and (5), we will have the capital formation

$$\dot{k} = (1-\tau) f(k) - E - \delta k \,, \tag{6}$$

where an "overdot" denotes the rate of change with respect to time. τ is a flat-rate of income tax ($\tau \in [0,1]$), and δ is the depreciation rate. The total stock of tourism expansion (ω) can be defined as

$$\omega = k + M \,. \tag{7}$$

Base on Eqs. (3), (6) and (7), and total differentiate Eq. (7) with time, we have the asset formation

$$\dot{\omega} = [1-\tau(1-\theta)]\, f(k) - E - \delta\,\omega. \tag{8}$$

From Eqs. (2), (7) and (8), the dynamic optimization of the discounted Hamiltonian function H can be shown as

$$H = u\,(E) + \phi\,(M\,, CO_2) + \lambda_1\{[1-\tau(1-\theta)]\, f(k) - E - \delta\omega\} + \lambda_2(\omega - k - M)\,, \tag{9}$$

where λ_1 is the shadow price of total asset, and λ_2 is the multiplier for the add-up condition or the identity of the total asset. The optimum conditions necessary for the representative household are

$$u_E = \lambda_1\,, \quad (10); \qquad \phi_M\,(M\,, CO_2) = \lambda_2\,, \tag{11}$$

$$\lambda_1[1-\tau(1-\theta)]\, f^{'}(k) = \lambda_2\,, \quad (12); \qquad -\delta\,\lambda_1 + \lambda_2 = -\dot{\lambda}_1 + \lambda_1\,\rho\,, \tag{13}$$

$$\dot{\omega} = [1-\tau(1-\theta)]\, f(k) - K - \delta\,\omega, \quad (14); \qquad \lim_{t\to\infty} \lambda_1\,\omega\, e^{-\rho\, t} = 0 \tag{15}$$

where Eq.(15) is the usual terms of transversality conditions. From Eqs. (10) to (14), we have the solutions denoted as $\lambda_1(\,E\,,\,\omega, CO_2, \tau, \theta)$, $M(\,E\,,\,\omega, CO_2, \tau, \theta)$ and $k(\,E\,,\,\omega, CO_2, \tau, \theta)$, respectively. The following necessary condition for optimality can be derived by differentiating Eq.(10) with respect to time and equating it to Eq. (13) and (14), thus we have

$$\dot{E} = \frac{u_E}{u_{EE}}\left\{\rho + \delta - [1-\tau(1-\theta)]\, f^{'}(k(\,E\,,\omega\,, CO_2, \tau, \theta))\right\}, \tag{16}$$

$$\dot{\omega} = [1-\tau(1-\theta)]\, f\,(k(\,E\,,\omega, CO_2, \tau, \theta)) - E - \delta\,\omega. \tag{17}$$

Eqs. (16) and (17) can be simplified as

$$\dot{E} = J(\,E\,,\,\omega, CO_2, \tau, \theta)\,, \quad (18); \qquad \dot{\omega} = F(\,E\,,\,\omega, CO_2, \tau, \theta)\,. \tag{19}$$

From Eqs. (18) and (19), we have the following properties

$J_E > 0,\;\; J_\omega < 0,\;\; J_{CO_2} > 0,\;\; J_\tau > 0,\;\; J_\theta < 0$; and

$F_E < 0,\;\; F_\omega < 0,\;\; F_{CO_2} < 0,\;\; F_\tau < 0,\;\; F_\theta > 0$.

By Eqs. (18) and (19), in order to characterize trajectories on a neighborhood of the steady state, we reduce the linear expansions of Eqs. (18) and (19) as

$$\begin{bmatrix} \dot{E} \\ \dot{\omega} \end{bmatrix} = \begin{bmatrix} J_E & J_\omega \\ F_E & F_\omega \end{bmatrix} \begin{bmatrix} E - \hat{E} \\ \omega - \hat{\omega} \end{bmatrix} + \begin{bmatrix} J_x \\ F_x \end{bmatrix} (x - x_0),$$

where $x \in (CO_2, \tau, \theta)$. At steady–growth equilibrium, the economy system is characterized by $\dot{E} = \dot{\omega} = 0$, and $\hat{E}$ and $\hat{\omega}$ are their stationary values, respectively. The general solution for E_t and ω_t in the dynamics system can be solved by

$$E_t = \hat{E}(\,CO_2\,,\,\tau, \theta) + \psi_1 \exp\,(s_{1t}) + \psi_2 \exp\,(s_{2t})\,, \tag{20}$$

$$\omega_t = \hat{\omega}(CO_2, \tau, \theta) + \left[(s_1 - J_E)/J_\omega\right]\psi_1 \exp(s_{1t}) + \left[(s_2 - J_E)/J_\omega\right]\psi_2 \exp(s_{2t}) \,, \quad (21)$$

where ψ_1 and ψ_2 are unknown parameters determined by the transversality condition, and the subscript t refers to time. The dynamic behavior of the system can be described by means of a phase diagram. From Eq. (18) and (19), the slopes of loci $\dot{c} = 0$ and $\dot{\omega} = 0$ are:

$$\frac{\partial E}{\partial \omega}\bigg|_{\dot{E}=0} = -\frac{J_\omega}{J_E} > 0 \,, \quad (26); \qquad \frac{\partial E}{\partial \omega}\bigg|_{\dot{\omega}=0} = -\frac{F_\omega}{F_E} < 0 \,. \quad (22)$$

2.2. Dynamic analysis of energy consumption and tourism expansion

In this section, we attempt to examine the dynamic impact of CO_2 emissions on energy consumption and tourism expansion in the short and long run, respectively.

2.3 An increase of CO_2 emissions in the short run

In Figure 1, the initial equilibrium, where $\dot{E} = 0(CO_2)_0$ intersects $\dot{\omega} = 0(CO_2)_0$, is established at Q_0, and the initial tourism expansion stock and energy consumption are ω_0 and E_0, respectively. Following a rise in CO_2 emissions, the $\dot{E} = 0(CO_2)_0$ locus shift rightwards to $\dot{E} = 0(CO_2)_1$ and the $\dot{\omega} = 0(CO_2)_0$ locus shift downwards to $\dot{\omega} = 0(CO_2)_1$. Figure 1 also depicts that only $ss(CO_2)_1$ line will reach the new short run status Q_{short}. As a result, at the time of CO_2 emissions increases, the energy consumption will correspondingly jump from Q_0 to Q_{0^+}, and the economy will move from Q_{0^+} along the $ss(CO_2)_1$ line towards the short run jump point Q_{short}. To be precise, we depict the path as $Q_0 \rightarrow Q_{0^+} \rightarrow Q_{short}$ during the convergent process in the short run. From 0^+ to the time after that, energy consumption falls to E_s and still lesser than the initial value E_0, and the tourism expansion stock are accumulated to the new stock value ω_s, respectively.

2.4 An increase of CO_2 emissions in the long run

Following the same consideration, during the instant of an permanent increase in CO_2 emissions, the energy consumption will move from Q_{A^+} to Q_{short} and then along the $ss(CO_2)_1$ line towards the steady-state point Q_{long}. To be precise, we depict the long run procedure of location as $Q_0 \rightarrow Q_{A^+} \rightarrow Q_{short} \rightarrow Q_{\mathrm{long}}$, and comparing with the short run in the steady state, the long run energy consumption and tourism expansion stock is larger than the short run status when CO_2 emissions increases.

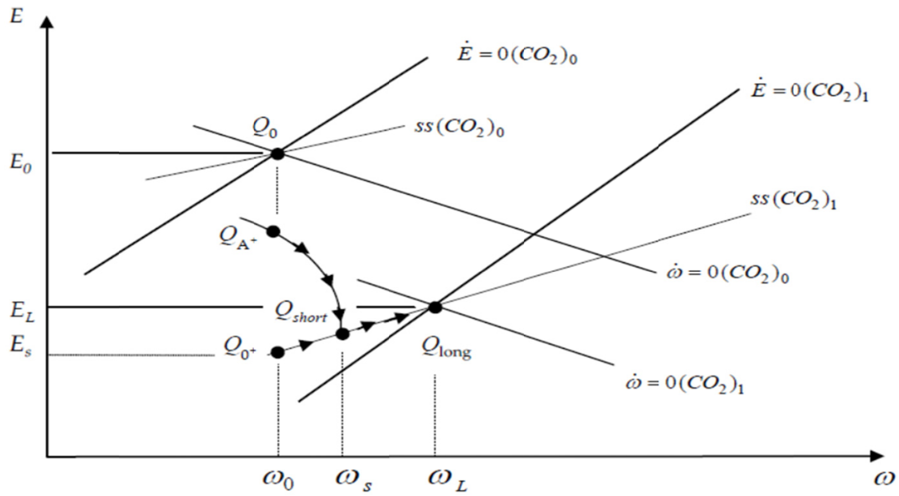

Figure 1. The increase of CO_2 emissions in the short and long run dynamic path

3. Empirical analysis

3.1 Model

This study investigates the main relationship between CO_2 emissions and economic growth in Taiwan while controlling other variables. The general empirical equation takes the following logarithmic form:

$$ln(CO_2)_t = \beta_1 + \beta_2\, ln\,(\omega_{IT})_t + \beta_3\, ln\,(\omega_{OT})_t + \beta_4\, ln\, Y_t + \beta_5\, ln\, E_t + \varepsilon \qquad (23)$$

where $(CO_2)_t$ is the CO_2 emissions measured in kt per capita, $(\omega_{IT})_t$ is inbound tourist arrivals to Taiwan, $(\omega_{OT})_t$ is outbound traveler receipts, Y_t represents the economic growth proxy by real GDP per capita, E_t is the total energy consumption per capita, and ε_t is the error term. The variables were collected from the *World Bank*, *Energy Information Administration Databas*e, and the data on inbound and outbound tourists were extracted from the *Tourism Statistics Database* of the *Taiwan Tourism Bureau* for the period 1980–2019.

3.2 ARDL bounds test approach

The first step of the following empirical analysis is testing the stationarity of the variables. By considering the first difference in Eq. (28), the augmented Dickey–Fuller (ADF) test (1979) is introduced to test the stationarity of variables by investigating the existence of a unit root. Non-stationary variables may result in a spurious regression (Granger and Newbold, 1974). The null hypothesis of the series has a unit root that is tested against the alternative of stationarity using the following regression:

$$\Delta x_t = \beta_0 + \beta_1 t + \beta_2 x_{t-1} + \sum_{i=1}^{n} \Delta x_{t-1} + \varepsilon_t \qquad (24)$$

where Δx_t is the first difference operator, and ε_t is the white noise of autocorrelation. β represents the *t*-statistic coefficient. The null hypothesis is that x_t is a non-stationary series and is rejected when β_2 is in a negative term ($H_0 : \beta_2 = 0$; $H_1 : \beta_2 < 0$). The Akaike information criterion (AIC) rule is used to select the lags of optimal number (n). After testing the stationarity of the series, the autoregressive distributed lag (ARDL) bounds testing approach developed by Pesaran and Shin (2001) is applied to determine the existence of a co-integrating relationship among variables. This approach has some advantages over the alternatives. First, it is applicable regardless of whether the specified regressions are integrated as $I(0)$ or $I(1)$ or a mixture of both. Second, both the short- and long-run effects of independent variables are assessed almost instantaneously. Thus, even though the sample size is small, this approach has better properties to avoid low power in detecting co-integration (Narayan, 2005). Finally, it assumes that all variables are endogenous by providing a specific unbiased estimate and practical *t*-statistic. Thus, the problem of endogeneity in the regression coupled with the other methods in the long run can be ignored (Harris and Sollis, 2003). We construct four models to examine the long-run co-integration relationship among CO_2 emissions, tourism expansion, energy consumption, and economic growth. The unrestricted error correction models of ARDL formation are expressed as follows:

$$\begin{aligned}\Delta ln(CO_2)_t = {} & \beta_{10} + \sum_{i=1}^{k} \gamma_{11} \Delta ln(CO_2)_{t-i} + \sum_{i=0}^{k} \gamma_{12} \Delta ln(\omega_{IT})_{t-i} + \sum_{i=0}^{k} \gamma_{13} \Delta(\omega_{OT})_{t-i} \\ & + \sum_{i=0}^{k} \gamma_{14} \Delta Y_{t-i} + \sum_{i=0}^{k} \gamma_{15} \Delta E_{t-i} + \tau_1 ln(CO_2)_{t-1} + \tau_2 ln(\omega_{IT})_{t-1} \\ & + \tau_3 ln(\omega_{OT})_{t-1} + \tau_4 lnY_{t-1} + \tau_5 ln E_{t-1} + \varepsilon_t \end{aligned} \qquad (25)$$

$$\begin{aligned}\Delta ln(\omega_{IT})_t = {} & \beta_{20} + \sum_{i=1}^{k} \gamma_{21} \Delta ln(\omega_{IT})_{t-i} + \sum_{i=0}^{k} \gamma_{22} \Delta ln CO_2 + \sum_{i=0}^{k} \gamma_{23} \Delta(\omega_{OT})_{t-i} \\ & + \sum_{i=0}^{k} \gamma_{24} \Delta Y_{t-i} + \sum_{i=0}^{k} \gamma_{25} \Delta E_{t-i} + \tau_1 ln(CO_2)_{t-1} + \tau_2 ln(\omega_{IT})_{t-1} \\ & + \tau_3 ln(\omega_{OT})_{t-1} + \tau_4 lnY_{t-1} + \tau_5 ln E_{t-1} + \varepsilon_t \end{aligned} \qquad (26)$$

$$\begin{aligned}\Delta ln((\omega_{OT}))_t = {} & \beta_{30} + \sum_{i=1}^{k} \gamma_{31} \Delta ln((\omega_{OT}))_{t-i} + \sum_{i=0}^{k} \gamma_{32} \Delta ln CO_2 + \sum_{i=0}^{k} \gamma_{33} \Delta(\omega_{IT})_{t-i} \\ & + \sum_{i=0}^{k} \gamma_{34} \Delta Y_{t-i} + \sum_{i=0}^{k} \gamma_{35} \Delta E_{t-i} + \tau_1 ln(CO_2)_{t-1} + \tau_2 ln(\omega_{IT})_{t-1} \\ & + \tau_3 ln(\omega_{OT})_{t-1} + \tau_4 lnY_{t-1} + \tau_5 ln E_{t-1} + \varepsilon_t \end{aligned} \qquad (27)$$

$$\Delta\, ln\,(Y)_{\,t} = \beta_{40} + \sum_{i=1}^{k} \gamma_{41}\,\Delta\, ln\,(Y)_{t-i} + \sum_{i=0}^{k} \gamma_{42}\,\Delta\, ln\, CO_2 + \sum_{i=0}^{k} \gamma_{43}\,\Delta\,(\omega_{IT})_{\,t-i}$$
$$+ \sum_{i=0}^{k} \gamma_{44}\,\Delta(\omega_{OT})_{t-i} + \sum_{i=0}^{k} \gamma_{45}\,\Delta\, E_{t-i} + \tau_1\, ln\,(CO_2)_{\,t-1} + \tau_2\, ln(\omega_{IT})_{\,t-1}$$
$$+\tau_3\, ln(\omega_{OT})_{\,t-1} + \tau_4\, lnY_{t-1} + \tau_5\, ln\, E_{\,t-1} + \varepsilon_t \tag{28}$$

$$\Delta\, ln\,(E)_{\,t} = \beta_{50} + \sum_{i=1}^{k} \gamma_{51}\,\Delta\, ln\,(E)_{t-i} + \sum_{i=0}^{k} \gamma_{52}\,\Delta\, ln\, CO_2 + \sum_{i=0}^{k} \gamma_{53}\,\Delta\,(\omega_{IT})_{\,t-i}$$
$$+ \sum_{i=0}^{k} \gamma_{54}\,\Delta(\omega_{OT})_{t-i} + \sum_{i=0}^{k} \gamma_{55}\,\Delta\, Y_{t-i} + \tau_1\, ln\,(CO_2)_{\,t-1} + \tau_2\, ln(\omega_{IT})_{\,t-1}$$
$$+\tau_3\, ln(\omega_{OT})_{\,t-1} + \tau_4\, lnY_{t-1} + \tau_5\, ln\, E_{\,t-1} + \varepsilon_t \tag{29}$$

where Δ is the first difference operator with n lags, ε_t is the error term, γ_1, γ_2, γ_3, and γ_4 are the shot-run parameters and τ_1, τ_2, τ_3, and τ_4 specify the long-run dynamics coefficients. Moreover, to avoid the possibility of heteroscedasticity all the variables are taken in natural logarithm (*ln*). To examine the presence of a co-integration relationship, the joint *F*-statistic on the lagged terms in Eqs. (25)–(29) for the null hypothesis of no co-integration is $H_0 : \tau_1 = \tau_2 = \tau_3 = \tau_4 = \tau_5 = 0$ against the alternative hypothesis of co-integration, $H_1 : \tau_1 \neq \tau_2 \neq \tau_3 \neq \tau_4 \neq \tau_5 \neq 0$. There are two sets of critical values for a specified level of the ARDL bounds test, with and without a time trend. One set assumes that all variables are $I(0)$, and the other that all variables are $I(1)$, which belong to the lower bounds and the upper bounds in the ARDL model, respectively (Narayan, 2005). The criterion of co-integration for the null hypothesis (H_0) is that when the tested *F*-statistic value exceeds that of the upper critical bounds, H_0 is rejected. On the contrary, when the tested *F*-statistic value drops to the value of the lower critical bounds, the null hypothesis H_1 of no co-integration cannot be rejected.

3.3 Granger causality tests

After using the co-integration approach to confirm the existence of the long-run relationship between variables, we apply Granger's (1974) causality test based on the vector error correction model (VECM) to examine the causal relationship among CO_2 emissions, inbound and outbound tourism, energy consumption, and economic growth. Granger causality tests help to inspect the relationship between two variables. The two variables X and Y estimate whether the past values of X are useful for predicting Y. Y is said to be Granger-caused by X, and vice versa. To examine the short- and long-run causality relationships, the VECM equations are constructed as follows:

$$\begin{bmatrix} \ln(CO_2)_t \\ \ln(\omega_{IT})_t \\ \ln(\omega_{OT})_t \\ \ln Y_t \\ \ln E_t \end{bmatrix} = \begin{bmatrix} \lambda_1 \\ \lambda_2 \\ \lambda_3 \\ \lambda_4 \\ \lambda_5 \end{bmatrix} + \begin{bmatrix} \rho_{11i} & \rho_{12i} & \rho_{13i} & \rho_{14i} & \rho_{15i} \\ \rho_{21i} & \rho_{22i} & \rho_{23i} & \rho_{24i} & \rho_{25i} \\ \rho_{31i} & \rho_{32i} & \rho_{33i} & \rho_{34i} & \rho_{35i} \\ \rho_{41i} & \rho_{42i} & \rho_{43i} & \rho_{44i} & \rho_{45i} \\ \rho_{51i} & \rho_{52i} & \rho_{53i} & \rho_{54i} & \rho_{55i} \end{bmatrix} \begin{bmatrix} \ln(CO_2)_{t-1} \\ \ln(\omega_{IT})_{t-1} \\ \ln(\omega_{OT})_{t-1} \\ \ln Y_{t-1} \\ \ln E_{t-1} \end{bmatrix} + \begin{bmatrix} \sigma_1 \\ \sigma_2 \\ \sigma_3 \\ \sigma_4 \\ \sigma_5 \end{bmatrix} ECT_{t-1} + \begin{bmatrix} \mu_{1t} \\ \mu_{2t} \\ \mu_{3t} \\ \mu_{4t} \\ \mu_{5t} \end{bmatrix} \quad (30)$$

ECT_{t-1} is the lagged error correction term derived from the long-run co-integration as an extra independent variable of the ARDL model. It indicates how the adjustment speed of the variables converges to the long-run equilibrium. μ_t are the residual terms of the uncorrected random disturbance. To capture the short- and long-run causal relationships, the short-run Granger causality can be detected by testing the significance of the relevant coefficients ρ_i in the first difference of the Wald test. The long-run causal relationship is determined through the *t*-test results of the lagged ECT_{t-1}. The criterion for the optimal lag length is specified based on the AIC.

4. Empirical Results

4.1 Results of Unit Root Tests

The results of the ADF unit root tests on the natural logarithms of each variable's level term are reported in Table 1 and confirm its stationarity after the first difference. The null hypothesis is to test the series with a unit root against the alternative of stationarity. The results suggest that all variables are integrated in order one $I(1)$. Thus, the ARDL bounds approach can be used to test the co-integration relationships.

4.2 Results of ARDL co-integration tests

We use the ARDL bounds testing procedure to investigate the possibility of a long-run relationship between the dependent and independent variables. The co-integration test results are reported in Table 2. These show that when CO_2 emissions is the dependent variable, its calculated *F*-statistic value of 6.352 lies above the upper critical bounds value at a significance level of 1%. This indicates that the null hypothesis of no co-integration relationship among CO_2 emissions, inbound tourist arrivals, outbound travelers, economic growth, and energy consumption can be rejected. Specifically, there is no evidence of a co-integration relationship as shown in Eq. (25) when the other series (inbound tourist arrivals, outbound travelers, economic growth, and energy consumption) are taken as dependent variables.

To express the long-run estimates from Eqs. (25) to Eq.(29), only Eq. (25) has a co-integration relationship among the series of $\ln(\omega_{\mathrm{IT}})_t$, $\ln(\omega_{\mathrm{OT}})$, $\ln Y$, and $\ln E_t$. Thus, Eq. (25) can be rewritten as:

$$\Delta \ln (CO_2)_t = \beta_{10} + \sum_{i=1}^{k} \gamma_{11} \Delta \ln (CO_2)_{t-i} + \sum_{i=0}^{k} \gamma_{12} \Delta \ln (\omega_{IT})_{t-i} + \sum_{i=0}^{k} \gamma_{13} \Delta (\omega_{OT})_{t-i}$$
$$+ \sum_{i=0}^{k} \gamma_{14} \Delta Y_{t-i} + \sum_{i=0}^{k} \gamma_{15} \Delta E_{t-i} + \tau_1 \ln (CO_2)_{t-1} + \tau_2 \ln (\omega_{IT})_{t-1}$$
$$+ \tau_3 \ln (\omega_{OT})_{t-1} + \tau_4 \ln Y_{t-1} + \tau_5 \ln E_{t-1} + \phi\, ECT + \varepsilon_t\,, \tag{31}$$

where the error correction term.

(*ECT*) indicates how the adjustment speed of the variables converges to the long-run equilibrium. In Table 3, the tourism coefficient of inbound tourist arrivals has a positive and statistically significant effect on CO_2 emissions. Specifically, a 1% increase in inbound tourist arrivals may lead to a 0.36% rise in the amount of CO_2 emissions in the long run. This result implies that inbound tourist arrivals have a greater influence on CO_2 emissions compared to outbound travelers. Without considering the future influence of the COVID-19 pandemic, this is not surprising as a large number of tourist arrivals to Taiwan (China and Japan listed in the top one and two) are through domestic transportation demand, which may directly or indirectly raise carbon emissions. In a study on 160 countries for the period 2009–2013, Manfred et al. (2018) found that carbon emissions from inbound tourists are on average 17% greater than outbound travelers.

As shown in Table 3, the results of Eq. (31) also indicate a similar long-run co-integration outcome between economic growth, energy consumption, and CO_2 emissions. The estimation results indicate that both GDP per capita and energy consumption have a positive and statistically significant effect on CO_2 emissions in the long run. In other words, a 1% increase in economic growth (energy consumption) leads to an average 1.66% (1.73%) increase in the amount of CO_2 emissions. This implies that both economic activities and energy consumption not only deteriorate air quality but also have a greater negative impact on it compared to the influence of tourism expansion. Previous studies on different countries such as China (Chen et al., 2019), India (Alam et al.,2011; Vidyarthi, 2013; Srinivasan and Ravindra, 2015), Malaysia (Shahbaz,et al., 2013 and Saboori, et al., 2013), Taiwan (Liu, et al., 2016), and Thailand (Kuo, et al., 2014) also present relevant evidence. The main output of CO_2 emissions in Taiwan is driven by energy consumption, especially by the industrial (48.9%), energy (14.5%), and transportation sectors (14.0%) (Bureau of Energy Taiwan, 2019). According to the Ministry of Economic Affairs (MOEA, 2019), even though its percentage share has been declining over the past few years, the manufacturing industry accounts for more than 30% of Taiwan's GDP. These percentages explain the causality linkage between energy consumption, economic growth, and CO_2 emissions.

Table 1. ADF unit root test results

Variables	Intercept	First difference	Trend and intercept	First difference
$\ln(CO_2)$	-0.3824	-5.5162 ***	-1.2687	-5.3324 ***
$\ln(\omega_{IT})$	-0.5527	-4.3314 ***	-1.5423	-4.5624***
$\ln(\omega_{OT})$	-1.0432	-3.8422 ***	-2.2156	-5.2561 ***
$\ln Y$	-0.8451	-5.3123 ***	-1.4432	-5.0081***
$\ln E$	-2.6632	-6.5612 ***	-3.0425	-6.2724***

Note: (a) *** and ** indicate the null is rejected at the 5% and 1% significance levels, respectively. (b) Numbers in parentheses are the optimal lag orders and selected based on the Akaike Information Criterion (AIC).

Table 2. The ARDL co-integration of bonds test results

Dependent variable	Optimal lag	F-statistic	Results
$\ln(CO_2)$: $Eq.(30)$	(1,3,1,0,2)	6.352 ***	Co-integrated
$\ln(\omega_{IT})_t$: $Eq.(31)$	(0,3,3,2,1)	1.331	
$\ln(\omega_{OT})_t$: $Eq.(32)$	(0,2,1,0,2)	0.894	
$\ln(Y)_t$: $Eq.(33)$	(3,1,1,2,2)	2.161	
$\ln(E)_t$: $Eq.(34)$	(1,3,1,1,0)	1.780	

Notes: (a) ***, **, and * indicate the null is rejected at the 1%, 5%, and 10% significance levels, respectively. (b) Asymptotic critical values are obtained based on Pesaran et al. (2001) and Narayan (2005).

Table 3. Long-run estimates results of ARDL

Dependent variable : $\ln(CO_2)_t$		
Variables	ARDL	DOLS
$\ln(\omega_{IT})_t$	0.36 *	0.42 *
$\ln(\omega_{OT})$	0.18 *	0.22 *
$\ln Y_t$	1.66 **	1.39 **
$\ln E_t$	1.73 **	2.36 **
$Constant$	-3.26 **	-5.34 **

Notes: (a) **, and * indicate the null is rejected at the 5%, and 10% significance levels, respectively. (b) We apply Newey-West on the estimates of the Dynamic OLS (DOLS). (c) the optimal lag orders are selected based on the Akaike Information Criterion (AIC) .

4.3 Results of Causality tests

The confirmed existence of a long-run relationship between economic growth, energy consumption, and CO_2 emissions implies that there should be Granger causality in at least one direction. The results of the short and long run Granger causality within the VECM framework are presented in Table 4. The causality suggests that there is unidirectional causality running from CO_2 emissions to inbound tourist arrivals in the short run, and a long-run causality running from inbound tourist arrivals to CO_2 emissions. Even though we do not find any bidirectional causality between them, this result reiterate the importance of the role played by inbound tourist arrivals in CO_2 emissions. We speculate that the reason CO_2 emissions seem to lead inbound tourist arrivals perhaps due to Taiwan's industrial development since 1970s followed by a more open tourism policy in the 1990s. For energy consumption, we find a short-run unidirectional causality running from energy consumption to CO_2 emissions, both for tourism expansion (inbound tourists arrivals and outbound travelers) and economic growth. This causal result is also similar to Ang (2007, 2008). In addition, we also identify unidirectional causality for the case of energy consumption to CO_2 emissions in both the short and long run. Therefore, any policy to alleviate or control the current level of emissions in the domestic country must not only consider tourism and energy conservation policies but also the possibility of economic recession.

Unidirectional causality is detected in the case of economic growth to CO_2 emissions both in the short and long run. This is in line with Apergis and Payne's (2012) findings in a study of 67 countries and Kim et al.'s (2012) results for the United States. Moreover, Lotfalipour et al. (2010) suggested that managing the reduction of emissions problem may not be a desirable outcome, because it is not likely to decrease the quantity of CO_2 emissions without forfeiting economic growth. Furthermore, short-run bidirectional causality exists between inbound tourist arrivals and economic growth in the short run. However, no feedback causality is detected between outbound travelers and economic growth. Examining the causality issues among tourism, CO_2 emissions, and economic growth, we speculate that, in previous studies, the insufficient undetermined tourism-led growth in Taiwan may be due to the role of missing the effects of CO_2 emissions, since CO_2 emissions may reduce the potential tourism expansion to economic performance.

Table 4. Granger causality test results

	Short run Causality F-statistics (*Prob.*)					Long run Causality
Dependent variable ↓	$\Delta\ln(CO_2)_{t-i}$	$\Delta\ln(\omega_{IT})_{t-i}$	$\Delta\ln(\omega_{OT})_{t-i}$	$\Delta\ln Y_{t-i}$	$\Delta\ln E_{t-i}$	ECT_{t-i} (t-stats)
$\Delta\ln(CO_2)_t$	-	2.33(0.16)	1.08(0.41)	3.12(0.01)**	2.84(0.02)**	-2.86(-3.44)***
$\Delta\ln(\omega_{OT})_t$	1.28(0.29)	-	1.16(0.39)	0.86(0.61)	2.92(0.02)**	-
$\Delta\ln(\omega_{IT})_t$	2.73(0.03)**	1.86(0.18)	-	4.76(0.04)**	4.07(0.04)**	-
$\Delta\ln Y_t$	1.12(0.35)	4.88(0.02)**	1.08(0.35)	-	9.13(0.00)***	-
$\Delta\ln E_t$	6.59(0.00)***	0.31(0.81)	0.82(0.56)	2.11(0.10)	-	-

Note: (a) *** and ** indicate the null is rejected at the 5% and 1% significance levels, respectively. (b) Numbers in parentheses are p-values for Wald tests with F distribution. ECT_{t-i} represents the error correction term.

5. Conclusions

Adopting Taiwan as a case example, this study investigates the dynamic short and long run causality between tourism expansion, energy consumption, economic growth, and CO_2 emissions on the basis of the theoretical model analysis. In addition, we contribute to the literature by using two proxies of tourist expansion, namely, inbound tourist arrivals and outbound travelers as a comparative determinant. The co-integration analysis reveals that a long-run relationship exists among variables when CO_2 emissions is a dependent variable. The main findings in this study show that on the basis of dynamic theoretical model, the effect of long run energy consumption and tourism expansion is greater than short run when CO_2 emissions increases. Moreover, the empirical evidence demonstrates that a short run unidirectional causality exists from CO_2 emissions to inbound tourist arrivals and energy consumption. Similarly, a short run unidirectional causality runs from energy consumption to inbound tourist arrivals and outbound travelers. In addition, there is a feedback causality relationship between economic growth and inbound tourist arrivals. These results may indicate that inbound tourist arrivals may have more leading impacts on energy consumption and economic growth compared to outbound travelers. In other words, motivating inbound tourist arrivals seems to be an effective way to stimulate economic growth without hindering energy consumption. This may also explain why the Tourism Bureau of Taiwan introduced the “Ten Years (2008–2018) Doubling Tourist Arrivals Plan (DTAP)” in 2008 to improve the traveling environment such as upgrading the ground transport infrastructure (railroads, ports, and air transport), and domestic accommodation services to attract inbound travelers. The causality flow from energy consumption to CO_2 emissions, tourism expansion, and economic growth is identified in the short run, along with a long-run causality relationship exists between energy consumption and CO_2 emissions. Moreover, unidirectional causality runs from economic growth to both CO_2 emissions and inbound tourist arrivals, indicating that a growth-led hypothesis explain the relationship between them.

Based on the findings, despite the fact that the common notion of tourism-led economic growth is applicable in most tourism expansion policies, the causality evidence thus far seems to suggest that inbound tourist arrivals are the main contributing factor to economic performance, and specifically, affect the level of CO_2 emissions in the long term. These findings suggest that Taiwan’s economic performance is significantly dependent on the tourism industry and energy consumption, and directly or indirectly affects the level of CO_2 emissions. This implies that tourism activities are the active contributors to pollution, and any conservation policies associated with tourism expansion and energy consumption may not only decrease CO_2 emissions but also hinder economic performance. Therefore, policies for promoting cleaner energy programs in tourism development or scheduling the switch to partial or total electric transportation may be a feasible way to alleviate the conflicts among tourism, energy, GDP growth, and pollution.

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