An empirical analysis of the role of China’s exports on CO2 emissions

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An empirical analysis of the role of China's exports on CO₂ emissions

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HIGHLIGHTS

- We attempt to correct China’s coal consumption data.
- We discover Granger Causality running from exports to CO₂ emissions.
- We discover Granger Causality running from exports to trade-openness.
- Policies aimed at controlling exports can control CO₂ emissions.
- Policies aimed at controlling coal consumption will affect exports and CO₂ emissions.

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ABSTRACT

China is one of the world’s most rapidly growing countries and the largest consumer of energy in the world. As a result, China’s pollution emissions almost doubled from 2002 to 2007, and in 2006 it surpassed the United States to become the world’s top carbon dioxide emitter. Understanding the sources of emissions is essential towards designing policies aimed at curbing carbon emissions in China. The surge in China’s exports has been partially blamed for this increase in emissions. To understand the sources of emissions, this study uses a vector autoregression model to examine the relationship among exports, CO₂ emissions, coal consumption and trade openness in China for the years 1970–2010. The study uses a modified version of Granger Causality developed by Toda and Yamamoto [56]. The main findings within the study indicate: (1) Granger Causality running from exports to emissions; (2) Granger Causality running from coal consumption to exports; and (3) GDP determines future variability in exports and CO₂ emissions. Results suggest that governmental policies aimed at controlling coal consumption could affect CO₂ emissions and exports. Results from this study should assist in formulating policies to mitigate both CO₂ emissions and coal consumption.

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1. Introduction

China is one of the most rapidly growing countries in the world and is the largest energy consumer [21]. In 2006, China surpassed the US as the world’s top gross carbon dioxide (CO₂) emitter with 6.1 billion tons of annual emissions and by 2008 had already outdistanced the US by 1.5 billion tons [40].¹ China’s CO₂ emissions grew at 3.3% per year between 1990 and 1999, accounting for 13% of global emissions. These emissions doubled over the next decade, growing at 8.9% per year between 2000 and 2007, and accounting for 17% of global emissions. Presently, China emits 21.3% of global CO₂ emissions [17,55]. The rapid expansion of the Chinese economy, coupled with a coal-oriented energy structure, has made coal consumption a major source of emissions [63]. The country is moving from a predominantly agricultural economy to one that is increasingly urbanized and industrialized [1]. Moreover, growth in coal-fired electricity generation has been cited as a reason for the surge in emissions.

New research indicates that about a third of all Chinese carbon dioxide emissions are the result of producing goods for export to developing and developed countries. Weber et al. [58] found that in 2005, around one-third of Chinese CO₂ emissions were generated by the production of goods for export while Wang and Watson [57] concluded that net exports from China accounted for 23% of its total CO₂ emissions in 2004. Shui and Harris [50] estimated that in 2003, close to 14% of China’s CO₂ emissions came from producing goods for export. This problem is likely to persist owing to the rising popularity of China’s exports which account for 10% of global exports. Theory implies that for some countries a competitive advantage for production exists directly because of differences in environmental regulations. The pollution haven hypothesis postulates that “pollution havens” will attract polluting industries that

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¹ The term “CO₂ emissions” and “emissions” are used interchangeably throughout this paper.

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relocate from more stringent locales, although studies have found little evidence to support this theory [13,23,9].

China’s exports are inexpensive and attractive because of the low wages and low cost of raw materials that minimize production costs. In addition, costly pollution controls are often not implemented in China [57]. This partially explains why China has overtaken Germany to become the world's top exporter [62]. Given the link between China's exports and carbon emissions, studies have sought to analyze this relationship using economy-wide modeling and econometric methods. These studies have not adequately addressed this analysis using accurate data; i.e., some studies have employed data with questionable reliability. This study contributes to the existing literature by analyzing the relationship between exports and emissions using improved coal consumption data in China as a number of studies have cast doubt on the validity of China's reported coal consumption figures. This issue is circumvented by employing a data-driven interpolation technique that gives more accurate figures over the past three decades. Given these accurate estimates the relationship between exports, coal consumption, GDP, CO2 emissions and trade openness is modeled within a multivariate time series model. The findings, from a global point of view, may provide ideas for emission reduction strategies that China can adopt. The analysis will forecast the variability of emissions and coal consumption to 10 years, while other studies have focused on constructing forecasts of longer horizons of 50 or 100 years [46]; McCarthy [38].

This study is important in some ways. Understanding the key drivers behind China’s growing CO2 emissions is critical for designing climate policies. They provide an insight into how other emerging economies like India and Vietnam may develop low emission economies in the future. In addition, CO2 emissions in China have a global impact, making its engagement in global climate change mitigation essential. Numerous studies have highlighted the domestic and global environmental impacts of China's coal usage [25,53,69]. Finally, given China's integration in the global economy, the study of China's economic development and energy infrastructure is vital to the health of global economic development.

This paper also seeks to investigate the relationship between China’s exports and CO2 emissions. A fraction of emissions are produced by the manufacturing, electric power and transportation industries needed for producing goods for export. Others are embodied in the exports themselves. China's energy infrastructure is primarily coal based which accounts for 74% of total national energy consumption. Consequently, large quantities of greenhouse gases are emitted contributing to global climate change. Further, trade liberalization has been touted as a reason for China's growth in GDP. The adoption of the open-door policy in China propelled the country to become one of the fastest growing economies in the world. The direction of causality between economic growth and trade openness has been a subject of extensive debate. Thus, the relationship between trade openness and GDP is sought to be examined. Trade openness is defined as the ratio of external trade (imports plus exports) to GDP as used in the literature [34]. Therefore, a variable for trade openness is explored in this analysis.

The remainder of the study is organized as follows. The next section reviews the literature pertaining to this study while the third section presents the model and data. Section 4 presents the results and Section 5 offers the conclusions.

2 Other energy sources of energy contribute to emissions but this study seeks to examine the contribution of coal and exports to CO2 emissions. Future studies in this area may look into the effect of these sources on emissions.

3 This summary is not meant to be an exhaustive review of the literature, but rather key findings as they relate to this particular study.

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2. Literature review

Energy consumption in China has attracted considerable research interest due to the environmental ramifications caused by the extensive use of coal, which has propelled high economic growth for the past two decades. This interest spans many sub-branches of economics. Past studies have looked into sources and ways of reducing CO2 emissions while others have analyzed the relationship between emissions and exports. The methods used vary – a majority employ economy-wide modeling that include input–output techniques while others use econometric techniques for analysis and forecasting. Given the breadth of interests, this literature review explores different literatures which relate directly or indirectly to this particular study. Since this analysis is broad, we present a brief summary in Table 1 of the major themes within the literature and key findings within particular studies.3

A number of regional and nationwide studies have sought to analyze the sources of emissions at the global and regional levels. Using the Kaya identity, Raupach et al. [45] found that population and GDP are the main drivers of emissions. The Kaya identity is a decomposition analysis that is used to explore the differing trends of factors contributing to carbon dioxide emissions [26]. The identity is comprised of three primary factors: economic growth, population growth, and energy consumption. A majority of studies on China concluded that structural changes across sectors of the economy are one of the main causes of emissions before the 1990s, whereas technological change within sectors has had a greater impact more recently [37]. Streets et al. [54] used an atmospheric transport model to study emissions in the Pearl River Delta region. This region is known to produce goods for export to North America, Europe and Asia. Streets et al. [54] discovered that pollution in the area is caused by the manufacturing and transportation industries. Their study found that the region is responsible for 5–30% of the ambient concentrations of various emissions. A study by Gregg et al. [17] recommended that controlling fossil fuel combustion from electricity power generation and the cement manufacturing in China would reduce emissions.

Fang et al. [14] found that simple improvements to small industrial boilers could reduce CO2 emissions in China by as much as 63 Mtons and save 34 Mtons of coal at an estimated cost of $10 per ton of CO2. Liang et al. [32] investigated stakeholder and public perceptions of deploying carbon capture and sequestration (CCS) technologies in China. They found that a majority of those surveyed perceived climate change to be a major problem and viewed CCS as a necessary mechanism to reduce CO2 emissions in China. Choi et al. [7] use a data envelope analysis to estimate the potential reductions of CO2 emissions through production and technological efficiencies. They find that by adopting better efficiencies, CO2 emissions can, on average, be reduced by approximately 56.1M tons in each province and 1683 Mtons nationwide; but, the efficiencies will be easier to achieve in the well-developed eastern part of the country as opposed to the less well-developed western part.

Two fairly recent studies highlight how the adoption of biofuels in China may reduce greenhouse gas (GHG) emissions including CO2. Hu et al. [20] consider the adoption of cassava-based ethanol as an alternative automotive fuel in China and conduct a lifecycle analysis (LCA) to examine the impacts on energy consumption and CO2 emissions from the adoption of such a policy. They find that 10% mandate of blending the ethanol with conventional automotive fuel could significantly lower CO2 emissions, but a nationwide program would require an untenable 42% of total farmland in
China in order to meet the fuel demand. Xunmin et al. [65] extend the analysis of Hu et al. [20] by considering six different biofuel pathways. Like the previous authors, Xunmin et al. [65] conduct a LCA to examine the impacts on energy consumption and GHG emissions. They argue that different biofuels pathways are required for China because each provincial region is geographically unique for the country. Ultimately, they find that these biofuel pathways can reduce both energy consumption and GHG emissions.

The Heckscher–Ohlin theory of trade suggests that given free trade, a developing country will specialize in the production of goods in which it is abundantly endowed [15]. This endowment then will determine how intensive certain factors will be used in producing those goods. Population and GDP were the main drivers of emissions.

1. Raupach et al. [45] Time series analysis and kaya identity China, region and the world Population and GDP were the main drivers of emissions

1.2. Streets et al. [54] Atmospheric transport model Pearl river delta region in China Pollution in the region is caused by the manufacturing and transportation industries

1.3. Gregg et al. [17] Time series analysis China Fossil fuel combustion from electricity power generation and the cement manufacturing in China

2. Economy-wide modeling techniques

2.1. Lin and Polenske [33] Structural decomposition analysis China Increased expenditures on capital products were the main cause of a rise in emissions.

2.2. Weber et al. [58] Input–output model China The export industry generated 33% of China’s total emissions. International trade played a significant role in redistributing carbon emissions.


2.4. Yunfeng and Laike [66] Input–output China and the European Union The intermediate demand sector was largely responsible for GHG emissions within the country.

2.5. Chung et al. [8] Index decomposition analysis and energy input–output model South Korea

3. Forecast emissions

3.1. ZhiDong [68] Integrated econometric model China China will sustain a 6% economic growth rate in the coming years, presenting challenges for CO2 emission reductions.

3.2. Auffhammer and Carson [3] Using dynamic models with spatial dependence and provincial – level panel data China The magnitude of the projected increase in Chinese emissions is several times larger than reductions embodied in the Kyoto Protocol.

4. Time series analysis

4.1. Lean and Smyth [30] Toda and Yamamoto [56], and Dolado and Lütkepohl [11], VAR VECM Malaysia Bi-directional Causality running between aggregate output and electricity consumption. They also found Granger Causality running from exports to aggregate output.

4.2. Sami [47] VECM Japan Causality running from exports and real GDP per capita to electricity consumption. The study also established a cointegrating relationship among electricity consumption, economic growth and exports.

4.3. Shiu and Lam [49] ECM China Real GDP and electricity consumption for China are cointegrated. There is Granger Causality running from electricity consumption to real GDP

Weber et al. [58] used a standard input–output model of the Chinese economy which reflected the amount of money flowing between sectors and found that in 2005, the export industry generated 33% of China’s total emissions. Chen and Chen [6] studied carbon emissions and resource use in the Chinese economy using an ecological input–output model. They found that international trade plays a significant role in redistributing carbon emissions. More specifically, 3.59 or 5.54 gigatons of carbon dioxide equivalents of GHG emissions are embodied in exported products. A recent study by Yunfeng and Laike [66] examined the quantity of CO2 emissions embodied in the trade between China and the European Union. The paper identifies the sectors contributing most to these embodied CO2 emissions using the input–output approach; they find that the machinery and manufacturing sectors substantially contribute to emissions embodied in exports. Chung et al. [8] conduct a similar input–output analysis but instead consider South Korea. Through the use index decomposition analysis and an energy input–output model they found that the intermediate demand sector including the industrial sector accounted for approximately 85% of final energy demand, and as a result the intermediate demand sector was largely responsible for GHG emissions within the country.

In the future, China’s CO2 emissions are projected to grow faster than the economy Hohne et al. [19]. It is therefore important to forecast emissions to predict future paths of CO2 emissions in China. Several econometric techniques have been employed for forecast analyses. ZhiDong [68] used an integrated econometric model to perform a long-term simulation study in China for a 30 year period and found that China will sustain a 6% economic growth rate in the coming years, presenting challenges for CO2 emission reductions. Using a panel dataset from 1985 to 2004,
Auffhammer and Carson [3] explore alternative econometric specifications for forecasting China’s CO2 emissions. Using dynamic models with spatial dependence and provincial-level panel data, they found that the magnitude of the projected increase in Chinese emissions (out to 2015) is several times larger than reductions embodied in the Kyoto Protocol.

A number of studies have incorporated time series analysis to study interactions among variables that fuel increasing emissions. Lean and Smyth [30] examined the causal relationship among aggregate output, electricity consumption, exports, labor and capital using a multivariate model for Malaysia. They found bi-directional Granger Causality running between aggregate output and electricity consumption. They also found Granger Causality running from exports to aggregate output. A study by Sami [47] reviewed the relationship among electricity consumption, exports and real income per capita in Japan. Using a vector error correction model (VECM), their results indicated causality running from exports to aggregate output. Another study by Shiu and Lam [49] established a cointegrating relationship among electricity consumption, exports and labor productivity. A similar study by Lee [12] also established a cointegrating relationship among electricity consumption, exports, labor and capital.

The studies here offer a comprehensive overview of the structure of China’s emissions and their sources; however, there is a paucity of studies that use time series analysis to determine the influence of exports on China’s emissions.

3. Model and data description

3.1. Model

The vector autoregressive (VAR) system is constructed using the following five variables: exports ($x_t$), emissions ($e_t$), coal consumption ($c_t$), GDP ($m_t$) and trade openness ($p_t$). The system of equations with one lag is expressed as:

$$
X_t = \begin{bmatrix} x_{1t} \\ x_{2t} \\ x_{3t} \\ x_{4t} \\ x_{5t} \end{bmatrix} = \begin{bmatrix} 1 \\ x_{1t-1} + x_{2t-1} + x_{3t-1} + x_{4t-1} + x_{5t-1} + e_{ct} \\ x_{2t-1} + x_{3t-1} + x_{4t-1} + x_{5t-1} + e_{ct} \\ x_{3t-1} + x_{4t-1} + x_{5t-1} + e_{ct} \\ x_{4t-1} + x_{5t-1} + e_{ct} \\ x_{5t-1} + e_{ct} \end{bmatrix} + \begin{bmatrix} e_{ct} \\ e_{ct} \\ e_{ct} \\ e_{ct} \end{bmatrix} + \begin{bmatrix} 0 \\ 0 \\ 0 \\ 0 \\ 0 \end{bmatrix},$$

(1)

where $A_t$ is a $(5 \times 1)$ column vector of intercepts and $A_{t}$ is a $(5 \times 5)$ matrix of estimated coefficients on the first lag of the explanatory variables. The system of equations can be extended to multiple lags, as follows:

$$
x_t = x_{10} + \sum_{j=1}^{r} a_{1j} x_{j-1} + \sum_{j=1}^{r} a_{1j} e_{j-1} + \sum_{j=1}^{r} a_{1j} c_{j-1} + \sum_{j=1}^{r} a_{1j} m_{j-1} + \sum_{j=1}^{r} a_{1j} p_{j-1} + e_{ct},
$$

(3)

$$
e_t = e_{20} + \sum_{j=1}^{r} a_{2j} x_{j-1} + \sum_{j=1}^{r} a_{2j} e_{j-1} + \sum_{j=1}^{r} a_{2j} c_{j-1} + \sum_{j=1}^{r} a_{2j} m_{j-1} + \sum_{j=1}^{r} a_{2j} p_{j-1} + e_{ct},
$$

(4)

$$
c_t = c_{30} + \sum_{j=1}^{r} a_{3j} x_{j-1} + \sum_{j=1}^{r} a_{3j} e_{j-1} + \sum_{j=1}^{r} a_{3j} c_{j-1} + \sum_{j=1}^{r} a_{3j} m_{j-1} + \sum_{j=1}^{r} a_{3j} p_{j-1} + e_{ct},
$$

$$
m_t = m_{40} + \sum_{j=1}^{r} a_{4j} x_{j-1} + \sum_{j=1}^{r} a_{4j} e_{j-1} + \sum_{j=1}^{r} a_{4j} c_{j-1} + \sum_{j=1}^{r} a_{4j} m_{j-1} + \sum_{j=1}^{r} a_{4j} p_{j-1} + e_{ct},
$$

$$
p_t = p_{50} + \sum_{j=1}^{r} a_{5j} x_{j-1} + \sum_{j=1}^{r} a_{5j} e_{j-1} + \sum_{j=1}^{r} a_{5j} c_{j-1} + \sum_{j=1}^{r} a_{5j} m_{j-1} + \sum_{j=1}^{r} a_{5j} p_{j-1} + e_{ct},
$$

(5)

which implies the following generalization,

$$
y_t = A_0 + A_1 y_{t-1} + \cdots + A_r y_{t-r} + e_t.
$$

(6)

Given multiple lags a generalization of the coefficient matrix, $A_t$, would indicate the $r$th lag of the explanatory variables [12].

To test the null hypothesis that there is “Granger Causality” from exports to emissions, the null: $H_0: A_{21} = 0$ is tested, where the $A_{21}$s are the coefficients of $x_{t-1}, x_{t-2}, \ldots, x_{t-r}$ respectively in the second equation in the VAR system. The causality from emissions to exports can be established through rejecting the null hypothesis which requires finding the significance of the Modified Wald (MWald) statistic for the group of the lagged independent variables identified above. To complement the VAR, vector decompositions were developed to check whether the variables affect one another in the “future,” which assist in confirming the results of Granger Causality. For completeness, the impulse response functions are presented to provide a visual depiction of variable’s responses to shocks.

3.2. Coal consumption data

The past literature has reported that data on China’s coal consumption suffer from under-reporting. Sinton [52] offers a comprehensive overview relating to the accuracy and reliability of China’s coal statistics. The point of contention in the data relates to the period between late 1990s and early 2000s. During this time, official energy statistics showed a significant decrease in coal consumption despite increases in Chinese CO2 emissions. Further, satellite data suggest that there was significant under-reporting of coal consumption, which lead Akimoto et al. [2] to conclude that the official statistics should not be used for emission inventories.
To account for the potential under-reporting for that period, coal consumption was scaled up to reflect a more accurate historic trend.

Values for coal consumption for the period between 1990s and early 2000s were to be plotted. However, the problem of fitting the curve through finite sequence of points while preserving the shape of the data was experienced. The literature states that a piecewise polynomial curve offers much more flexibility than a single polynomial in preserving the shape of the data [16]. In addition, piecewise cubic polynomials are used because their plots are smooth and are the lowest degree polynomials that support inflection points. Given the nature of the data and shape of the curve, data for the years 1995–2008 was constructed using a piecewise cubic hermite interpolating polynomial. This method was also employed by Auffhammer and Carson [3]. The interpolated data is shown in Fig. 1.

3.3. The data

Data on coal consumption was obtained from BP statistical data [4]. Real gross domestic product (GDP), imports and exports were obtained from the World Bank indicators database [61]. Data on emissions was obtained from the Carbon Dioxide Information Analysis Center [5]. The data set ranges from 1970 to 2010. In this study, the relationship between exports, emissions, coal consumption, GDP and trade openness are investigated within a (VAR) framework. A statistical summary of these variables is shown in Table 2.

4. Empirical results

The Granger no-causality test method applied in this analysis is based upon the work of Toda and Yamamoto [56]. This procedure is expected to improve the standard F-statistic in the causality testing procedure. In determining whether some parameters of the model are jointly zero, the traditional F-test is not valid when the variables are integrated or cointegrated; in this case, the joint distribution of the variables is not characterized by a normal distribution. In other words, if the data is integrated or cointegrated, the usual tests for exact linear restrictions on the parameters (e.g. the Wald test) do not have their usual asymptotic normal distributions. The procedure proposed by Toda and Yamamoto [56] ensures that the usual test statistics for Granger Causality have standard asymptotic distributions. This procedure can be used to avoid the pre-testing distortions associated with prior tests for non-stationarity and cointegration. The basic idea of the approach is to artificially augment the correct order, k, by the maximal order of integration, \( d_{\text{max}} \) [44]. Once this is done, a \( (k + d_{\text{max}}) \)th order of VAR is estimated and the coefficients of the last lagged \( d_{\text{max}} \) vectors are ignored. To use this approach, the true lag length (k) and the maximum order of integration (\( d_{\text{max}} \)) of the series need to be obtained. The advantage of using the Toda and Yamamoto [56] method is that it does not require a priori knowledge of cointegration within the system [67].

To ensure that the time series within the VAR model satisfy the assumption of normality, a number of stationarity tests were conducted. Time series data is often characterized by unit root [39]. In both raw and log-transformed data, it is found that all the variables have a non-zero mean. Tests for unit roots were conducted using the Augmented Dickey and Fuller [10], Phillips–Perron [43] and Kwiatkowski–Phillips–Schmidt–Shin [27]. The Phillips Perron (PP) test was used to complement the standard augmented dickey fuller (ADF) test in testing for unit root. The PP procedure tests for unit roots in the presence of structural change [43]. The Kwiatkowski–Phillips–Schmidt–Shin test (KPSS) was also used to complement the ADF and PP tests; KPSS tests the null hypothesis of non-stationarity against the alternative of trend stationarity [41]. The PP and KPSS tests are used together with the ADF tests for the sake of robustness. The results of the unit root tests are reported in Table 3. Test results indicate that all the time series were I(1) except for coal consumption which was I(2).

The next step was to find out the appropriate lag length. The approach by Lütkepohl [35] was employed in which the optimal lag length (mlag) is based upon the number of endogenous variables in the system (m) and the sample size (T) according to the formula:

\[ m \times \text{mlag} = T^{0.75} \]

With a sample size of 40 this rule implies a maximal lag length of one. Using the Toda and Yamamoto [56] approach, the Granger Causality tests were conducted using these lags (Using \( k = 1 \) and \( d_{\text{max}} = 2 \)) and the results presented in Table 4.

The results appearing in Table 4 indicate one-way causality from coal consumption to exports. They also indicate unidirectional ordering from coal consumption to emissions, confirming hypotheses that past and present values of coal consumption help explain emissions. Also, one-way causality running from GDP to coal consumption was discovered. Regarding the energy-growth literature, results favored the conservation hypothesis which asserts that economic growth leads energy consumption, implying that energy conservation policies may not adversely affect GDP. No causality was discovered between trade openness and economic growth.

The results appearing on Table 4 also indicate causality running from exports to emissions; this finding is consistent with other findings in the literature [42,58,64,66]. The direction of causality between exports and emissions implies that the government can

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\footnote{The unit root test results provide the value of \( d_{\text{max}} \) while the method by Lütkepohl [35] is used to calculate k. The sum of these values was used to select the number of lags to test for Granger Causality.}
The decomposition results are presented in Table 5. Variables in the system. This allows us to provide an indication of the variance of exports, consumption, emissions, GDP and trade openness were decomposed into proportions attributed to shocks in all variables in the system. This allows us to provide an indication of the Granger Causality beyond the sample period [51]. The variance decomposition results are presented in Table 5.

The cells in the variance decomposition represent percentages of the forecast variance (error) in one variable at different time periods induced by innovations of the other variables. These percentages help determine the relative contribution the innovations make towards explaining movements in the other variables. The Table 5 also shows that GDP and coal consumption have the greatest effect on export variability over the forecast period. GDP explains 20.34% variability at five years and 24.76% variability at a ten year horizon while coal consumption explains 14.81% and 19.19% of export variability at five and ten year horizons respectively. The shocks explained by coal consumption confirm the Granger Causality tests. Emissions have an increasing effect on export variability, explaining 6.83% and 15.26% at the end of five and ten year horizons. Trade openness has a decreasing effect on export variability of exports with time.

While coal consumption and exports appear to be an important factor to emissions in China, the variance decomposition analysis shows that they explain 4.6% and 2.8% of variability at the end of the forecast period. Furthermore, GDP is the most important factor in explaining emissions variability. It is beyond the scope of the paper to thoroughly examine the underlying reasons behind these weak consumption–emissions and export-emission relationships but it can be surmised that in the future, China will find more efficient ways of using of coal, which in turn affect electricity production and exports, and thereby reduce CO2 emissions. The table also indicates that GDP has an increasing effect on coal consumption explaining 11.59% and 44.44% of consumption variability in the short and long-run respectively. In addition, exports explain 7.33% of consumption variability in the long run. The relatively low contribution may be an indication that the causal relationship between exports and coal consumption is relatively weak over the long run compared to that of GDP and coal consumption. For the forecast variance decomposition of trade openness, GDP has an increasing effect on variability, explaining 52.69% at the end of the tenth year – up from 43.74% in the fifth year. Exports also have a decreasing effect on trade openness, explaining 16.29% at the end of the forecast period. This result confirms the earlier Granger Causality tests. Finally, Table 5 shows that trade openness has a

5 Each entry is the percentage of forecast error variance. Due to rounding, the numbers in the rows do not always sum to 100.
marginal effect on GDP, explaining 1.53% at the end of the forecast period.

Next the generalized impulse response functions (GIRFs) were generated as shown in Fig. 2. The GIRFs represent the reactions of the variables to shocks in the system. While the Toda and Yamamoto [56] method tests the long-run Granger Causality relationships, it does not consider how variables respond to shocks in other variables. The generalized impulse response function examines how a shock to one variable affects another, and how long the effect lasts. Ordering of variables in the VAR system is important in order to calculate the impulse response functions (IRFs) analyses. Different ordering may result in different IRF results. The generalized GIRFs which are invariant to the ordering of the variables in a VAR were employed [28]. The charts in Fig. 2 reflect the dynamic properties of the system where without any shock, the response plots would be flat. The horizontal line in GIRFs shows the time period after the initial shock. The vertical line in GIRFs shows the magnitude of response to shocks.

Fig. 2 shows that the response of the emissions path to a one standard deviation shock in GDP and coal consumption is positive over the forecast period, whereas the response of emissions to a one standard deviation shock in exports drifts around zero over the forecast period. This implies that GDP and coal will continue to have a positive effect on emissions over the forecast period while exports will have a marginal effect on the emissions path. The emissions path is negative in response to a shock in trade openness, suggesting that opening trade in China may reduce emissions.

The path of exports in response to a one standard deviation shock in coal consumption is initially negative but then positive; the effect levels off after the fifth period. The response path is reversed when observing the effect of a shock of trade openness on exports. The response path is positive over the first four years before crossing zero and decreasing over time. The response of exports to a shock in emissions and GDP is positive, implying that coal consumption and GDP positively influence the path of exports in the long run. The path of coal consumption in response to a shock in exports is negative until the ninth period when it approaches zero while its response from a GDP shock is positive over the forecast period.

The variance of GDP was shocked with coal consumption and trade openness but the path was unresponsive. Of importance is the finding that the path of GDP from a shock in trade openness is negative. This implies that some regions, especially those in the east, may experience a decrease to GDP when exposed to further liberalization of trade. This may occur due to the lack of competitiveness in international markets as pointed by Jin [24]. Nevertheless the GDP path remains positive and unresponsive when shocked by emissions and exports. The unresponsive nature of GDP to shocks from all the variables paths confirm the Granger Causality findings, implying that GDP is impacted by shocks outside the system. Finally, the response path of trade openness in response to GDP shock is negative over the forecast period, while remaining unresponsive when shocked by emissions. This analysis was conducted using the interpolated coal consumption data.

5. Conclusion

China’s economic reforms have liberalized the economy, resulting in remarkable economic growth and energy consumption since the late 1970s. Evidence that China has overtaken the United States to take the number one spot has led to renewed calls for China to act to reduce the environmental impact of its phenomenal growth [29]. As China observes a rapid increase in emissions, its policy makers may question why the country is criticized by the very consumers who import relatively inexpensive Chinese goods. It has been argued that the steep rise in China’s emissions has been fuelled by exports of cheap goods to the rest of the world.

This study employed a vector autoregressive analysis to investigate the link between China’s exports and carbon dioxide emissions. Based on the empirical analysis, Granger Causality running from exports to emissions was discovered. These results imply that the government should consider policies aimed at controlling exports to reduce emissions. For example, the country can implement policies that place an environmental levy on exports to fund domestic GHG mitigation programs. Such projects entail the installation of emission reducing technologies in industries that

\[ \text{Variance decomposition of } \ln_m, \ln_c, \ln_e, \ln_x, \ln_{p}, \ln_{p} \]

\[ \text{Period} \quad \text{S.E.} \quad \ln_m \quad \ln_c \quad \ln_e \quad \ln_x \quad \ln_{p} \quad \ln_{p} \]

\[ \begin{array}{cccccccc}
1 & 0.008391 & 0 & 0 & 0 & 0 & 100 & 0 \\
5 & 0.025876 & 0.002304 & 1.087862 & 0.048208 & 97.24468 & 1.616946 \\
10 & 0.05027 & 0.06292 & 2.095298 & 0.030711 & 95.41664 & 1.530436 \\
\end{array} \]

\[ \text{Variance decomposition of } \ln_c: \]

\[ \begin{array}{cccccccc}
1 & 0.048794 & 97.22053 & 0 & 0 & 2.779469 & 0 \\
5 & 0.051488 & 71.50651 & 7.088608 & 9.24577 & 11.38904 & 0.170077 \\
10 & 0.113396 & 37.33687 & 10.33621 & 7.331531 & 44.44783 & 0.567567 \\
\end{array} \]

\[ \text{Variance decomposition of } \ln_x: \]

\[ \begin{array}{cccccccc}
1 & 0.117682 & 19.24216 & 0 & 60.59998 & 20.15787 & 0 \\
5 & 0.156152 & 14.81005 & 6.834465 & 50.71922 & 20.34278 & 7.293481 \\
10 & 0.193008 & 19.18808 & 15.26063 & 33.1931 & 24.76041 & 5.597784 \\
\end{array} \]

\[ \text{Variance decomposition of } \ln_{p}: \]

\[ \begin{array}{cccccccc}
1 & 0.087028 & 15.71462 & 0 & 50.1422 & 9.54676 & 24.59642 \\
5 & 0.189721 & 6.997893 & 1.716841 & 22.31577 & 43.73825 & 25.23124 \\
10 & 0.264067 & 9.509195 & 2.172582 & 16.28689 & 52.69731 & 19.33222 \\
\end{array} \]

\[ \text{Variance decomposition of } \ln_e: \]

\[ \begin{array}{cccccccc}
1 & 0.111395 & 0.300299 & 92.93357 & 0.017222 & 2.64086 & 4.108052 \\
5 & 0.197998 & 2.849479 & 81.65356 & 1.795379 & 6.113843 & 7.587738 \\
10 & 0.242661 & 4.641847 & 69.37177 & 2.789918 & 17.65177 & 5.544688 \\
\end{array} \]

Cholesky ordering: \( \ln_m, \ln_c, \ln_e, \ln_x, \ln_{p} \).
manufacture goods for export. Another potential policy may encourage foreign direct investment in domestic, energy efficient industries which emit less CO2 emissions. Also, unidirectional causality running from coal consumption to exports, and coal consumption to emissions was found. China can consider market-based mechanisms, such as cap-and-trade, which reduce coal consumption and consequently reduce emissions. Other policies include renewable energy strategies or the use of clean coal technologies in the formulation of a long–term emission reduction portfolio. Vector error decomposition analysis revealed that GDP had the greatest effect on exports, emissions and coal consumption variability.

Predictions indicate that the increase in greenhouse gas emissions from 2000 to 2030 in China alone will nearly equal the increase from the entire industrialized world. It is important for China to take a lead in reducing CO2 emissions [22]. Their efforts in taking responsibility for reducing the carbon emissions will resonate across countries following similar developmental patterns. In addition, China can invest returns from exports on projects that promote use of renewables to mitigate emissions and further achieve better human health from reduced air pollution.

One limitation of this study is that it uses interpolated data for coal consumption which may not reflect actual trends. Future work should consider a different technique improving this data set. Another limitation is that the VAR is a reduced form model; therefore, IRFs may not capture shocks to the true underlying innovations.

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