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To cite this article: Qiang Ma, Zeeshan Khan, Muhammad Tariq, Hayriye Işık & Husam Rjoub (2022) Sustainable digital economy and trade adjusted carbon emissions: Evidence from China's provincial data, Economic Research-Ekonomiska Istraživanja, 35:1, 5469-5485, DOI: [10.1080/1331677X.2022.2028179](https://doi.org/10.1080/1331677X.2022.2028179)

To link to this article: <https://doi.org/10.1080/1331677X.2022.2028179>



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Published online: 09 Feb 2022.



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Sustainable digital economy and trade adjusted carbon emissions: Evidence from China's provincial data

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ABSTRACT

The importance of the digital economy and trade adjusted emissions is of great importance to study, especially in case of China. Since China is the leading exporter of the world and achieving high economic growth consecutively for the last 2-3 decades, this study, unlike past studies, evaluates the importance of digital economy, exports, imports and gross domestic product on trade adjusted carbon emissions for China. This is the only study that incorporates the importance of digital economy on trade adjusted carbon emissions for provincial data of China. This study determines whether the digital economy is a viable source of green economy. Research and development will simply replace a physical resource, flows through energy and transportation networks? This question is answered by using updated data, especially for digital economy. This study uses panel data for the Chinese provinces to investigate the impact of the digital economy in limiting CO₂ emissions, taking into account GDP, exports and imports as control variables. Using method of moments quantile regression, we find a negative impact of digital economy and exports on consumption-based carbon emissions. Moreover, we find that GDP, and imports amplify consumption-based carbon emissions.

ARTICLE HISTORY

Received 8 November 2021
Accepted 6 January 2022

KEYWORDS

Digitalization of economy; trade adjusted carbon emissions; research and development; method of moment quantile regression analysis

1. Introduction

In recent years, fossil energy demand has grown due to the rapidly growing population and industrialization process in emerging nations. Thus, environmental degradation represented by carbon dioxide (CO₂) emissions has become a frequent and significant concern endangering humans for every government across the world.

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Currently, carbon emission can be measured in two ways: Production-based accounting (PBA) and consumption-based accounting (CBA) (Zhang et al., 2016). Past studies have extensively used the PBA, as it directs the responsibility for the producer of the carbon emission by considering the country's total emission levels, including exports (Qin et al., 2021). In the production-based method, CO₂ emissions come from the producer's productivity side, which misleads the true picture of environmental degradation. Because it does not account for the ultimate destination of the final goods and services. Moreover, in the global economy, trade redistribution results interregional transfer of CO₂ emissions. In the absence of such indirect CO₂ emissions, production-based emissions either underestimate CO₂ emissions in regions with high output but low consumption or overestimate CO₂ emissions in areas with low production but high consumption. Therefore consumption-based carbon emissions are usually employed in the current literature. It sums up emissions in importing nations' inventories and subtracts CO₂ emissions included in exported commodities, including transportation-related emissions (Liddel, 2018a; Liddle, 2018b and Baker, 2018). Thus, PBA allows such a producer of carbon emission to mitigate its emission level by switching toward a more energy-efficient way of production. However, despite PBA's apparent advantages, it fails to consider that the product-producing country may not be the product-consuming country (Steininger et al., 2014). Hence, the need to shift from PBA to CBA is gradually gaining momentum within academic and developing countries, where countries having a higher CBA should be more ethically responsible and exert more efforts for mitigation (Khan et al., 2020). In comparison to PBA, CBA measures the total emission by including imports and excluding exports. CBA restricts the carbon leakage among countries, which has not been considered under the PBA approach. As a result of such a process, the end-user of a product is held accountable for the carbon emissions related to the manufacture of such products. (Wiedmann, 2009). Existing literature has termed many factors responsible for creating consumption-based CO₂ emissions. Exports and imports are the most widely discussed factors of consumption-based CO₂ emissions (Yuan et al., 2018; Salman et al., 2019; Chang et al., 2018). Since, CBA measures the total emission by including imports and excluding exports; hence, existing literature considers the negative impact of export and the positive impact of import on consumption-based CO₂ emission.

Besides these, the influence of information and communication technologies (ICTs) on consumption-based CO₂ emissions through various has been widely documented. ICT can have an impact on consumption-based CO₂ emissions through different channels like improving productivity, reducing energy intensity, reducing carbon footprints and facilitating trade-related activities. Miller and Wilsdon (2001) defined the digital economy as an important decisive factor in the technological revolution, fundamentally changing the value chain of almost every kind of industry. Digital energy owns responsibility in reduction of energy consumption through either demand or supply side. On the demand side, the applicability of digital economy in transportation sectors like usages of smart cars, housing, and other electric appliances can lead towards dematerialization of human activities, which contributes to increased energy efficiency and energy conservation (Strauss & Aydin, 2018). Each of these

connections has a different impact on Consumption based CO₂ emissions. However, no consensus has been reached on the overall influence of ICTs on climate change (Chen, 2021; De Rademaeker et al., 2014; Soares & Tolmasquim, 2000). The latest report of the China Academy of information and communication technology in 2019 (China Academy of Information & Communications Technology, 2020) reflects the development process of digitization of the economic system with four orientations, i.e., digital industrialization, industrial digitalization, digital governance, and data valuation. The first two orientations help vigorously accelerate the reshaping of human production according to their living patterns. The concept of digital governance promotes a collaborative governance system, social participation and departmental coordination. Digital value development as the fourth orientation of the digital economy promotes reconstructing value-oriented data, a key production factor in the digital economy.

China is the greatest contributor to global CO₂ emissions. In 2019, China was responsible for 27% of the world's CO₂ emissions. At the same time, China is the largest producer and exporter of main industrial and consumer products, contributing about 25% of the nation's GDP. Hence it is the largest net exporter of CO₂ emissions to the rest of the world. To overcome such a problem, China has established many objectives for reducing consumption-based carbon emissions to safeguard the environment (Wang et al., 2020). They presented a Nationally Determined Contribution Document in 2015, during the United Nations session on climate change, in which they promised to reduce CO₂ intensity from 2005 levels to 60-65 percent by 2030. In response to a solution to the problems, the digital economy, being one of the measures to play a vital role has been adopted in various industries such as manufacture, land use, construction, transportation, services and most importantly in the energy sector, which reduce global carbon emissions by 15% (Exponential Road Map initiatives 2020).

So far, the impact of technological development has been recorded for a fundamental change in economic development and the environment as well, either better or worse. In fact, the emerging digital economy has a great potential in the contribution of the environment due to dematerialization, decarbonization and demobilization incurred in the digital economy (Alam & Murad, 2020; Junior et al. 2016; Kjaer et al., 2018). Domestic and international research on the relationship between the digital economy and pollution has three basic perspectives. Firstly, the digital economy has a negative impact on pollution. Secondly, the digital economy can help to improve environmental quality to some extent. Thirdly, the Internet's openness, engagement, and true essence enable the general people to easily participate in environmental governance (Zhong & Jiang, 2021). Shifting business into digital economy, for example, can decrease waste such as printed catalogs, shop space, and logistic necessities. Still, it also requires creating more energy-intensive computers that contribute to consumption-based CO₂ emissions. Likewise, Li et al. (2020) concluded that the advancement of digital technology increases energy demand, which negatively impacts the environment. Hence the impact of digital economy is still ambiguous, either negative or positive. The purpose of this study is to determine whether, in China, the digital economy is a viable source of green economy. Moreover, the impact of GDP, import and export are also controlled in the model.

2. Literature review

Multiple studies have examined the determinants of carbon emission using evidence from an individual country, group of countries, and regions. At the same time, others have taken a more popular approach to find carbon emission determinants using data from developed and developing countries. Though such studies have broadened the understanding of how various factors impact carbon emissions, these studies have relied on carbon emission data collected through the production-based accounting (PBA) approach. While studies considering the consumption-based accounting approach (CBA) tend to be more qualitative than quantitative (Hasanov et al., 2018; Karakaya et al., 2019), thus creating a visible gap in the literature.

A vast body of literature regarded import and exports are important determinants for consumption-based CO₂ emissions (Yuan et al., 2018; Salman et al., 2019; Chang et al., 2018; Suri & Chapman, 1998 and Agras & Chapman, 1999). Knight and Schor (2014), in their study of 29 high-income economies for the periods of 1991-2008 found a negative impact of export and positive impact of import on consumption-based CO₂ emission. Antweiler et al. (2001) find that the impact of trade on the environment can be either positive or negative through the following channels: negative impact through increasing economic activities and consumption of resources; positive impact through using energy-efficient technology for efficient productivity, which reduces emission levels (Grossman & Krueger, 1996); and through composition effect where the positive and adverse impact of trade depends upon the comparative advantage of the countries (Kahuthu, 2006). Trade openness involves in transferring consumption-based CO₂ emission through export and import (Fernandez et al., 2017; Lamb et al., 2017; Knight and Schor, 2014). Moreover, in the study of Shafik (1994), Grossman and Krueger (1995), Sala-iMartin (1996), Karakaya et al. (2019), Usman et al. (2019), national income has been found as an important factor determining consumption-based CO₂ emission in a country.

Literature examining the determinants of carbon emission can be categorized into three groups. The first group studies the effect of economic growth in the form of per capita income on carbon emission (Lee & Oh, 2015; Umar et al., 2021). While, the second group examines the impact of emission convergence in the form of the Environmental Kuznets Curve (EKC) hypothesis on carbon emission (Ali et al., 2014; 2021; Safi et al., 2021). Lastly, the third group considers the impact of multiple arrays of control variables on carbon emission (Ben Jebli & Ben Youssef, 2015; Naqvi et al., 2021, Ji et al., 2021; Rahman, 2017). All such literature works consider carbon emission data under the PBA approach, which results in inconclusive evidence. In contrast, most of the studies finding determinants of carbon emission have considered energy consumption in their empirical models, which may lead to systematic volatility in coefficients because of its strong correlation with other explanatory variables (Shahzad et al., 2017).

To sum up, studies considering the impact on carbon emissions in China mostly use production-based emissions (David & Venkatachalam, 2019; Karakaya et al. 2019; Du et al., 2012; Jiao et al., 2018; Lee & Oh, 2015; Li et al., 2020; Peng et al., 2018; Wang et al., 2020; Yang et al., 2017). Nevertheless, no study used CBA approach in case of China. CBA tends to be beneficial for China in reducing its emission

mitigation target as its exports exceed imports. Moreover, very little literature has been found on the digital economy and its influence on the environment through various channels. However, no research has been identified that evaluates the influence of the digital economy on consumption-based CO₂ emissions. This research is unique because it contributes to the literature by analyzing the impact of the digital economy, trade and income on environmental sustainability measured via consumption-based accounting approach.

3. Methodology

3.1. Theoretical background

The theoretical foundation for the linkages described in this article is depicted in Figure 1. Consumption-based carbon (CCO₂) emissions are a trade-adjusted estimate that considers the impact of international transactions. This measure accounts for

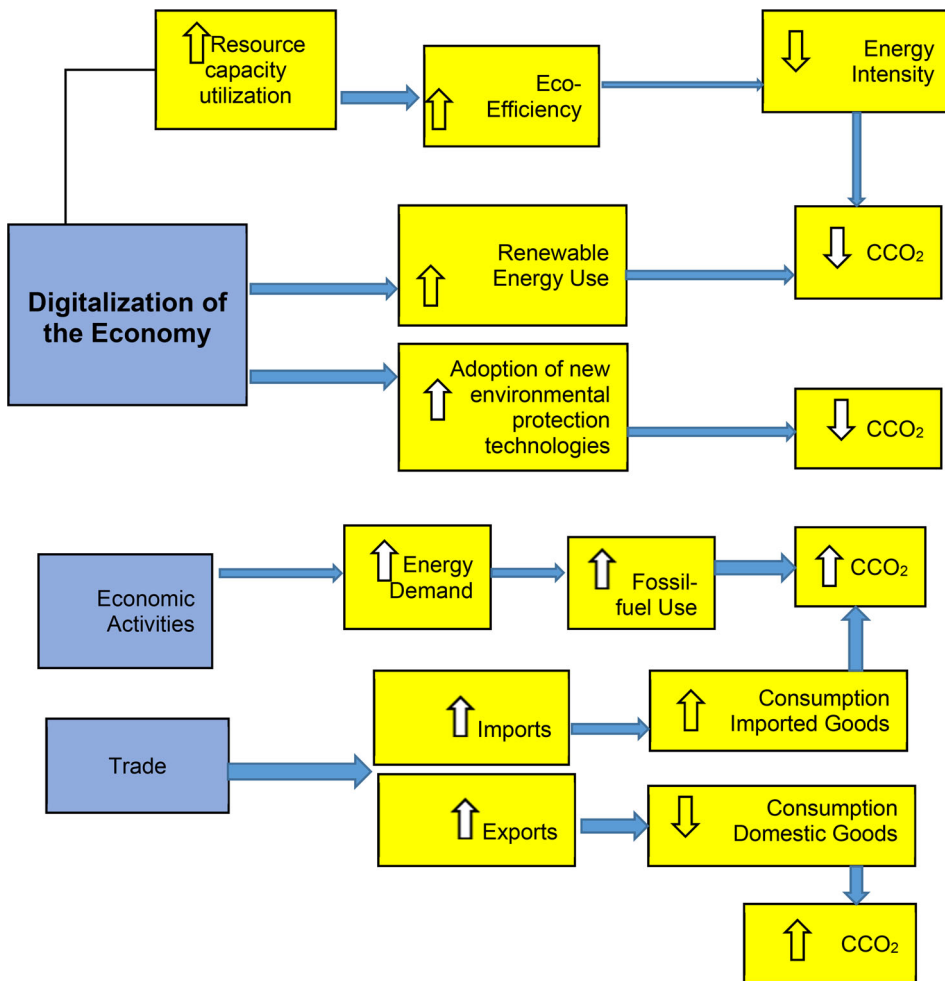


Figure 1. The theoretical framework.
Source: Author own derivations.

emissions from exports and imports. This measure is determined by adding import emissions to domestic consumption demand from the government and households and subtracting exports (Liddle, 2018a). This measurement also includes emissions induced by production in one country and consumption in another. As a result, this study used exports and imports separately to assess the component-based effects of international commerce, which is consistent with previous research (Qin et al., 2021). It is widely acknowledged that imports increase CCO₂ emissions, particularly when a commodity is produced in another country and imported. On the other side, local output is exported to other countries and consumed by people in the receiving country. This arrangement reduces domestic CO₂ emissions while increasing CCO₂ emissions in the recipient country (Hasanov et al., 2018).

Following Junior et al. (2016), Kjaer et al. (2018), Alam and Murad (2020), digital economy has a negative impact on pollution. The digital economy has a great potential in the contribution of the environment due to dematerialization, decarbonization and demobilization incurred in the digital economy. However, dematerialization, decarbonization and demobilization are one side of the story. On the opposite side, in digital economy each possible beneficial effect is accompanied by a potentially devastating adverse effect. Shifting business into digital economy, for example, can decrease waste such as printed catalogs, shop space, and logistic necessities. Still, it also requires creating more energy-intensive computers that contribute to greenhouse gas emissions. Hence the impact of the digital economy is still in ambiguous, either negative or positive. This study introduces GDP as an independent variable in the regression. We predict that the increase in GDP (i.e., national income) will enhance CO₂ emissions.

3.2. Data

This study collects China's provincial data for CCO₂, GDP, EX, IM and DE. We do not see any excessive volatility in any variable based on the standard deviations of the sample statistics. Table 1 presents the descriptive statistics of variables presented in model 1.

3.3. Model

This study empirically examines the impact of digital economy along with other variables such as GDP, exports and imports on environmental performance of China

Table 1. Descriptive statistics.

<i>Statistics</i>	<i>CCO₂</i>	<i>IM</i>	<i>EX</i>	<i>GDP</i>	<i>DE</i>
<i>Mean</i>	31655.90	1555.628	1926.145	19557.63	1.072445
<i>Median</i>	25754.61	208.9200	266.9800	15148.08	1.044300
<i>Maximum</i>	105339.0	27751.26	42186.80	89705.23	2.140700
<i>Minimum</i>	1564.586	1.180000	2.510000	648.5000	0.574000
<i>Standard Deviation</i>	21906.90	4260.085	6013.315	17024.87	0.157936
<i>Skewness</i>	1.181901	4.437758	5.369708	1.822871	1.463532
<i>Kurtosis</i>	3.874881	23.00650	33.01166	6.648390	9.466090
<i>Jarque – Bera</i>	119.1182	8981.902	19050.65	498.7911	944.5878
<i>p – values</i>	0.000000	0.000000	0.000000	0.000000	0.000000

Source: Author own derivations.

from 2006 to 2017. The general econometric model for describing the effect of digital economy on CCO₂ emissions for the *i*th province in the *t*th time period is given as:

$$CCO_{2it} = \beta_0 + \beta_1 DE_{it} + \beta_2 GDP_{it} + \beta_3 EX_{it} + \beta_4 IM_{it} + v_{it} \quad (1)$$

Where, CCO₂ represents consumption-based carbon emissions, GDP represents gross domestic product. DE represents digital economy. EX and IM represent exports and imports, respectively.

After performing the sensitivity analysis, only robust variables are selected. In above equations (1 and 2) β 's are the coefficients and v is the error term.

3.4. Econometric methodology

In equations (1 and 2), since the error terms are correlated with the variable ‘digital economy’, we conclude that there is the problem of endogeneity. Hence, this study utilizes advanced econometric techniques. We utilize Westerlund’s co-integration and Augmented mean Group methods to assess the effect of the impact of the digital economy along with other variables such as income, exports and imports on environmental performance of China. However, before using cointegration techniques, it is necessary to apply cross sectional dependency and slope heterogeneity tests.

3.4.1. Cross-section dependence and slope heterogeneity (SH) tests

Cross sectional dependency (CSD) is one of the most threatening problems of panel data. The possibility of cross-section dependence (CRSD) in the data set has increased as a result of trade between countries. Trade spillover effects occur as a result of many shocks, such as global financial crises and oil price shocks. Hence, a shock in one variable in one country may have serious repercussions for other countries. The study uses CSD test developed by Pesaran (2004). Moreover, slope heterogeneity is also a potential problem in panel data. It is widely acknowledged that slope heterogeneity can affect estimates. Hence, it is important to check the slope heterogeneity of the model as the presence of SH might skew estimates generated using the OLS approach. In the context of slope heterogeneity, one would like to retrieve each individual’s slope coefficient. However, across most empirical test settings, the goal is to offer a summary statistic for policy objectives. If all individuals are not identical, the OLS method provides inconsistent results; hence, second generation methods are preferable that can deal with the problems of CSD and SH. For slope heterogeneity or homogeneity, this study employed Pesaran and Yamagata (2008) test, preferred over other relevant tests as its power to perform better even having a small sample size (Atasoy, 2017).

3.4.2. Unit root tests

It is important to check the unit root properties of series because unit root tests can be used to identify whether trending data should be first differenced or not. Recently, studies have used second generation tests, which relax the assumption of independent cross-sections. Pesaran’s Cross Sectionally Augmented IPS (CIPS) is used in this work (2007). The CIPS considers the CSD (Ali and Malik) (2021). The averaged Cross

Sectionally Augmented Dicky Fuller (CADF) statistic value is used in the test. The following is the CIPS test equation:

$$\Delta W_{i,t} = \varphi_i + \varphi_i Z_{i,t-1} + \varphi_i \overline{W}_{it-1} + \sum_{l=0}^p \varphi_{il} \Delta \overline{W}_{i\bar{i}} + \sum_{l=1}^p \varphi_{il} \Delta W_{i,t-l} + \eta_{it} \quad (2)$$

Where, \overline{Z}_{t-1} and $\Delta \overline{Z}_{i\bar{i}}$ present the cross-section averages and η is the serially uncorrelated error term. The CIPS statistic is given below as:

$$\widehat{\text{CIPS}} = N^{-1} \sum_{i=1}^n \text{CDF}_i \quad (3)$$

Whereas, CDF is Cross-Sectionally Augmented Dickey-Fuller (CADF) statistic obtained from the t-ratio of the coefficient of $Z_{i,t-1}$ in equation (4).

3.4.3. Westerlund (2007) cointegration test

For long-run cointegrating relationship among consumption-based carbon emissions, digital economy, exports, imports and gross domestic product. This study will use Westerlund (2007) cointegration test. Westerlund is a second-generation test, which relaxes the assumption of independent cross-sections and heterogeneous slope as well. The four test statistics are given below as:

$$G_t = N^{-1} \sum_{i=1}^N \frac{\hat{\vartheta}_i}{\text{Standard Error}(\hat{\vartheta}_i)} \quad (4)$$

$$G_a = N^{-1} \sum_{i=1}^N \frac{T \hat{\vartheta}_i}{\widehat{\vartheta}_i(1)} \quad (5)$$

$$P_t = \frac{\hat{\vartheta}}{\text{Standard Error}(\hat{\vartheta})} \quad (6)$$

$$P_a = T \hat{\vartheta} \quad (7)$$

The first two equations (4 and 5) are for group test statistics, whereas the latter two (6 and 7) are for panel test statistics.

3.4.4. Method of moment quantile regression

Previous studies OLS, AMG and CSARDL approached to discover the influence of explanatory variables on carbon emissions. However, it is argued that explanatory variables can affect the mean and other parameters such as the median or other quantiles. Since, this study pool data from potentially heterogeneous provinces, linear regression techniques would provide inconsistent results. Due to these reasons, this study employs nonparametric quantile regressions provided by Silva (2019) to

Table 2. Diagnostic tests.

Slope Heterogeneity	
Δ	11.785*** (0.000)
$\sim \Delta - Adjusted$	15.214*** (0.000)
Cross-Section Dependence	
Variables	CD-Statistics
CCO_2	56.699***
IM	68.708***
DE	10.11***
EX	69.00***
GDP	79.757***

Note: ***, ** and * is for 1%, 5% and 10% significance level.

Source: Author own derivations.

examine the impact of the digital economy, GDP, exports, and imports on consumption-based carbon emissions in China across quartiles. This approach outperforms other conventional regressions because of its ability to deal with outliers in the data. Furthermore, because quantile regressions do not account for variable distribution, they produce consistent estimates even when the dependent variable's data is skewed.

4. Results and discussions

Since the main objective of this study examined the role of exports, imports, digital economy and gross domestic product in endorsing a sustainable environment for China from 2006 – 2019, initially we checked the cross-sectional dependency for the variables CCO_2 , DE , GDP , EX and IM . The results indicate that all variables are statistically significant at the 1% level of significance; thus, the cross-sections are dependent. The slope homogeneity test is then used to see if the coefficients' slopes are consistent across models for different cross sections. The results reveal that slopes are not homogeneous, and so both models have an issue with slope heterogeneity. The slopes of the coefficients can be affected by a variety of diverse causes. As a result, applying the homogeneity requirement on the variable may result in incorrect inferences (Table 2).

This study uses the CIPS unit root test to account for the existence of CSD in all variables and SH in both models. Table 3 shows the results of the CIPS test. The unit root characteristics of the series were checked using trends in the specification. The findings reveal that all variables are integrated with the same sequence, i.e., I. (1). We then looked for long-run cointegration in all of the models.

The long-run Cointegration is confirmed by the Westerlund (2007) Cointegration test. The output is given in Table 4. The results are robust to both heterogeneous slope and cross-section dependence. The results are both verified via panel as well as group statistics.

Next, this study employs Quantile regression to estimate the impact of digital economy, GDP, exports and imports on consumption-based carbon emissions. The results of Quantile regression are presented in Table 4. It is evident that the digital economy, GDP, exports and imports are significantly related to consumption-based carbon emissions for lower, median and upper quartiles. This section contains a discussion of the paper's findings as well as a connection to similar papers in the field.

Table 3. Unit root test.

Variables	Trend and Intercept	
	Level	First-Difference
CCO ₂	-3.319***	-
IM	-1.912	-3.520***
EX	-1.790	-3.169***
GDP	-1.825	-2.739**
DE	-4.068***	-

Note: ***, ** and * is for 1%, 5% and 10% significance level.

Source: Author own derivations.

Table 4. Westerlund (2007) ECM based cointegration.

Statistics	Value(s)
G_t	-5.052***
G_a	-2.450
P_t	-18.071***
P_a	-2.605

Note: ***, ** and * is for 1%, 5% and 10% significance level.

Source: Author own derivations.

The empirical results show that the coefficient of digital economy (DE) is negative and significant in case of all three quartiles, which infer that digitalization of the economy is effective in abating CCO₂ emissions. There was a negative marginal connection between DE and CCO₂ emissions at the lower, median, and upper quartiles, with this association becoming more significant as the quartile increased. This suggests that improvement in digital economy is linked to decreases in China's CCO₂ emissions. These results suggest that digitalization of the economy is important for achieving sustainable development (fewer CO₂ emissions). Digital economy has a great potential in the contribution of the environment due to dematerialization, decarbonization and demobilization incurred in digital economy. Such argument is reinforced with the fact that by converting business into a digital economy, many printed catalogs, including books, newspapers, magazines, and business manual, are no longer needed. Moreover, information technology works well in the domain of digital economy, which spreads motivation for intelligent management of the environment. The results support the earlier findings of Granell et al. (2016), Junior et al. (2016), Kjaer et al. (2018), Alam and Murad (2020), Allam and Jones (2021), Usman et al. (2021). Digital economy may affect environmental sustainability via two directions: On the supply side, the digital economy predictably warns production risk through monitoring energy production data, which improves the energy efficiency of the fossil fuel system and reduces the expected damages to the environment. Almost many business leaders have shifted their business activities towards knowledge-based industry through the Internet, which is expected to bring sustainable development with a friendly environment. For instance, the growing usage of "paperless transactions" looks to save energy; therefore, Chinese industries intend to convert 50% of their purchase orders to a paper-free procedure by 2020. These measures will have significant implications for environmental sustainability. Furthermore, the internet has compensated for previous shortcomings in environmental governance by increasing the intelligence and accuracy of environmental data.

Table 5. Method of moment quantile regression.

<i>Variables</i>	<i>Coefficients</i>	<i>Std. Error</i>
Q_{0.25}		
<i>IM</i>	0.0171***	0.0037
<i>EX</i>	-0.032***	0.0028
<i>GDP</i>	0.484***	0.0467
<i>DE</i>	-0.140*	0.0818
<i>Constant</i>	2.472***	0.1591
Q_{0.50}		
<i>IM</i>	0.0238***	0.0031
<i>EX</i>	-0.0916***	0.0219
<i>GDP</i>	0.427***	0.0283
<i>DE</i>	-0.093*	0.0488
<i>Constant</i>	2.717***	0.0970
Q_{0.75}		
<i>IM</i>	0.027*	0.0147
<i>EX</i>	-0.038***	0.0078
<i>GDP</i>	0.394***	0.0241
<i>DE</i>	-0.066***	0.0104
<i>Constant</i>	2.856***	0.0820

Source: Author own derivations.

For the income (GDP), the effect on CCO2 emissions is positive for all quartiles. A closer examination of the data reveals that at the lower, median, and upper quartiles, there was a positive marginal connection between GDP and CCO2 emissions. The sign and size of the GDP coefficient are consistent for all three quartiles, implying that improved economic performance is linked to increase in China's CCO2 emissions from short run to long run. The empirical results infer that an increase in economic activities has detrimental environmental sustainability in China. The results support the earlier findings of Ali et al. (2014), Kirikkaleli et al. (2021), Safi et al. (2021), Chi et al. (2021) who argue that economic performance has a significant impact on environmental sustainability.

The empirical results show that the coefficient of exports (EX) is negative and significant in all three quartiles, which infer that an increase in exports effectively abate CCO2 emissions. The results support the earlier findings of Liddle (2018) and Khan et al. (2020). Moreover, the coefficient of imports (IM) is positive and significant in all three quartiles, which infer that an increase in imports effectively enhances CCO2 emissions. The positive effect of IM on CCO2 emissions loses trace of significance for the subsequent quartiles and reaches its bottom at upper quartile. The results support the earlier findings of Liddle (2018) and Khan et al. (2020). This study uses CBA approach, takes into account imports and excludes exports while measuring total emission. As per CBA approach, the end-user of a product is held accountable for the carbon emissions related with the manufacture of such products. Hence, exports are negatively related with CCO2 emissions, while imports are positively related to CCO2 emissions (Table 5).

Table 6 compares the CBA approach with PBA approach. When comparing the CBA to the PBA, a ratio greater than one indicates that the country consumes more emissions than it produces, and vice versa (Khan et al., 2020). In case of Chinese' provinces, Beijing, Tianjin, Hebei, Shaanxi, Inner Mongolia, Liaoning, Heilongjiang, Jiangsu, Anhui, Jiangxi, Shandong, Henan, Hubei, Hunan, Guangxi, Guizhou, Yunnan, Shaanxi and Ningxia are net emission importer as the ratio of CBA to PBA is greater than 1

Table 6. Ratio of CBA/PBA.

Province	CBA/PBA	Status	Province	CBA/PBA	Status
Beijing	2.089	Emission Importer	Jilin	0.359	Emission Exporter
Tianjin	2.348	Emission Importer	Shanghai	0.397	Emission Exporter
Hebei	7.326	Emission Importer	Zhejiang	0.448	Emission Exporter
Shaanxi	3.280	Emission Importer	Fujian	0.787	Emission Exporter
Inner Mogolia	1.117	Emission Importer	Guangdong	0.447	Emission Exporter
Liaoning	1.545	Emission Importer	Hainan	0.115	Emission Exporter
Heilongjiang	2.784	Emission Importer	Chongqing	0.839	Emission Exporter
Jiangsu	3.207	Emission Importer	Sichuan	0.763	Emission Exporter
Anhui	4.524	Emission Importer	Gansu	0.659	Emission Exporter
Jiangxi	1.678	Emission Importer	Qinghai	0.065	Emission Exporter
Shandong	3.573	Emission Importer	Xinjiang	0.774	Emission Exporter
Henan	4.108	Emission Importer			
Hubei	1.840	Emission Importer			
Hunan	1.247	Emission Importer			
Guangxi	1.016	Emission Importer			
Guizhou	2.166	Emission Importer			
Yunnan	3.551	Emission Importer			
Shaanxi	2.897	Emission Importer			
Ningxia	1.283	Emission Importer			
Xinjiang	0.774	Emission Importer			

Source: Author own derivations.

Table 6. Dumitrescu Hurlin panel causality.

H_0	$Wald_{Stats}$	\bar{Z}_{Stats}	$p - value(s)$
IM - CCO ₂	4.77291	3.46000	0.000
CCO ₂ - IM	2.71905	3.96842	0.000
EX - CCO ₂	1.86347	1.70009	0.089
CCO ₂ - EX	3.37295	5.70205	0.000
GDP - CCO ₂	2.49551	3.37577	0.000
CCO ₂ - GDP	10.1504	23.6706	0.000
DE - CCO ₂	4.76801	4.44700	0.000
CCO ₂ - DE	2.19018	2.56627	0.010

Source: Author own derivations.

for these provinces. Whereas other provinces such as Jilin, Shanghai, Zhejiang, Fujian, Guangdong, Hainan, Chongqing, Sichuan, Gansu, Qinghai and Xinjiang are net carbon exporter as the ratio of CBA to PBA is less than 1 for these provinces.

The results of panel causality tests are reported in Table 6. It is evident that there is bi-directional causality among the variables DE, GDP, EX and IM with CCO₂ emissions. Any policy shock in these variables significantly changes CCO₂ emissions. Moreover, any policy shock to target CCO₂ emission also affect these variables substantially. An increase in DE, GDP, EX and IM have a predictive control over CCO₂ emissions and vice versa. These findings support the earlier findings of Khan et al. (2021) and Li et al. (2020).

5. Conclusions and policy implications

Being the largest contributor to global CO₂ emissions, China is the world's greatest producer and exporter of major industrial and consumer goods. To address such a challenge, China has created a number of targets for lowering consumption-based carbon emissions in order to protect the environment. It is generally acknowledged

that digitalization of the economy has a great potential to abate the rising environmental degradation in China. The digitalization of economy has attained enormous importance from the researchers, predominantly in the fourth industrial revolution. With the introduction of new innovations in the world of digital technologies, the significance of digital technologies has grown even more. Besides its different other impacts, the emerging digital economy has a great potential in the contribution of the environment. This research investigates whether the digital economy is a potential source of green economy, wherein R&D simply replace physical resources. To answer such a question, data about China's economy has been utilized for the period of 2006 and 2017. This research adds to the existing literature by examining the impact of digitalization of economy on consumption-based carbon emissions in China. Previous studies have been challenged for employing PBA approach, which is a poor proxy for measuring CO₂ emissions. Data comparing the China's provinces shows that most of the Chinese provinces are net carbon exporters. Hebei province is the highest net exporters of CO₂ emissions among the Chinese provinces. Chinese provinces export intermediate and manufacturing goods to other countries and regions such as the US, UK, and Asia. Because of the substantial exports to other nations, the carbon emissions in the manufacture of goods consumed by other countries are attributed to most Chinese provinces. Since countries import intermediate goods that are energy demanding, resulting in increasing consumption-based CO₂ emissions. The econometric tests offer robust results that support the previous findings; i) there is ample evidence of the presence of CSD in all series; ii) both models suffer from slope heterogeneity problem; iii) All variables, such as CCO₂, DE, GDP, EX and IM follow a unit-root process; iv) there is a stable long run relationship among variables; iv) we find negative impact of digital economy and EX on CCO₂ emissions of China; v) GDP and imports are positively related with CCO₂ emissions; vi) there is bi-directional causality among the variables DE, GDP, EX and IM with CCO₂ emissions.

In terms of policy implications, this study suggests that China should get more benefits from the digitalization of the economy. A fully enabled digital economic system is required as an emerging economic system that considers digitalized technology as the main driver in protecting environmental degradation in China. The digitalization of the economy should not only be used and confined to achieve economic growth but also for economic growth achieving environmental sustainability as well. Currently, the digital economy in China is contributing RMB 35.8 trillion to GDP (36.2% as share in GDP).

Disclosure statement

No potential conflict of interest was reported by the authors.

Funding

Liaoning Social Science Planning Fund Project, Research on Mechanism and path of digital development promoting carbon emissions reduction (grant number L21BJY031).

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