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The Relationship between Trade Liberalization, Financial Development and Carbon Dioxide Emission—An Empirical Analysis

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Abstract: In recent years, the global economy has become more closely related among countries, and people’s pursuit of economic growth has caused the destruction of the environment. This paper selected panel data from 30 provinces in China from 1997 to 2020 to investigate the dynamic relationship between trade liberalization, financial development and carbon dioxide emissions by constructing a PVAR model. We also consider technology as an important variable for studying the effect on carbon dioxide emissions. We draw the following conclusions. First, financial development promotes carbon dioxide emissions, while trade liberalization has no significant impact on carbon dioxide emissions. Second, China’s trade liberalization promotes financial development, which has limited support for international trade. Third, there is a two-way causal relationship between financial development and carbon dioxide emissions, and there is also a two-way causal relationship between trade liberalization and financial development. Finally, there is a significant inverted “U” curve relationship between trade liberalization and innovation efficiency, environmental regulation and innovation. According to the results, we believe that openness to trade impacts emissions of carbon dioxide, opening a new function path: namely, trade openness and financial development result in high carbon dioxide emissions; consequently, China has relied on this process in the development of their financial system.

Keywords: trade liberalization; economic development; carbon dioxide emissions; technology innovation

1. Introduction

The biggest problem of climate change is global warming. Energy technology innovation is viewed as a crucial method for achieving a low-carbon economy in response to global warming [1]. Technological innovation is critical in balancing the amount and quality of economic growth. High-quality financial development requires innovation, and financial development is inextricably linked to the advancement of green technology innovation systems. Cost-cutting technological improvements may not be ecologically benign.

As a new global player, China’s economic growth has been widely observed; after more than 40 years of reform and opening-up, China’s rapid economic growth has been accompanied by rapid growth in trade liberalization and a sharp increase in CO2 emissions. At the end of 2021, China’s total carbon emissions accounted for 36.7% of the world’s total emissions. At the same time, China’s overseas trade has expanded quickly; the trade scale from 35.50 billion yuan in 1978 jumped to 39.1 trillion yuan in 2021 (General Administration of Customs of China). Table 1 shows the corresponding study of the relationship between CO2 emission, FD, TR and other factors.
Table 1. The corresponding study of the relationship between CO\(_2\) emission, FD, TR and other factors.

| Author          | Variables | Method               | Conclusion                                      | Countries                        |
|-----------------|-----------|----------------------|-------------------------------------------------|----------------------------------|
| Stephen (2021)  | CO\(_2\), FD, TR | DOLS, FMOLS          | TR and FD contribute to CO\(_2\); EC mitigates CO\(_2\) | Turkey and the Caspian countries |
| Pardyot (2018)  | CO\(_2\), SO\(_2\), NO\(_2\), SPM, FD, TR | Panel regression analysis | FD contributes to NO\(_2\), TR mitigates CO\(_2\), SPM, SO\(_2\) | India                            |
| Gulzara (2018)  | FDI, FD, TR, CO\(_2\) | ARDL                | FDI, TR contributes to CO\(_2\)                 | Pakistan and India               |
| Dennis (2019)   | TR, GDP, Pollution, | SLM                 | TR and GDP mitigate Pollution                   | 183 countries                    |
| Eyup (2016)     | TR, FD, NREC, REC | CADF, CIPS, Panel unit root test | TR, FD and REC mitigate CO\(_2\); NREC contributes to CO\(_2\) | European countries               |
| Mehmood (2020)  | CO\(_2\), TR | Co-integration, Unit root test | TR contributes to CO\(_2\)                      | South Asia countries             |
| Haider (2018)   | CO\(_2\), TR | Unit root analysis, ARDL | EGY contributes to CO\(_2\)                     | Tunisia                          |
| Mahmood (2017)  | CO\(_2\), TR | Cointegration         | TR mitigates CO\(_2\)                           | Saudi Arabia                     |
| Shahbaz (2017)  | CO\(_2\), TR, | Causality            | TR contributes to CO\(_2\)                      | 105 countries                    |
| Kizito (2018)   | FD, TR, GDP | Panel unit root test, cointegration test | FD contributes to TR, GDP; TR contributes to FD, GDP | Nigeria and South Africa         |
| Hélide (2020)   | TR, CO\(_2\), FD, GDP | DOLS FMOLS, DOLS | GDP contributes to CO\(_2\), CO\(_2\) and TR contribute to FD | Brazil                           |

NOTE: FD (financial development), ADL (autoregressive distributed lag model), ARDL (autoregressive distributed bound test), CE (environment degradation), TR (trade), EC (energy consumption), FMOLS (cointegration regression methods), DOLS (dynamic ordinary least squares).

The economy increases production level, which increases carbon emissions, and urbanization has a direct relationship with environmental deterioration [13]. Green technology is a significant factor in reducing carbon emissions [14]. Godil, Yu [15] used QARDL to analyze data from China and concluded that carbon dioxide would decrease due to technology. Braungardt, Elsland [16] pointed out that green technology is a solution to green growth, but cannot reduce carbon dioxide emissions, Wang, Yang [17] also have the same conclusion. Iqbal, Ahmad [18] further highlighted that some organizations did not encourage technology innovation since it is a cost-bearing activity. Wang and Zhu [1] thought that innovation of renewable energy technology negatively influences carbon dioxide emissions. Chien, Ajaz [19] validate the EKC hypothesis to find that economic growth positively affects carbon dioxide emissions. Hence, using technology as a moderator to verify the relationship between financial development, trade liberalization and carbon dioxide emissions is necessary.

Through the above analysis, the objective evaluation of trade liberalization and financial development affecting carbon dioxide emissions is of great importance. The focus is on how trade liberalization and financial development affect carbon dioxide emissions. Will trade liberalization and financial development indirectly contribute to carbon dioxide emissions by other means? Existing literature only studies the independent effects of trade liberalization and financial development on carbon dioxide emissions, which may ignore the objective link between trade liberalization and financial development in carbon emission reduction. In addition, some previous literature lacks empirical data to examine the relationship, and the conclusion only shows unidirectional causality. Based
on this, our paper brings trade liberalization, financial development and carbon dioxide emissions into a unified research framework and adopts the panel vector autoregression (PVAR) analysis method to study the internal relationship between trade liberalization, financial development and carbon dioxide emissions. Without any previous restrictions, the vector autoregressive (VAR) model is used to evaluate the dynamic connection of joint endogenous variables. It creates a model based on statistical data features. It builds a model by treating each endogenous variable in the system as a function of the lag value of all endogenous variables in the system in order to explain variable interaction [20].

Based on the foregoing analysis, this paper intends to examine the link between financial development, trade liberalization and environmental pollution using China’s panel data from 1997 to 2020. Furthermore, given the importance of technology in economic growth, technological innovation is utilized as one factor to analyze financial development’s influence on lowering carbon emissions. The rest of this paper is structured as follows. Section 2 reviews the literature and hypothesis on trade liberalization, financial development and carbon dioxide emissions. Section 3 is the model setting and data description. Section 4 is the empirical analysis of this paper. In Section 5, we summarize the conclusions and give policy recommendations. The limitation and further recommendations are shown in the last section.

2. Literature and Hypothesis

Numerous studies on carbon dioxide emissions have been conducted in recent years. However, the influence of trade liberalization and financial development on carbon dioxide emissions is more dynamic than that of other factors [21].

2.1. Trade Liberalization and Carbon Dioxide Emissions

Some researchers believe that trade liberalization reduces carbon dioxide emissions, and others hold the opposite view [22], based on the analytical framework of Grossman and Krueger [23], Chang and Chang [24] used four alternative measures to find that the relationship between trade liberalization and environmental quality also depends on country corruption. Oh and Bhuyan [25] studied the relationship between economic growth, energy consumption, trade liberalization and carbon dioxide emissions, they found that energy consumption has a positive effect on CO$_2$ emissions, but other variables have a positive effect only in the long run. Tariq, Sun [4] further confirmed the positive relationship between trade liberalization and CO$_2$ emissions. Hdom and Fuinhas [12] used cointegration regression methods to analyze the relationship between economic activities, such as trade, and CO$_2$ emissions in Brazil, they assumed the more trade openness, the more pollution. Still, this situation is not suitable in Brazil and all the countries. Many studies have tested the relationship between trade—environment relationship primarily by factoring trade liberalization into Environmental Kuznets Curve (EKC) theory [5], according to EKC theory, there is an inverted U-shaped, which means that with the growth of the economy, the environmental pollution will increase. When the economy develops to a threshold, environmental pollution will improve. This change is due to endogenously. Although some studies have provided evidence for the pollution paradise theory [26,27], there are still some debates about whether trade liberalization promotes carbon dioxide emissions, and the selection of research objects and the use of different methods are the reasons for the inconsistent results. Previous studies have held that trade liberalization has led to an increase in economic activities, directly leading to an increase in carbon dioxide emissions. At the same time, the degree of trade openness determines the degree of trade liberalization, so trade globalization will also increase carbon dioxide emissions. Accordingly, the first hypothesis is proposed.

Hypothesis 1 (H1). Trade liberalization has a direct effect on CO$_2$. 
2.2. Financial Development and Carbon Dioxide Emissions

Many researchers have found the relationship between financial development and the environment. Since different economic development levels exist across developed and developing countries, recent literature has come to different conclusions about both developed and developing countries [28]. Some studies conclude that financial development may have a negative effect on the environment. Firstly, financial development will prompt consumers to obtain more loans to buy houses, cars and other commodities, whose purchase directly increases the energy demand and thus promotes carbon dioxide emission [29]. Secondly, financial development reduces financing costs to a certain extent, which will prompt enterprises to expand production scale, and also hurt the environment [30]. On the other hand, researchers concluded that financial development might also positively affect the environment. Khan and Ozturk [31] used 88 developing countries’ samples for research and concluded that financial development reduces pollution emissions. Le, Le [32] also reached the same conclusion with Asia as the research object. Phong [33] further took ASEAN-5 countries as the research object. They measured financial development through Durbin–Hausman–Wu statistics to determine the appropriate model, and also believed that financial development was beneficial to environmental improvement. Other scholars [34,35] reached a similar conclusion. According to the quantity theory of money (QTM), financial development will occur through wealth and scale effects, as explained by Xiong and Qi [36]. The financial system can change the flow of capital. By guiding the flow of capital, the industrial structure can be optimized and backward and highly polluting enterprises can be phased out. Financial development also can increase support for basic research, especially for low-carbon technology research, which can bring technological innovation and help to curb environmental pollution. Most importantly, when a country’s finance is highly developed, national policies, consumer preferences, market mechanisms, etc., will change and more attention will be paid to environmental protection, which is also beneficial to reducing carbon dioxide emissions. Accordingly, the second hypothesis is proposed.

Hypothesis 2 (H2). Financial development can decrease CO$_2$ emissions.

2.3. Trade Liberalization and Financial Development

The study of trade liberalization and financial development can be roughly divided into two groups. One group suggests that financial development promotes trade liberalization. They emphasize that the financial system is a kind of resource endowment with highly developed financial systems in countries. Its dependence on the external financing department has a high growth rate [37], that is to say, the financial system in developed countries exports capital-intensive products [38–40]. Yakubu, Aboagye [41] examined the relationship between financial development and international trade relay on 46 countries in Africa, and they revealed the differential effects of finance on trade, and that private credit affects trade. Chan and Manova [42] confirmed theoretically and empirically that countries with developed financial markets have more trading partners. Because these countries have lower financing costs and can achieve greater profits. The other group believes that trade liberalization can promote financial development. It is believed that as a country’s trade liberalization increases, it will increase the demand for external financing products, thus continuously promoting financial development [11,43]. Ibrahim and Sare [44] used the systematic GMM method to study the impact of Africa’s trade liberalization on the development of the financial sector. The study believed that trade liberalization promoted financial development and that human capital accumulation and trade liberalization could be substituted for each other in influencing Africa’s financial development. Ashraf [45] used bank-level data from emerging economies to examine the impact of trade and financial openness on financial development. Their results showed that trade liberalization promoted the development of banking by increasing trading volume and reducing transaction costs. Zhang, Zhu [46] used dynamic panel estimation technology to study the impact of
China’s trade and financial openness on financial development. The results showed that trade liberalization did not promote financial development due to inappropriate resource allocation. According to conventional trade theory, international commerce with a reallocation of resources inside national borders is influenced by exogenous differences between nations [47]. However, some researchers pointed out that conventional trade theory is inadequate to explain what actually happens in the real world, such as the changing character of international trade, the changing roles and relative competitive positions of countries in the world economy [48]. New development theories, in addition, do not predict that trade will unambiguously raise economic development [47]. In empirical studies, since most scholars have studied the impact of financial development on trade liberalization, while only a few have studied the impact of financial development on trade liberalization, further empirical work is needed. Accordingly, the third hypothesis is proposed.

**Hypothesis 3 (H3).** There is a bi-directional causal relationship between financial development and trade liberalization.

3. Model Setting and Data Description

3.1. PVAR Model

The panel data vector autoregressive (PVAR) model was used in Green finance [20], the relationship between renewable energy consumption, economic growth and CO₂ [49], fiscal and taxation policies [50], the interaction effect of government [51]. The proposed panel VAR model was shown as Equation (1).

\[ \Delta \ln(\text{CO}_2) = \mu_{it} + \sum_{j=1}^{p} a_{ij} \Delta \ln(\text{CO}_2) - j + \sum_{j=1}^{p} b_{ij} \Delta \ln(\text{FD}) - j + \sum_{j=1}^{p} c_{ij} \Delta \ln(\text{TR}) - j + \alpha_i + \delta_t + \epsilon_{it} \]  

where \( i = 1, 2 \ldots N, t = 1, 2 \ldots T \), represents the total number of individuals, The subscripts, which are defined as \( i \), \( t \) and \( j \), refer to individual, time and lag order, respectively. \( Y_{it} \) denotes a vector of the endogenous stationary series, \( \alpha_i \) denotes the individual fixed effect, \( \delta_t \) denotes the time fixed effect and \( \epsilon_{it} \) denotes the random error term. The dynamic relationship among different factors was shown in Equations (2)–(4):

\[ \Delta \ln(\text{FD}) = \mu_{it} + \sum_{j=1}^{p} a_{ij} \Delta \ln(\text{FD}) - j + \sum_{j=1}^{p} b_{ij} \Delta \ln(\text{CO}_2) - j + \sum_{j=1}^{p} c_{ij} \Delta \ln(\text{TR}) - j + \alpha_i + \delta_t + \epsilon_{it} \]

\[ \Delta \ln(\text{TR}) = \mu_{it} + \sum_{j=1}^{p} a_{ij} \Delta \ln(\text{TR}) - j + \sum_{j=1}^{p} b_{ij} \Delta \ln(\text{CO}_2) - j + \sum_{j=1}^{p} c_{ij} \Delta \ln(\text{FD}) - j + \alpha_i + \delta_t + \epsilon_{it} \]

3.2. Data Description

Annual provincial panel data from 2005 to 2020 in China were collected from the China Statistical Yearbook, which does not contain Hong Kong, Macao, Taiwan and Tibet due to lack of data. The time interval includes important international events such as China’s accession to the WTO (2001), Financial Crisis (2008) and Brexit (2016).

The carbon dioxide emission (CO₂) was shown in Equation (5).

\[ \text{CO}_2 = \sum a_i \beta_i E_i \]

where \( a_i \) refers to the standard coal coefficient of energy \( i \), \( \beta_i \) refers to the carbon dioxide emission coefficient of energy \( i \), and \( E_i \) refers to the consumption of energy coefficient \( i \). Trade openness (TR) refers to the ratio of the import and export to gross domestic product.
Financial development (FD) refers to the ratio of the sum of deposits and loans of financial institutions to GDP.

3.3. Technology Effect on CO₂ Emission

This study examines the relationship between technology innovation and CO₂ emission. Technology innovation is defined by patents and R&D investment. The corresponding data were from the China Statistical Yearbook and the annual report of listed companies. The model was built as Equations (6) and (7):

\[ \text{CO}_2 = \text{A} \times \text{Technology innovation factor} + \text{B} \]

3.4. SFA Model

In order to study the technology innovation effect on trade liberalization, the SFA model was used. In this paper, based on the SFA model of Battese and Coelli [52], the input and output activities of technological innovation are used in a Trans-Log form.

The detailed models were shown in Equations (8)–(12). The specific models are set as follows: \( Y_{it} \) is each region’s innovation output, \( L_{it} \) is the amount of R&D personnel input in each region, \( K_{it} \) is the amount of R&D capital input in each region, \( i \) is the ranking number of each province and city in China, \( t \) is the period number; \( \beta_0, \beta_1, \ldots, \beta_5 \) are the parameters to be estimated. \( \varepsilon_{it} \) is the random disturbance, \( U_{it} \) is the random error term and obeys \( N(0, \sigma_v^2) \); \( W_{it} \) is the error correction of the regression model for the technical inefficiency term and obeys a truncated normal distribution, i.e., \( W_{it} \sim N(0, \sigma_u^2) \); \( X_{it} \) is the control variable affecting the technical inefficiency; \( \gamma \) is the parameter to be estimated.

The sample period of this study is 1997–2020, and this paper used data from 30 provinces in China obtained from China Science and Technology Statistical Yearbook, China Environmental Statistical Yearbook, China Statistical Yearbook, and China Education Statistical Yearbook.

- \( Y \): innovation output (pieces);
- \( K \): R&D capital stock;
- \( L \): Personnel input in regional R&D activities;
- \( TRL \): Regional trade liberalization level;
- \( ER \): Environmental regulation variables;
- Control variables: The intensity of R&D investment (ST): the ratio of R&D expenditure to GDP; human capital (SCH): the indicator of average years of education. The education level of each province is divided into five levels: no schooling, primary school, junior high school, senior high school and college and above, and the corresponding years of education are 0, 6, 9, 12 and 16, respectively. The average number of years of education required is calculated by multiplying the number of people aged 6 and above at each education level by the corresponding number of years of education and then summing them up to obtain the average number of years of education required. The degree of economic development (GDPPC): The gross regional product per capita (RMB); foreign direct investment (FDI):
The actual amount of foreign investment utilized in the region, which is converted to the average exchange rate of each year, and the logarithm is taken to eliminate systematic errors caused by differences in the order of magnitude of the data.

4. Results and Discussion

4.1. Descriptive Statistics Analysis

Table 2 shows the standard energy coefficient, carbon dioxide emission coefficient and consumption of energy coefficient. As shown in Table 3, the average of lnCO$_2$, lnTR, lnFD is 4.82, −2.43 and 18.54; the standard error of lnCO$_2$, lnTR, lnFD is 9.89, 0.68 and 25.38; the minimum value of lnCO$_2$, lnTR, lnFD is 8.01, −2.13 and 18.65; the maximum is 0.86, 1.68 and 1.76. We used 1000 observations to analyze the nexus between financial development, trade liberalization and carbon dioxide emissions. Standard errors are examined for the effect on sample size. The standard error of lnFD is 25.38, which means lnFD is easily affected by sample size, while lnTR is not. The minimum and maximum of lnFR are very different, which shows that deposits and loans of financial institutions are different according to economic level.

Table 2. Energy Standard Coal Coefficient ($\alpha_i$), Carbon Dioxide Emission Coefficient ($\beta_i$) and consumption of energy coefficient ($E_i$).

| Energy     | Coal     | Coke    | Crude Oil | Kerosene | Fuel | Gasoline | Diesel | Natural Gas |
|------------|----------|---------|-----------|----------|------|----------|--------|-------------|
| $\alpha_i$ | 0.756    | 0.855   | 0.586     | 0.571    | 0.619 | 0.554    | 0.592  | 0.448       |
| $\beta_i$  | 0.714    | 0.971   | 1.429     | 1.471    | 1.429 | 1.471    | 1.457  | 1.330       |
| $E_i$      | 0.942    | 0.4653  | 1.4286    | 1.4714   | 1.4714| 1.428    | 1.4571 | 1.737       |

Table 3. Descriptive Statistics.

| Variable  | lnCO$_2$ | lnTR   | lnFD   |
|-----------|----------|--------|--------|
| Observations | 1000     | 1000   | 1000   |
| The Average | 4.82     | −2.43  | 18.54  |
| Standard Error | 9.89     | 0.68   | 25.38  |
| The Minimum Value | 8.01     | −2.13  | 18.65  |
| The Maximum   | 0.86     | 1.68   | 1.76   |

4.2. Panel Unit Root Test

Table 4 summarizes the results of the unit root tests. It showed that the variables are stationary at levels. LLC test showed lnCO$_2$ is stationary at levels 1% and 5% significance levels, which are 0.0298 and 0.2862. lnFD is 5% significance level, which is 0.2318 and 0.1839. lnTR is 1% and 10% significance level, which is 0.1836 and 0.2736. All variables are stationary at the first differenced form. The conclusion of the IPS test showed that all variables reject the unit root null hypothesis, and lnCO$_2$ it is at 1% and 5% significance levels, which are 1.325 and 1.438. lnTR is significant at the level of 10%, which is 0.416 and 1.428.

Table 4. Results of Unit Root Test.

| Variable    | LLC Test               | IPS Test               |
|-------------|------------------------|------------------------|
|             | Constant Term | Trend and Constant Terms | Constant Term | Trend and Constant Terms |
| The Level   | lnCO$_2$       | −0.0298 **             | −0.2862 ***         | 1.325 **               | −1.438 ***         |
|             | lnFD           | −0.2318 **             | −0.1839 **          | −2.136 **             | 1.462 **           |
|             | lnTR           | −0.1836 *              | −0.2736 ***         | −0.416 **             | −1.428 **          |
| A First Order Differential | lnCO$_2$       | −0.8654 **             | −1.3584 ***         | −7.652 ***            | −6.864 **          |
|             | lnFD           | −0.7826 **             | −0.9128 ***         | −6.648 **             | −7.126 ***         |
|             | lnTR           | −0.8012 ***            | −1.358 **           | −8.165 **             | −5.864 **          |

Note: * $p < 0.1$ ** $p < 0.05$ *** $p < 0.01$. 
4.3. PVAR Evaluation

4.3.1. Lagging Items Screening

Table 5 showed the lagging item screening. The AIC, BIC and HQIC for the lag 1 were $-5.7624$, $-5.2346$, $-6.2345$. And the BIC and HQIC were significant for lag 1. For lag 2, the AIC, BIC and HQIC values were $-5.6219$, $-5.0138$, $-5.4326$, respectively. For lag 3, the AIC, BIC and HQIC values were $-5.5628$, $-4.4316$, $-5.6138$, respectively. For lag 4, the AIC, BIC and HQIC values were $-5.3129$, $-4.2364$, $-5.6183$, respectively. For the lag 4, the AIC, BIC and HQIC values were significant.

Table 5. Lagging Item Screening.

| Lag | AIC    | BIC    | HQIC    |
|-----|--------|--------|---------|
| 1   | $-5.7624$ | $-5.2346$ * | $-6.2345$ ** |
| 2   | $-5.6219$ | $-5.0138$ | $-5.4326$ |
| 3   | $-5.5628$ *** | $-4.4316$ | $-5.6138$ |
| 4   | $-5.3129$ *** | $-4.2364$ ** | $-5.6183$ ** |

Note: * $p < 0.1$ ** $p < 0.05$ *** $p < 0.01$.

4.3.2. PVAR Evaluation Results

Table 6 reports the estimation results of the PVAR model. The results show that the first and third lags of the CO$_2$ are positively correlated with its current level. The estimated coefficients associated with the first and third lags of CO$_2$ are equal to 1.912 and 0.236, and they are significant both at the 1% levels, indicating that the carbon dioxide in the previous period promoted the increase of carbon dioxide emissions in the current period. Additionally, the first and third lags of CO$_2$ positively determine the current level of financial development at the 5% and 1% level of significance, which means that the carbon dioxide emissions increase financial development, which is consistent with Hypothesis 2, financial development can affect CO$_2$ emissions. The coefficient is significant at the level of 1% level of financial development, the coefficient is 0.236. It is the third-order lag coefficient, indicating financial development promotes CO$_2$ emissions.

Table 6. PVAR Evaluation Results.

|        | $h_{\ln CO_2}$ | $h_{\ln FD}$ | $h_{\ln TR}$ |
|--------|----------------|--------------|--------------|
| L.$h_{\ln CO_2}$ | 1.912 *** (2.39) | 0.068 ** (0.196) | $-0.023$ (-0.17) |
| L.$h_{\ln FD}$ | 0.218 ** (0.873) | $0.624$ ** (1.86) | $0.723$ ** (0.65) |
| L.$h_{\ln TR}$ | $-0.023$ ** (-0.18) | $-0.076$ *** (-1.96) | 1.126 *** (3.86) |
| L2.$h_{\ln CO_2}$ | $-0.216$ (-1.36) | $0.076$ ** (1.46) | $-0.051$ (-0.42) |
| L2.$h_{\ln FD}$ | $0.054$ ** (0.38) | $-0.204$ (-1.54) | $-0.286$ ** (-0.68) |
| L2.$h_{\ln TR}$ | $0.014$ ** (0.23) | $0.027$ * (2.19) | $-0.321$ *** (-1.54) |
| L3.$h_{\ln CO_2}$ | $0.236$ *** (0.56) | $0.048$ *** (1.29) | 0.064 ** (0.44) |
| L3.$h_{\ln FD}$ | 0.238 ** (1.41) | 0.312 ** (0.71) | $-0.253$ ** (-1.54) |
| L3.$h_{\ln TR}$ | 0.184 (1.42) | 0.039 ** (1.74) | 0.154 ** (2.12) |
| L4.$h_{\ln CO_2}$ | $-0.108$ ** (-0.48) | $-0.065$ * (-0.37) | $-0.224$ (-1.86) |
| L4.$h_{\ln FD}$ | 0.018 (0.12) | $-0.064$ (-0.22) | 0.264 (0.754) |
| L4.$h_{\ln TR}$ | $-0.178$ (1.54) | 0.116 ** (1.14) | $-0.122$ *** (-1.46) |

Note: * $p < 0.1$ ** $p < 0.05$ *** $p < 0.01$. 
4.4. Variance Decomposition

Table 7 showed the variance decomposition. The results indicated that for the results of the 10 periods, the contribution from highest to lowest are carbon dioxide emissions (81.3%), trade liberalization (11.8%) and financial development (4.6%). The smallest is trade liberalization is responsible for 63.4%, 31.4% and 11.2% respectively. As for trade liberalization (51.3%), then carbon dioxide emissions were 13.2%.

Table 7. Variance Decomposition.

|          | lnCO$_2$ | lnFD | lnTR |
|----------|----------|------|------|
| lnCO$_2$ | 0.813    | 0.046| 0.118|
| lnFD     | 0.634    | 0.314| 0.112|
| lnTR     | 0.132    | 0.026| 0.513|
| lnCO$_2$ | 0.584    | 0.026| 0.038|
| lnFD     | 0.664    | 0.038| 0.126|
| lnTR     | 0.178    | 0.038| 0.882|

4.5. Granger Causality Test

Table 8 showed the results of the Granger causality test. When the variable was lnCO$_2$, the chi-square value for lnFD was not the cause, lnTR is not the cause, and all were 27.124, 4.436 and 47.238, respectively. The $p$ values were 0.003, 0.246 and 0.012, respectively.

Table 8. The Results of Granger Causality Test.

| Variable | Causal Relationship | Chi-Square Value | $p$ Values |
|----------|---------------------|------------------|------------|
| lnCO$_2$ | lnFD is not the cause | 27.124           | 0.003      |
|          | lnTR is not the cause | 4.436            | 0.246      |
|          | ALL                 | 47.238           | 0.012      |
| lnFD     | lnCO$_2$ is not the cause | 17.241          | 0.003      |
|          | lnTR is not the cause | 25.132           | 0.001      |
|          | ALL                 | 43.218           | 0.002      |
| lnTR     | lnCO$_2$ is not the cause | 6.2413          | 0.026      |
|          | lnFD is not the cause | 12.746           | 0.022      |
|          | ALL                 | 23.244           | 0.002      |

From the carbon dioxide emission equation, the null hypothesis is rejected at the significance level of 1%, that the carbon dioxide emissions rely on financial development. From the financial development equation, the original hypothesis is rejected at the 1% level of significance that financial development is not determined by carbon dioxide emissions and trade liberalization.

4.6. Technology Innovation Effect on Carbon Dioxide Emissions

Figure 1 shows the trend of carbon dioxide emissions and the technology innovation factor, which indicates carbon dioxide emissions have a strong correlation with the technology innovation factor. The coefficient of determination R-Square is 0.9755, indicating that 97.6% of the increase in carbon dioxide can be explained by technological innovation, and the fitting degree is good. The adjusted Adj. R-square is 0.974, which also indicates that the model fitting effect is good.

4.7. Technology Innovation Effect on Trade Liberation

Table 9 gives the estimation results of the SFA of the main function of models 1 and 2. As shown in Table 9, the $\sigma$ value passes the test at the 5% level of significance, which is 0.3214 in model 1, and the 1% level of significance, which is 0.1324. The $\gamma$ values pass the test at the 1% level of significance; in model 1 and model 2, the $\gamma$ value reaches 0.5238 and 0.6852, respectively, which indicates technical inefficiency was affected by random disturbance.
This paper adds TRL$^2$ and ER$^2$ to study the nonlinear relationship between trade liberalization and environmental regulation in model 2 and model 3. Models 4, 5 and 6 test the synergistic effects of trade liberalization and environmental regulation intensity on innovation efficiency. As shown in model 1 and model 2 in Table 10, we can see that there is a “U” shape relationship between trade liberalization and innovation inefficiency, i.e., an inverted “U” shape relationship with innovation efficiency. In model 1, TR, ER and SCH are significant at a 5% level, and ST and InFDI are significant at a 1% level. In model 2, TRL$^2$ is significant at a 5% level, which is 0.6254. In model 4 and 5, we can see both TRL and ER are significant at a 5% level, and environmental regulation positively regulates the non-linear effect of trade liberalization on innovation efficiency. The same show that trade liberalization also positively regulates the inverted “U” shape of environmental regulation on innovation efficiency.
Table 10. SFA estimation of the impact of trade liberalization and environmental regulation intensity on innovation inefficiency.

| Explanatory Variable | Model 1 | Model 2 | Model 3 | Model 4 | Model 5 | Model 6 |
|----------------------|---------|---------|---------|---------|---------|---------|
| TRL                  | −0.7938** | −1.2635*** | −0.7836*** | −1.3245** | −1.8234*** | −1.8642*** |
|                      | (−2.94) | (−5.12) | (−3.13) | (−6.14) | (−4.63) | (−5.24) |
| ER                   | −0.0016** | 0.008* | −0.0186** | −0.0345** | −0.0038*** | −0.0084** |
|                      | (−1.83) | (2.64) | (−5.65) | (−2.31) | (−1.89) | (−3.41) |
| ST                   | 53.3126*** | 35.6214*** | 51.2354*** | 7.2142** | 28.3126*** | 23.1264*** |
|                      | (4.36) | (9.21) | (8.14) | (2.58) | (8.38) | (7.68) |
| SCH                  | −1.3842** | −0.2435* | −0.1462** | 0.1327* | −0.0125* | 0.0256* |
|                      | (−1.85) | (−1.15) | (−1.69) | (0.96) | (−0.28) | (0.84) |
| GDPPC                | −0.2135* | −0.1328** | −0.1564** | −0.1625** | −0.1628** | −0.1832* |
|                      | (−0.65) | (−1.94) | (−1.38) | (−2.42) | (−1.68) | (−4.16) |
| lnFDI                | −0.1245*** | 0.0186* | 0.0846** | −0.2438** | −0.0628** | −0.0542** |
|                      | (−2.46) | (0.54) | (1.37) | (−3.46) | (−1.86) | (−1.68) |
| TRL^2                | 0.6254** | (2.57) | 0.8654*** | (4.56) | 0.8321** | (2.46) |
| ER^2                 | 0.0004*** | (5.18) | 0.0013** | (2.41) | 0.0008** | (4.28) |
| ER × TRL             | 0.0116** | (0.64) | 0.0285** | (2.16) | 0.0011** | (1.32) |
| ER × TRL^2           | 2.4268** | 0.8854** | 1.6824*** | 1.2454** | 0.9245** | 0.8324** |
|                      | (2.34) | (3.18) | (1.98) | (1.65) | (2.14) | (2.34) |
| Observed Value       | 690 | 690 | 690 | 690 | 690 | 690 |
| σ^2                  | 0.2245*** | 0.1768** | 0.1589** | 0.2345** | 0.1158*** | 0.1254** |
|                      | (6.48) | (13.46) | (8.24) | (3.76) | (8.42) | (1.74) |
| r                    | 0.2546** | 0.6824*** | 0.1948** | 0.4326*** | 0.5342*** | 0.6218*** |
|                      | (1.35) | (10.74) | (2.17) | (6.18) | (1.86) | (1.53) |
| Likelihood Ratio (LR)| −152.4856 | −137.5246 | −131.8426 | −151.2164 | −130.4258 | −114.2376 |

Note: * p < 0.1 ** p < 0.05 *** p < 0.01.

5. Conclusions and Policy Recommendations

This paper investigated the dynamic relationship between trade liberalization, financial development and carbon dioxide emissions employing the PVAR model and Chinese panel data of 30 provinces. This paper also analysis technology innovation as a variable to analyze the relationship between trade liberalization, environmental regulation and carbon dioxide emissions. Based on the analysis, we draw the following conclusions.

First, trade liberalization in China supports financial development, which in turn boosts carbon dioxide emissions, but trade liberalization has negligible effects on carbon dioxide emissions and limited support for international commerce. As a result, it is critical to limit the negative environmental effect of financial development, continually improve the financial system and direct money to invest in the green economy, low-carbon economy and circular economy. As the primary polluters of the environment, enterprises should actively engage in technological innovation activities aimed at improving enterprise production efficiency, lowering the cost of pollution discharge per unit of output and reducing pollution from enterprise production to the ecological environment, as well as promoting the development of high-tech industries, exit outdated, high-polluting businesses.

Second, China’s financial development increases carbon dioxide emissions, whereas trade liberalization has little influence. The government should preserve the financial system’s service stability and build a diverse financial service system. To avoid increased environmental pollution due to financial development, it is necessary to use financial means to accelerate the transition of economic development mode, promoting more financial
resources to flow into green finance and prioritizing support for green, environmental protection, energy-saving and low-polluting enterprises.

Third, there is a bi-directional causal link that occurs not just between financial development and CO₂ emissions but also between trade liberalization and financial development. The amount of technical innovation influences the environmental effect of financial development. Environmental protection technology should be regularly updated to increase firm production efficiency and achieve energy-saving emissions. Simultaneously, consideration should be given to the indirect impact of trade liberalization on the environment. In the future, Chinese enterprises should prioritize independent research and development in the globalization process and integrate themselves into the global value chain, shifting from the production of low-value-added, high-energy-consuming products to the production of high-value-added, low-energy-consumption products.

Fourth, the government should fully embrace the role of financial development in trade liberalization. Since China’s reform and its opening up, the domestic financial industry has grown. However, because China’s financial system is still in its early stages, foreign trade development has not played a significant role. With the rise of trade protectionism, China will continue to follow the road of trade liberalization, improving financial products and boosting the level of financial services, all of which benefit global economic development. Simultaneously, as part of the financial development and trade structure adjustment, greater attention should be made to the formation and upgrading of finance-related systems, laws and regulations in order to meet China’s carbon emission reduction targets.

Fifth, there is a significant inverted “U” curve relationship between trade liberalization and innovation efficiency, environmental regulation and innovation, Foreign direct investment also had a positive impact on technological innovation. Although environmental regulations have been strengthened, regional innovation efficiency has shown a trend of increasing first and then decreasing. Thus, we should further increase the degree of trade liberalization, combine trade liberalization with environmental regulation and improve independent innovation capability.

6. Limitations and Future Recommendations

In our study, there are several limits in our research that can be solved in the approaching years. To begin, a substantial body of literature indicates that financial growth and trade liberalization are major mechanisms influencing carbon dioxide emissions, and our study focuses on these two factors. However, we use the ratio of each province’s total import and export volume to GDP to gauge trade liberalization, which may potentially affect carbon dioxide emissions through other pathways. What exactly are these channels? Further research is required for our study. Second, the panel data used in this paper’s empirical analysis is limited at the province level due to data availability. The findings will be strengthened if it reaches the municipal or county level.

Given the limitations mentioned above, future studies can focus on analyzing the influence of financial outcomes and financial efficiency on carbon dioxide to acquire a more thorough knowledge of the link between financial development and carbon dioxide. Second, investigating how financial development and trade liberalization impact carbon dioxide emissions can help to enhance the relevant theoretical theory. Third, future research may expand existing research by adding data analysis at the municipal level and also add new variables, such as the impact of environmental regulations on carbon dioxide emissions, as well as new models, to solve the endogenous problem and investigate the two-way influence mechanism of trade liberalization, financial development and carbon emissions.

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