Does China's outward direct investment decrease carbon intensity in ASEAN countries? Evidence from CS-ARDL model analysis

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Abstract

Purpose – China's outward foreign direct investment (OFDI) in the member countries of the Association of Southeast Asian Nations (ASEAN) has increased significantly over the past few decades. However, the literature concerning FDI's environmental effect on host countries has not reached a consensus. This paper aims to identify the effects of China's OFDI on the carbon intensity of 10 ASEAN nations from 2003 to 2021.

Design/methodology/approach – This paper applies advanced econometric techniques, such as the stationarity test, Westerlund cointegration test and cross-sectional autoregressive distributed lags (CS-ARDL) model. The novel CS-ARDL estimation technique is used to evaluate the long- and short-run effects, and this approach can address the issues of cross-sectional dependency, heterogeneity and endogeneity.

Findings – The results of this investigation validate a long-term cointegrating relationship between China's OFDI and the carbon intensity of ASEAN nations. The estimated results from the CS-ARDL model reveal that Chinese FDI is inversely related to carbon intensity. A 1% increase in Chinese FDI will decrease the carbon intensity by 0.1045% and 0.0386% in the long and short run, respectively. The empirical analyses also reveal that it takes more than a year for policies related to carbon intensity to absorb their effects and help to achieve equilibrium. In addition, the economic level and urbanization curb carbon intensity, while energy consumption and industrial structure are positively associated with carbon intensity.

Originality/value – This paper is one of the first to quantitatively identify the carbon impact of Chinese direct investment in ASEAN countries. It provides the first empirical evidence for the topic using the CS-ARDL estimator, which is advantageous over other methods in analyzing both the short- and long-run effects. It is a methodological innovation in the literature on the FDI–environment nexus. Investigating how Chinese FDI affects ASEAN's carbon intensity provides a theoretical basis for ASEAN nations to formulate more coordinated environmental and investment policies.

Keywords ASEAN countries, Carbon intensity, China's OFDI, CS-ARDL model

Paper type Research paper

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1. Introduction

Since China implemented the "Go Global" policy in 1999, its outward foreign direct investment (OFDI) has increased significantly. In the last few decades, the Association of Southeast Asian Nations (ASEAN) region has gradually become one of China's main OFDI destinations. Its OFDI in the region has increased rapidly since the China-ASEAN Free Trade Area came into force in 2010 (Chiang and de Micheaux, 2022). The Belt and Road Initiative (BRI), proposed in 2013, has also sped up OFDI in ASEAN countries. Since 2018, this region has become the second-largest destination for Chinese direct investment, following only Hong Kong (China) (Ministry of Commerce PRC, n.d.). According to China's official statistics, the share of its OFDI flow to ASEAN in total OFDI flow grew from 4% in 2003 to 11.4% in 2022, only behind Hong Kong (China) at 59.8%. Its OFDI stock in ASEAN was US$154.66bn at the end of 2022, accounting for 5.6% of total OFDI stock. The top three industries for OFDI stock were manufacturing, wholesale and retail trade, and mining. The investments help to spur the economic development of both China and ASEAN nations through investment-driven effects.

However, with the fast development of the ASEAN region come urgent environmental challenges. The ASEAN region is among the most vulnerable areas influenced by climate change (Lau, 2022). The average temperature in this region has kept rising every decade since the 1960s (Prakash, 2018). ASEAN region has become the fastest area in increasing CO_2 emissions from 1990 to 2010 (Prakash, 2018), primarily due to its heavy reliance on fossil fuels, especially coal. Its dependence on coal consumption is partly because of its abundance and relatively low cost compared to other energies. According to the International Energy Agency (IEA) (2019), energy demand in this region is expected to increase by as much as 66% by 2040. Its production and investment activities relying on burning fossil fuels will continue to generate large amounts of CO_2 emissions, potentially presenting a challenge to the aims of the Paris Agreement (Lau *et al.*, 2021). With the ongoing industrialization and heavy dependence on fossil fuels, ASEAN might be among the leading sources of increasing CO_2 emissions in the future, urgently requiring a prompt transition to green and sustainable development.

Due to severe climate degradation, countries are increasingly focused on the "quality" of FDI and intend to introduce green and energy-efficient investments (Mahadevan and Sun, 2020). The literature concerning FDI's environmental effect on host countries has not reached a consensus. Until now, some research offered evidence to confirm the pollution haven hypothesis (Cole, 2004; Sapkota and Bastola, 2017; Wang *et al.*, 2021), whereas other existing studies had findings consistent with the pollution halo hypothesis (Acheampong *et al.*, 2019; Zubair *et al.*, 2020; Saqib *et al.*, 2023). Some research following the environmental Kuznets curve (EKC) theory supported an EKC relationship between FDI and emissions (Balsalobre-Lorente *et al.*, 2021). As Chinese direct investment increases in the ASEAN region, it is imperative to investigate its influence on the environment of ASEAN nations. A thorough evaluation of the carbon effect of Chinese direct investment in ASEAN nations offers policy reference value to enhance green investment and sustainable development in the region. However, to our knowledge, despite several literary works on the nexus between China's OFDI and CO_2 emissions of BRI member countries (Muhammad *et al.*, 2020; Su *et al.*, 2022; Wang *et al.*, 2023), few have explored its impact on the carbon intensity in ASEAN. As the first region to participate in the BRI, ASEAN serves as the core region for China to promote BRI. In addition, the above studies focused on BRI countries have inconsistent conclusions. Some scholars have empirically shown that China's OFDI helps to decrease CO_2 emissions in B&R countries (e.g. Su *et al.*, 2022; Wang *et al.*, 2023). By contrast, some other scholars believe that China's OFDI could lead to an increase in CO_2

emissions in these countries (e.g. Muhammad *et al.*, 2020; Wang *et al.*, 2021). Therefore, the following research questions are worth further investigation: (1) Does China's OFDI decrease carbon intensity in ASEAN countries? (2) What are the long- and short-run effects of China's OFDI on carbon intensity in this region?

Given this background, this paper aims to understand the influence of Chinese FDI on the carbon intensity of 10 ASEAN nations from 2003 to 2021. This paper makes possible contributions in four primary aspects. (1) As far as we know, despite China's growing OFDI in ASEAN, this is one of the first research works that quantitatively explores its impact on carbon intensity in ASEAN. The existing literature has not thoroughly examined the environmental impact of Chinese direct investment in these countries. (2) Unlike most earlier studies that only focused on the long-run effects, our study analyzes both the short- and long-run ones using the cross-sectional autoregressive distributed lags (CS-ARDL) model, which appropriately depicts the complex relationships between China's OFDI and carbon intensity. Therefore, our results can enrich the existing literature and offer theoretical support for formulating more coordinated environmental and investment policies for ASEAN countries. (3) The current paper uses novel and sophisticated econometric techniques, including the CS-ARDL model, which are advantageous over other methods in handling the issues of cross-section dependence, endogeneity, serial correlation and heterogeneity. The CS-ARDL method we use is considered a significant innovation over the methods used in previous empirical analyses on this research topic. (4) By investigating the ecological effect of Chinese direct investment in ASEAN, we offer compelling evidence for the shifts towards green OFDI under the framework of introducing FDI and reducing carbon intensity in this region and other host developing nations.

The rest of the article is structured as follows. Section 2 presents a detailed review of the related literature. Section 3 discusses the methodologies and data applied in our research. Section 4 presents the empirical results and the discussion. The last section summarizes the conclusion and offers related policy implications of the study.

2. Literature review

Research interest in the nexus between FDI and environmental quality has grown recently. The pollution haven hypothesis (Copeland and Taylor, 1994) and the pollution halo hypothesis (Birdsall and Wheeler, 1993) are two conflicting hypotheses illustrating the nexus in host countries. The haven hypothesis suggests FDI can lead to ecological degradation in host countries by relocating the pollution industries from the investing home countries. The pollution halo hypothesis depicts FDI contributes to a cleaner environment through positive environmental spillovers. Through FDI, green and clean technologies and practices are likely to be transferred to developing countries, thus leading to an overall abatement in emissions (Golub *et al.*, 2011). According to Pao and Tsai (2011), by adhering to universal environmental regulations, multinational companies involved in FDI activities help spread clean technology to local enterprises in invested nations, reducing emissions and improving energy efficiency.

Researchers have conducted a series of empirical studies to address the theoretical ambiguity surrounding the nexus between FDI and the environment. However, these empirical studies have only reinforced this ambiguity due to their contrasting results (Zhu *et al.*, 2016). The difference in data, environmental indicators and econometric methods used in prior studies may partly account for the contrasting results in the literature (Mahadevan and Sun, 2020; Demena and Afesorgbor, 2019). For instance, Cole *et al.* (2011) found that foreign-owned firms that indicate the presence of FDI significantly aggravated industrial pollution emissions in China from 2001 to 2004. Sapkota and Bastola (2017) similarly noted an adverse environmental impact of FDI in 14 Latin American countries. They found that a rise of 1% in FDI is related to a 0.04% increase in pollution emissions.

Using the ARDL method, Salahuddin *et al.* (2018) and Minh (2020) found evidence that FDI exacerbates environmental degradation, both in the short term and the long term. Although a large body of literature holds an adverse view of FDI's effect on the environment, it is also possible that FDI is conducive to environmental quality. For example, using fixed- and random-effect estimators, Acheampong *et al.* (2019) showed a pollution halo effect of FDI in sub-Saharan African countries from 1980 to 2015. Demena and Afesorgbor (2019) performed a meta-analysis of the FDI–environment nexus using 65 primary studies and confirmed a significantly decreasing effect of FDI on environmental emissions. Neves *et al.* (2020) validated the pollution halo hypothesis for 17 European Union countries. Zubair *et al.* (2020) suggested that FDI was beneficial for reducing CO_2 emissions in Nigeria from 1980 to 2018, using the improved VAR approaches. In addition, Mahadevan and Sun (2020) found a mixed effect of Chinese FDI on the pollution emissions of BRI countries.

With the rising FDI inflow in ASEAN countries, scholars have paid increasing attention to investigating its impact on CO_2 emissions in these countries. The evidence of FDI on the environment in ASEAN is also uncertain and varies. Some studies have offered proof of the pollution haven hypothesis. At the national level, Tang and Tan (2015) empirically found FDI to be the primary factor leading to the rise in CO_2 emissions in Vietnam between 1976 and 2009. At the regional level, using data from 17 South and Southeast Asia nations between 1980 and 2012, Behera and Dash (2017) concluded that FDI aggravated carbon emissions in the middle- and high-income ones. Using data from ASEAN-5 nations from 1982 to 2014, Nasir *et al.* (2019) also noted that FDI exacerbated CO_2 emissions. However, using a sample of five selected ASEAN countries, Zhu *et al.* (2016) showed a pollution halo effect in higher-emission countries based on a panel quantile regression model. Zhao *et al.* (2023) used a DID model to explore the environmental impacts of Chinese FDI in ASEAN nations. They also found an evident pollution halo effect. In addition, using panel Granger causality tests, Eriandani *et al.* (2020) found that FDI increases CO_2 emissions in pollutant-intensive sectors. However, there is little evidence that FDI affects CO_2 emissions in other sectors in five ASEAN nations between 1980 and 2018.

Concerning FDI's impact on carbon intensity, Ren *et al.* (2014) noted a haven effect from 2000 to 2010 for China's 19 industrial sectors, using a two-step generalized method of moments (GMM) estimation. Yu *et al.* (2023) documented that inward FDI positively affects CO_2 intensity in developing economies, supporting the pollution haven hypothesis. Hu *et al.* (2021) revealed that FDI stimulates carbon emissions intensity in China's 11 provinces and cities between 2008 and 2016, using a panel threshold model. On the contrary, Zhang *et al.* (2020) found that inward FDI presents a pollution halo effect based on panel data from 30 Chinese provinces covering the period 2009–2017. Using a sample of 188 countries from 1990 to 2013, Shao (2018) used a system GMM approach to examine the influence of FDI on carbon intensity. They also found evidence of the pollution halo effect. In addition, using a sample of 56B&R countries between 2005 and 2018, Wang *et al.* (2023) indicated that Chinese direct investment has a net reduction effect there, approximately −3.0%.

3. Methodology

3.1 The data and variables

We use a panel data set of 10 ASEAN nations from 2003 to 2021 to determine the effects of China's OFDI on their carbon intensity. The core variables in our study are OFDI and carbon intensity. As the total accumulated level of direct investment, FDI stocks can efficiently reflect long-run effects, so we adopt OFDI stock as the representative variable of OFDI. Carbon intensity is measured by the ratio of total CO_2 emissions to gross domestic product (GDP). The data for total CO_2 emissions is taken from the U.S. Energy Information Administration (EIA), while the data for GDP is from the World Development Indicators (WDI).

Referring to the prior studies, we include several control variables in our empirical model. These are economic development (Wang *et al.*, 2022; Wu *et al.*, 2021), industrial structure (Zhang *et al.*, 2020; Su *et al.*, 2022), energy consumption (Muhammad and Long, 2021; Chen *et al.*, 2022), urbanization (Wu *et al.*, 2021; Dou *et al.*, 2021) and trade openness (Wang and Wang, 2021; Dou *et al.*, 2021). This paper uses GDP per capita as an indicator to measure economic development, the percentage of industry value added to GDP to stand for the industrial structure, the primary energy consumption per million people to represent energy consumption, and the percentage of exports and imports of goods and services in GDP to represent trade openness. Urbanization is proxied by the ratio of the urban population to the total population. We have presented the detailed definitions of variables, data sources and units of measurement in Table 1. Table 2 reports the summary statistics for the variables used in our analysis.

3.2 Model

Our study evaluates the influence of Chinese FDI on the carbon intensity of ASEAN nations in the presence of GDP per capita, trade, urbanization, industrial structure and energy

Table 1. Variable definitions

Variable	Definition	Source
CI	Carbon Intensity (ratio of total CO_2 emissions to GDP, kg per constant 2015 US$)	EIA, WDI
OFDI	China's outward FDI stock in ASEAN countries (millions of US dollars)	Statistical Bulletin of China's OFDI
IS	Industrial structure (the share of the tertiary industry sector in GDP)	WDI
EL	Economic development (GDP per capita constant 2015 US$)	WDI
OPEN	Trade openness (imports and exports of goods and services, % of GDP)	WDI
UR	Urbanization (ratio of urban population to total population)	WDI
EC	Energy consumption (quad Btu per million people)	EIA, WDI
POP	Total population (million people)	WDI

Notes: WDI = World Development Indicators (available at: https://data.worldbank.org); Statistical Bulletin of China's OFDI (available at: http://hzs.mofcom.gov.cn/)
Source: Authors' own work

Table 2. Descriptive statistics

Variables	Obs	Mean	SD	Min.	Max.
CI	190	0.6120894	0.2846167	0.0736821	1.893877
OFDI	190	460974.5	974582.9	13	6720228
IS	190	36.61821	12.23658	14.25826	74.11302
EL	190	10961.58	16449.49	410.4734	67175.87
OPEN	190	125.9083	89.96261	11.8554	437.3267
UR	190	50.30894	23.9356	18.937	100
EC	190	0.0012379	0.0018739	0.0000274	0.0066452

Source: Authors' own work

consumption. Based on the previous study of Shao (2018) and Mahadevan and Sun (2020), we constructed the following basic econometric model:

$$lnCI_{it} = \beta_0 + \beta_1 lnOFDI_{it} + \beta_2 lnIS_{it} + \beta_3 lnEL_{it} + \beta_4 lnOPEN_{it} + \beta_5 lnUR_{it} + \beta_6 lnEC_{it} + \varepsilon_{it} \quad (1)$$

where β_0 denotes the constant term, i signifies each of the ASEAN nations (1, 2, …, 10), and t is the year (2003, …, 2021). *CI* is the carbon intensity, and *OFDI* denotes China's OFDI stock in ASEAN. *IS* denotes industrial structure, *EL* represents economic development, *OPEN* is trade openness, *UR* signifies urbanization, and *EC* represents energy consumption. β_1–β_6 denote the parameters of OFDI, industrial structure, economic development, trade openness, urbanization and energy consumption on carbon intensity, respectively. Error term ε_{it} follows the independent and identical distribution. All variables in this research are log transformed to linearize relationships and eliminate heteroscedasticity.

3.3 Estimation strategy and econometric techniques

To properly assess the long-term impact of panel data, it is crucial to check for different issues in the model, including cross-section dependence (CSD), heterogeneity and stationarity. To begin our analysis, we apply the Pesaran (2004) and Pesaran and Yamagata (2008) tests to verify the CSD and slope heterogeneity of the panel data, respectively. Once the issues of CSD and slope heterogeneity are confirmed, the subsequent step is to conduct an appropriate stationary test. A second-generation unit root test, augmented IPS (CIPS), advanced through Pesaran (2007), is applied to determine the stationarity of the variables. After validating the data's stationarity, this paper employs the Westerlund (2007) test to reveal the long-term association among the adopted variables. Westerlund (2007) can deal with CSD and slop heterogeneity and consequently compute reliable cointegration. Next, we proceed to estimate both the long- and short-run coefficients. This paper uses the CS-ARDL model to compute the long- and short-run effects of China's OFDI on carbon intensity for ASEAN countries. We use this model because traditional techniques would produce biased results if CSD and heterogeneous slope coefficients exist. In contrast, this model gives satisfactory results even in the presence of these issues (Chudik and Pesaran, 2015).

3.3.1 Cross-section dependence and slope heterogeneity tests. Recent research confirms that a critical issue concerning panel data is the presence of CSD in residuals. To that end, this study uses a CSD analysis developed by Pesaran (2004). The equation is given as:

$$CRSD = \sqrt{\frac{2T}{N(N-1)}}\left(\sum_{i=1}^{N-1}\sum_{j=i+1}^{N}\widehat{\rho}^{ij}\right) \sim N(0,1) \quad (2)$$

In equation (2), T denotes time, N denotes cross-sections and $\widehat{\rho}^{ij}$ represents the CS correlation of error. Before testing for a unit root, it is indispensable to consider the potential slope heterogeneity of panel data. Incorrectly ignoring slope heterogeneity when we proceed with the data can lead to biased and misleading results. Hence, we use the test for slope heterogeneity designed by Pesaran and Yamagata (2008) to confront this issue. The equation for the test is provided as follows:

$$\widetilde{\Delta}_{SH} = (N)^{\frac{1}{2}}(2k)^{-1}\left(\frac{1}{N}\widetilde{S} - k\right) \quad (3)$$

$$\widetilde{\Delta}_{ASH} = (N)^{\frac{1}{2}} \frac{2k(T-k-1)}{T+1}^{-1/2} \frac{1}{N}\widetilde{S} - 2k \tag{4}$$

where $\widetilde{\Delta}_{SH}$ is delta tilde and $\widetilde{\Delta}_{ASH}$ is adjusted delta tilde.

3.3.2 Stationarity test. The following step is to adopt an appropriate unit root test to validate the variables' stationarity in our panel data set. While CSD and slope heterogeneity exist, first-generation unit tests may yield biased and invalid results (Banerjee *et al.*, 2001). However, second-generation tests consider the CSD when checking the integration order for selected variables. Therefore, to handle the problem of CSD and slope heterogeneity, our research work conducts CIPS, a second-generation unit root test put forward by Pesaran (2007), to verify the stationarity. The test statistics can be expressed as follows:

$$\widehat{CIPS} = 1/N \sum_{i=1}^{n} CADF_i \tag{5}$$

where $CADF_i$ represents the cross-sectionally augmented Dickey–Fuller statistics for the ith cross-section unit. In addition, it is worth mentioning that if the test shows the series is stationary in the first difference, we need to perform a cointegration test before estimating the parameters.

3.3.3 Cointegration test. Panel cointegration tests determine if the long-run cointegration relationship exists between variables in the panel. Several panel cointegration tests, like Pedroni (2004) and Westerlund (2007), are designed either with the null hypothesis of cointegration or the absence of cointegration. The Westerlund (2007) test produces consistent results, even for panels subjected to CSD. Compared to the Pedroni (2004) test, the Westerlund (2007) test, based on structural dynamics, exhibits better size accuracy and is higher in power. This is mainly because the Pedroni (2004) test has a likely problem of imposing invalid common factor restrictions. Therefore, we use the Westerlund (2007) test to compute reliable cointegration for our panel data. The equation of the test statistics is given as follows:

$$\Delta Y_{it} = \delta_i^{'} d_t + b_i Y_{i,t-1} + \lambda_i^{'} X_{i,t-1} + \sum_{j=1}^{p_i} b_{ij} \Delta Y_{i,t-j} + \sum_{j=0}^{p_i} \gamma_{ij} \Delta X_{i,t-j} + \varepsilon_{it} \tag{6}$$

where i denotes cross-sectional units, t represents periods and p_i is the lag order. d_t is deterministic part. The panel test assumes no cointegration as the null hypothesis.

3.3.4 CS-ARDL. We employ a CS-ARDL model to estimate the parameters. It is a novel econometric technique that considers structural breaks and other factors to produce unbiased results. The CS-ARDL estimation comprises both short- and long-run parameters, error correction terms and the short- and long-run cross-sectional means of each variable. The method is superior to other cointegration methods and a suitable approach for this study. First, even though incorporating selected variables with distinct orders of differencing, such as I (0) or I (1), the technique can still give robust estimates (Usman *et al.*, 2020). Second, according to Chudik and Pesaran (2015), the method can generate accurate results even in the presence of long- and short-run CSD. Third, it is an efficient method that can handle the issues of endogeneity, slope heterogeneity and structural breaks (Ding *et al.*, 2021). The equation for the ARDL model is:

$$C_{it} = \sum_{I=0}^{P_C} \eta_{I,i} C_{i,t-I} + \sum_{I=0}^{P_Y} \delta_{I,i} Y_{i,t-I} + \varepsilon_{it} \tag{7}$$

Equation (7) provides the basic equation. Equation (8) gives an extended version by adding a term of cross-section averages. According to Chudik and Pesaran (2015), introducing cross-section averages removes the threshold effect arising from CSD:

$$C_{it} = \sum_{I=0}^{P_C} \eta_{I,i} C_{i,t-I} + \sum_{I=0}^{P_Y} \delta_{I,i} Y_{i,t-I} + \sum_{I=0}^{P_W} \sigma_i' I \overline{W}_{t-I} + \varepsilon_{it} \tag{8}$$

The cross-section averages are indicated by $\overline{W}_{t-I} = \left(\overline{C}_{i,t-I}, \overline{Y}_{t-I}\right.$, and P_C, P_Y and P_W are lags. C_{it} represents the explained variable *lnCI* (carbon intensity). $Y_{i,t-I}$ indicates a group of the explanatory variables in the study, namely, *lnOFDI*, *lnIS*, *lnEL*, *lnOPEN*, *lnUR* and *lnEC*. ε_{it} is randomly distributed error terms. The long-run coefficient can be calculated as follows:

$$\widehat{\beta}_{\mathrm{CS}-ARDL,i} = \frac{\sum_{I=0}^{P_Y} \widehat{\delta}_{I,i}}{1 - \sum_{I=0}^{P_C} \widehat{\eta_{I,i}}} \tag{9}$$

whereas the mean group is given as:

$$\widehat{\overline{\beta}}_{MG} = \frac{1}{N} \sum_{i=1}^{N} \widehat{\beta}_i \tag{10}$$

Equation (11) provides the short-run coefficients:

$$\Delta C_{i,t} = \eta_i [C_{i,t-1} - \theta_i Y_{i,t} - \sum_{I=1}^{P_{C-1}} \eta_{I,i}, \Delta_I C_{i,t-I} + \sum_{I=0}^{P_Y} \delta_{I,i} \Delta_I Y_{i,t-I} + \sum_{I=0}^{P_W} \sigma_i', I \overline{W}_{t-I} + \varepsilon_{it} \tag{11}$$

where $\Delta_I = t - (t-1)$:

$$\widehat{\gamma}_i = - \quad 1 - \sum_{I=1}^{P_C} \widehat{\eta_{I,i}} \Big) \tag{12}$$

$$\widehat{\beta}_i = \frac{\sum_{I=0}^{P_Y} \widehat{\delta}_{I,i}}{\widehat{\gamma}_i} \tag{13}$$

$$\widehat{\overline{\beta}}_{MG} = \frac{1}{N} \sum_{i=1}^{N} \widehat{\beta}_i \tag{14}$$

In CS-ARDL, the ECM (−1) indicates the speed of adjustment to equilibrium, with a positive value indicating divergence and a negative value signifying convergence. Moreover, in this study, we apply the augmented mean group (AMG) to conduct a robustness test analysis to confirm the validity of our CS-ARDL results. Eberhardt and Teal (2010) propose the AMG approach, which accounts for heterogeneity and CSD. Bond and Eberhardt (2013) highlight its applicability for cross-country panel data analysis.

4. Results and discussion

We use the above methods to evaluate the possible effects of Chinese investment on carbon intensity in ASEAN. The findings in Table 3 confirm that slope heterogeneity exists, as suggested by the statistically significant values of the statistics. Concerning the CD test

Table 3. Slope heterogeneity and cross-sectional dependency analysis

Slope homogeneity test		
Statistics	Delta tilde (*p*-value)	Delta tilde adjusted
	2.208** (0.027)	3.035*** (0.002)
Cross-sectional dependence test		
Variables	CD test	Means abs (ρ)
CI	−2.302**	0.54
OFDI	28.036***	0.96
IS	1.423	0.67
EL	17.567***	0.97
OPEN	3.365***	0.38
UR	22.242***	0.76
EC	22.281***	0.76

Source: Authors' own work

results, the null hypothesis of no cross-sectional dependency is rejected, implying that the panel is dependent. The correlation values between 0.38 and 0.96 further verify that the panel shows the sign of CSD. The slope heterogeneity test results obtained using the Pesaran and Yamagata (2008) method suggest that a bias exists in this model, meaning that a policy shock in one ASEAN nation appears to spread to the other ASEAN nations.

Given the existence of CSD that may lead to heteroscedasticity problems, we perform CIPS, a second-generation unit root test proposed by Pesaran (2007), to test the stability of each selected variable. Table 4 shows that, except OFDI, all variables do not strongly reject the null hypothesis that assumes a unit root in a panel. This means that most of these variables are nonstationary, and only the variable OFDI is stationary at I(0). However, all variables except OFDI pass the tests and are stable in the first-order difference form I(1). The stability of the panel data provides a prerequisite for the following cointegration test.

After testing the variables' stationarity, we use the Westerlund (2007) test to determine whether the selected variables are cointegrated. Our test results are demonstrated in Table 5. The empirical evidence suggests that the null hypothesis of no cointegration under Westerlund (2007) appears to be rejected at a 1% significance level based on the Gt, Pa and Pt statistics. It offers evidence of a substantial long-run linkage between carbon intensity, OFDI, industrial structure, economic level, trade openness, urbanization and energy consumption, indicating that the coefficients' estimation can be proceeded using CS-ARDL.

Table 4. Results of panel unit root tests

	Level		First difference		Order of
Variables	Constant	Constant and trend	Constant	Constant and trend	integration
Cross-sectionally augmented IPS (*CIPS*)					
CI	−2.290*	−2.387	−3.782***	−3.988 ***	I (1)
OFDI	−2.564**	−3.606 ***	−4.874***	−4.948***	I (0)
IS	−1.053	−1.884	−4.096***	−4.652***	I (1)
EL	−2.008	−1.713	−2.622***	−2.954**	I (1)
OPEN	−1.361	−2.456	−3.602***	−3.712***	I (1)
UR	−2.258*	−1.439	−2.286 *	−2.881**	I (1)
EC	−2.178	−2.737	−4.032***	−4.217***	I (1)

Source: Authors' own work

Table 5. Cointegration tests

Westerlund test for cointegration	Statistics	Prob.
Gt	−2.240	0.000
Ga	−3.451	1.000
Pt	−15.903	0.000
Pa	−4.747	0.000

Source: Authors' own work

Table 6 depicts the estimates of the CS-ARDL method. The results suggest that Chinese FDI is accountable for reducing carbon intensity in ASEAN economies in the short and long run. It implies that a 1% increase in Chinese FDI appears to decrease the carbon intensity by 0.0386% in the short run. Likewise, the long-run estimates are akin to the short-run estimated results. The estimated OFDI coefficient (LNOFDI) is significantly negative at the 5% level, showing that a 1% increase in Chinese FDI mitigates carbon intensity by 0.1045% in the long run. This finding reveals that increased Chinese FDI improves environmental quality in ASEAN economies. In other words, China's OFDI does not lead to the pollution haven phenomenon but helps achieve a clean environment in these countries. Our finding is in sharp contrast with those of Teo *et al.* (2019) and Wang *et al.* (2021), who show that Chinese direct investment appears to exacerbate CO_2 emissions of BRI countries. However, this finding aligns with several prior research conducted by Shao (2018), Pazienza (2019), Zubair *et al.* (2020) and Saqib *et al.* (2023). As a significant source of know-how and technology spillovers, foreign investment transfers technological innovation and brings technological development to the host country. In recent years, since climate change has become one of the most urgent problems worldwide, ASEAN countries have been paying increasing attention to environmental issues, and their environmental regulations are becoming increasingly stricter. Chinese multinational enterprises may also have more advanced technologies than their counterparts in the ASEAN region and can disseminate cleaner production technology

Table 6. Results of CS-ARDL

Variables	Coefficient	*Z*-stats
Short run		
ΔOFDI	−0.0386**	−2.12
ΔIS	0.3479**	2.01
ΔEL	−0.4385*	−1.69
ΔOPEN	−0.2090	−1.14
ΔUR	−0.5766**	−2.40
ΔEC	0.4489***	2.81
ΔECM (−1)	−0.8324***	−6.29
Long run		
OFDI	−0.1045**	−2.38
IS	0.6889***	4.78
EL	−1.1343**	−2.12
OPEN	−0.4075	−1.03
UR	−1.5911***	−3.62
EC	1.2399***	4.37

Source: Authors' own work

that is less harmful to the environment. The technology can be indirectly spread to domestic firms via backward or forward linkage. Therefore, the carbon intensity-reducing effect of China's OFDI is significant because it promotes the spillover of cleaner and more environment-friendly production technologies in ASEAN economies. Our findings agree with those of Zhu *et al.* (2016), who also found the improving impact of FDI on environmental quality and provided no evidence for the pollution haven hypothesis in the region.

Like OFDI, the economic level is one determinant directly associated with carbon intensity. Our estimated results show that the carbon intensity of the selected sample decreases by 0.4385% as the GDP per capita improves by 1% in the short run. Also, a 1% rise in GDP per capita mitigates the carbon intensity by 1.1343% in the long run, supporting the short-run coefficients. A possible explanation for the positive association between economic level and carbon intensity might be: Strong economies attract capital and highly skilled talents essential for driving technological advancements in clean production. Therefore, affluent nations with advanced production technologies are better positioned to achieve lower carbon intensity by enhancing energy efficiency. It also implies an opportunity emerges in ASEAN nations to achieve economic development while reducing carbon intensity. Wang *et al.* (2023) also observed the same results.

Similarly, urbanization significantly improves the environmental quality in ASEAN countries by decreasing carbon intensity. The coefficients of the variable report that carbon intensity appears to decline by 0.5766% in the short run and 1.5911% in the long run on account of a rise in urbanization by 1%. The urbanization process not only drives the development of the urban economy but also promotes the advancement of low-carbon production technology. The negative relationship between urbanization and carbon intensity signifies that urbanization can help ease the prevailing energy poverty problems in rural regions in the sample countries, increasing energy efficiency and reducing carbon intensity. The research finding agrees with the extant literature such as Wang *et al.* (2021), Dou *et al.* (2021) and Chen *et al.* (2022).

However, unlike the above variables, energy consumption (EC) demonstrates a positive link with carbon intensity. The estimated results imply that the sample countries experience a 0.4489% and 1.2399% upsurge in carbon intensity as energy consumption per capita increases by 1% in the short run and long run, respectively. It may be because of the current energy consumption structure of ASEAN countries, where fossil fuels make up 83% of their energy mix, which is adverse to the abating of carbon intensity. This finding aligns with those of Zhu *et al.* (2016) and Wang *et al.* (2023).

In a similar vein, industrial structure (IS) exhibits a positive influence on carbon intensity. The estimated results demonstrate that a one-point increase in the share of the industry value added to GDP appears to increase the carbon intensity by 0.3479% and 0.6889% in the short run and long run, respectively, at the 5% level. This positive nexus is in line with the intuitive impression. Among all the production activities, the industry is the largest producer of carbon emissions. Therefore, a country with a higher proportion of industry tends to have higher carbon emissions and, as a result, a higher carbon intensity. The results align with Shao (2018) and Zhang *et al.* (2020).

Beyond that, the ECM (−1) results shown in Table 6 imply the adjustment speed toward the long-run equilibrium. Our estimated coefficient of ECM (−1) is −0.8324, indicating that 83.24% of disequilibrium is corrected yearly. Therefore, it will take more than a year for the difference in the nexus between carbon intensity and its influencing factors to be adjusted, showing fair convergence to the long-run equilibrium in ASEAN countries.

In addition, we use the AMG method to validate the robustness of our model. We present the AMG results in Table 7. The results show that China's OFDI significantly reduces carbon

Table 7. Robustness analysis (AMG)

Variables	Coefficient	*Z*-stats
OFDI	−0.0878**	−2.52
IS	0.4829**	2.17
EL	−0.8935***	−4.21
OPEN	0.0758	0.94
UR	−1.7460***	−2.98
EC	0.9413***	9.14

Source: Authors' own work

intensity in ASEAN. In addition, the economic level and urbanization are negatively associated with carbon intensity, and their coefficient values are −0.8935 and −1.7460, respectively. In contrast, the results are significantly positive for industrial structure and energy consumption, with coefficient values of 0.4829 and 0.9413, respectively. Therefore, we prove that the estimated results of the CS-ARDL model in this study are valid, as shown by the robustness test.

5. Conclusion and policy implications

China's OFDI has grown rapidly over the previous decades in ASEAN countries. Policymakers and academic researchers are increasingly concerned about identifying the environmental impacts of these OFDI flows. The existing literature provides empirical evidence on FDI–emissions linkage, further adding to the theoretical ambiguity. We investigate the link between Chinese direct investment and the carbon intensity of ASEAN nations from 2003 to 2021. We have performed the advanced CS-ARDL estimation technique to evaluate the effects of the OFDI on carbon intensity. The method can address issues such as CSD, heterogeneity and endogeneity.

The findings of our investigation validate a long-term co-integrating relationship between China's OFDI and the carbon intensity of ASEAN nations. Specifically, the results of our CS-ARDL analysis reveal that Chinese FDI is inversely related to carbon intensity. A 1% increase in Chinese FDI appears to decrease the carbon intensity by 0.1045% and 0.0386% in the long and short run, respectively, indicating that China's OFDI appears to curb the carbon intensity in ASEAN nations by promoting technology spillovers and transferring technological innovation to the host countries. Similarly, the economic level and urbanization have a detrimental effect on carbon intensity. Conversely, a 1% rise in energy consumption and industrial structure leads to a 1.2399% and 0.6889% increase in carbon intensity, respectively. In addition, trade openness does not significantly affect carbon intensity.

Following our research findings, we propose the following main policy implications.

First, China can strengthen its economic engagement with ASEAN countries and continue to promote the OFDI expansion there, which is still essential for these countries. Besides being beneficial for the economic development of ASEAN, it appears to help the region lower its carbon intensity, which contributes to the goal of limiting temperature increase to below 2°C. In addition, we suggest that Chinese firms adhere to the environmental laws, regulations and standards of ASEAN while prioritizing ecological protection. To fully leverage the technology spillover of Chinese investment in ASEAN, it is necessary to encourage Chinese firms to implement various strategies and measures to go green and help achieve the net-zero aim when investing in this region, including the transfers of clean technologies, undertaking cooperative renewable energy projects and collaborating on green financial initiatives.

Second, since Chinese investment has an inverse effect on carbon intensity in ASEAN countries, ASEAN countries should continue making preferential policies to attract FDI from China to drive their economic development. Specifically, for high-energy demand ASEAN countries, especially those with competitiveness in manufacturing production, there is a need to enhance energy productivity and efficiency through vigorously fostering clean technologies and harnessing environmentally friendly resources when using Chinese investment to facilitate the region's economic development. Meanwhile, given ASEAN countries' reliance on fossil fuels, they can also strive to encourage FDI inflow directed to low-carbon industries and R&D projects of renewable energy and promote an energy transition that shifts away from consuming fossil energies towards cleaner energy. Also, it is critical for ASEAN to ensure that all FDI inflows are subject to an environmental impact assessment when attracting FDI.

Third, following the results, an increase in industrialization should be well-planned in ASEAN countries, as the share of the industry value added to GDP increases carbon intensity. It is indispensable to actively optimize the industrial structure and shift the way of production and the process of industrialization to a low-carbon mode. Priority should be given to the high-tech and modern service industry, and investment in industrial upgrading and green production innovation should be encouraged in the ASEAN region. Meanwhile, ASEAN countries can continue to promote their urbanization process and showcase its positive role in curbing carbon intensity, with the urbanization process being planned properly and conducive to sustainable development. In addition, governments need to pay attention to the role of GDP per capita in reducing carbon intensity in ASEAN countries and take full advantage of the opportunity to achieve economic development and carbon intensity reduction simultaneously in this region.

There are still some limitations in this work. First, we introduce economic development, industrial structure, energy consumption and trade openness into the model to determine the FDI's impact on carbon intensity. However, researchers can investigate other factors in future research, such as energy prices and government scale. Second, our study only focused on total carbon intensity without distinguishing it among different sectors. In addition, it did not differentiate whether FDI inflows are green, which can be a future research direction.

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