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THE DYNAMIC IMPACTS OF FINANCIAL DEVELOPMENT AND HUMAN CAPITAL ON CO_2 EMISSION INTENSITY IN CHINA: AN ARDL APPROACH

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Abstract. This paper studies the dynamic impacts of financial development, human capital, and economic growth on CO_2 emission intensity in China for the period 1978–2015, with a structural breakpoint in 1992, by employing an autoregressive distributed lag (ARDL) approach. The estimations show that there exists a long-run cointegration linkage among the variables, with three main findings. First, financial openness measured by net FDI inflows can significantly reduce CO_2 emission intensity in both the short-term and the long-term, whereas the effects of both financial scale and financial efficiency are limited and insignificant. Second, there exists an inverted N-shaped relationship between human capital and CO_2 emission intensity: improving human capital first decreases CO_2 emission intensity (before 1992), then increases it in the short-run (after 1992), and, finally lessens it in the long-run. Last, raising per capita income can also significantly lower CO_2 emission intensity in the long-run. Accordingly, some policy implications are also discussed.

Keywords: CO_2 emission intensity, financial development, human capital, economic growth, ARDL, China.

JEL Classification: D82, D83, D86, I11.

Introduction

Over the last four decades, China has witnessed tremendous economic growth along with rapid development both in the finance sector and in the labor sector (Lan, Kakinaka, & Huang, 2012; Tian, Chen, & Zhu, 2017; Zhang, 2011). Nevertheless, the economic growth has been also accompanied by increasing consumption of fuel energy and, thus, increasing CO_2 emissions (Belke, Dobnik, & Dreger, 2011; Huang, Hwang, & Yang, 2008; Kasman & Duman, 2015; Kim & Le, 2018; Lapinskiene, Peleckis, & Nedelko, 2017; Lapinskiene, Peleckis,

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& Slavinskaite, 2017; Mose, 2017; Omri, 2013).[1] Emissions of CO_2, which is one of the major greenhouse gases, are generated mainly by the consumption of fuel energy and are creating a global warming crisis (Katircioglu, 2017). To cope with this, governments in dominant countries worldwide have cooperated and put forward the low-carbon transformation strategy. In doing this, the Chinese government has taken proactive steps to improve energy efficiency and develop renewable energy. Despite these efforts, CO_2 emission intensity in China is still much higher than that in developed countries (Tan, Li, Wang, & Wang, 2011).[2] Against this background, at the 2015 Paris Climate Conference, the government further committed to reducing 60–65% of its CO_2 emission intensity in 2030 and incorporated this target into its long-term national project. Therefore, for the purposes of fulfilling this target and achieving green and sustainable economic growth, understanding the precise relationship between economic growth, financial development, and CO_2 emission intensity is significant and has attracted much research.

Most of the literature on CO_2 emission intensity generally seeks to decompose the intensity by employing either structural decomposition analysis or the logarithmic mean divisia index, to identify the critical factors for its changes (Ebohon & Ikeme, 2006; Greening, Ting, & Davis, 1999; Voigt, Cian, Schymura, & Verdolini, 2014; Wang, Ang, & Su, 2017). However, these studies are subject to three limitations: first, in spite of the merits of the decomposition approaches, econometric regression methods are more flexible in incorporating many other important economic factors. Second, few papers have considered the effect of financial development on CO_2 emission intensity since its impact on energy consumptions and CO_2 emissions has been studied extensively in the literature (Ouyang & Li, 2018; Sadorsky, 2010).[3] Financial development may affect CO_2 emission intensity through three channels: 1) promote economic growth and thus interact with environmental factors (Frankel & Romer, 1999); 2) support the R&D activities related to low-carbon technologies (Ang, 2010; Islam, Shahbaz, Ahmed, & Alam, 2013; Tamazian, Chousa, & Vadlamannati, 2009), or help the home country adopt existing low-carbon technologies from other countries (Shahbaz, Solarin, Mahmood, & Arouri, 2013; Stern, 2015); 3) confer superior financial services for environment-friendly programs at lower costs (Claessens & Feijen, 2007; Halicioglu, 2009; Tamazian & Rao, 2010).[4] Moreover, the literature does not consider the possible role of human capital, despite its great importance. From the demand side, higher educational attainment has a positive effect on environmental quality as more educated consumers demand more green products and are more likely to push firms to reduce pollution levels (Goetz, Debertin, & Pagoulatos, 1998). From the production side, more training

[1] In fact, China has been the largest energy-related CO_2 emitter in the world since 2006 (https://www.theguardian.com/environment/2007/jun/1%9/china.usnews). Find more in IEA (2016b).

[2] In 2016, CO_2 emission intensity in China amounted to 0.51 kg CO_2/\$2005p, whereas the figures for the UK, Germany, and France were 0.15, 0.24, and 0.15 kg CO_2/\$2005p, respectively. See the Global Energy Statistics Yearbook at https://yearbook.enerdata.net/CO_2-fuel-combustion/world-CO_2-intensity.html.

[3] To the best of our knowledge, the effect of financial aspects on carbon intensity is considered in detail only by Tian, Chen, and Zhu (2017), which is discussed in details below.

[4] Meanwhile, financial development may intend investors to adopt low-carbon technologies and, thus, lower CO_2 emissions, for instance, in Indonesia (Shahbaz, Hye, Tiwari, & Leitão, 2013) and in Malaysia (Shahbaz, Solarin, Mahmood, & Arouri, 2013).

of the workers may reduce the energy needed in the production process due to a strong substitution relationship between human capital and energy (Pablo-Romero & Sánchez-Braza, 2015). Also, high schooling levels can accelerate the diffusion of renewable energy technology (Pfeiffer & Mulder, 2013). Third, as economic structure evolves with economic growth, the impact of economic variables on CO_2 emission intensity might be asymmetric in different stages of development. This potential asymmetric linkage is supported partially by Ebohon and Ikeme (2006) and Zhang (2009), who find the structural effects on carbon intensity differ across periods.

This paper attempts to overcome these limitations and studies the dynamic impacts of financial development, human capital, and economic growth on CO_2 emission intensity in China for the period 1978–2015. It contributes to the literature in three ways. First, due to the complexity of the financial system, this paper follows Zhang (2011) and measure financial development in three dimensions: scale (m^2), efficiency (private sector credit), and openness (net foreign direct investment (FDI) inflows), which allows us to capture the impact of financial development on CO_2 emission intensity in a more complete and subtle way. Second, to the best of our knowledge, this is likely to be the first attempt to include human capital in the literature on CO_2 emission intensity.[5] Last, we also account for the asymmetric effects of the selected variables on CO_2 emission intensity at different stages of development by taking the year 1992 as a breakpoint.[6]

The results show that there indeed exists a long-run cointegration relationship between financial development, human capital, and CO_2 emission intensity. Three main findings are highlighted. First, financial openness indicated by net FDI inflows significantly reduces the CO_2 emission intensity in both the short- and the long-term. This finding provides evidence for the Pollution Halo Hypothesis (Zarsky, 1999). However, the effects of financial scale and efficiency are limited and insignificant, which is partially in tandem with Zhang (2011). Second, there exists an inverted N-shaped relationship between human capital and CO_2 emission intensity. Specifically, improving human capital initially mitigates CO_2 emission intensity (before 1992), then raises it in the short-run (after 1992), and, finally, alleviates it in the long-run. Last, raising per capita income can also significantly lower CO_2 emission intensity in the long-run.

The rest of the paper proceeds as follows. The following section reviews the related literature. Section 2 first specifies the empirical model and data and then conducts both unit root tests and structural breakpoint tests. Section 3 presents the estimation results with policy implications in Section 4. The last section concludes.

[5] Two papers on environmental pollution have considered human capital. Lan, Kakinaka, and Huang (2012) introduce human capital for studying the impact of FDI on pollution emission, and Fang and Chang (2016) include human capital in the energy–growth nexus. Therefore, their focuses are different.

[6] In this year, China opened a new economic reform epoch, as Deng Xiaoping, the previous Chinese paramount leader, propelled continual economic reform and opening up in his tour to the Special Economic Zones. The result of Zivot–Andrew unit root tests in Section 2 also confirms that there exists only one structural break in 1992 for most of the variable series.

1. Related literature

By methods of decomposition, the literature identifies some critical factors for either increases or decreases of CO_2 emission intensity. First, Greening, Ting, and Davis (1999) study the carbon emissions from the freight sector of 10 OECD countries for the period 1970–1993 and show that increases in aggregate carbon intensity for nine of the countries are driven primarily by an increase in activity, paralleling the GDP growth. Related to this result, Nag and Parikh (2000) find that the income effect of economic growth is a primary determinant for increases of India's CO_2 emission intensity. Meanwhile, carbon intensity is also increased by changes of the structure of economy, such as economic structure in both oil-producing and non-oil-producing sub-Saharan countries (Ebohon & Ikeme, 2006), demand pattern of final products in China (Zhang, 2009), and export structure in China (Xia, Fan, & Yang, 2015). Finally, Liu, Ma, and Kang (2015) further show that the expansion of electricity consumption, particularly in the metal and machinery and chemicals' sub-sectors contributes to increases in carbon intensity. On the other hand, these studies also find some factors that might reduce carbon emission intensity; these include utilization of less carbon-intensive fuels and technologies (Greening, Ting, & Davis, 1999) and higher end use-efficiency of the electricity industry (Ang & Su, 2016; Nag & Parikh, 2000; Tan, Li, Wang, & Wang, 2011). Furthermore, some recent studies show that the adjustments of energy and industry structures also can decrease carbon intensity (Chen, 2011; Voigt, Cian, Schymura, & Verdolini, 2014; Wang, Ang, & Su, 2017; Xu & Ang, 2013; Zhang, Li, Zhou, Zhang, & Gao, 2016).

A few papers also employ regression approaches to study the impact of economic factors on CO_2 emission intensity. By applying an ARDL-ECM approach, Y.-J. Zhang, Liu, H. Zhang, and Tan (2014) study the impact of economic growth, industrial structure, and urbanization on carbon emission intensity in China. They show that economic growth and increasing the share of the tertiary industry can significantly reduce carbon emission intensity, whereas promoting urbanization has an adverse effect. Cole, Elliott, Okubo, and Zhou (2013), Forslid, Okubo Karen, and Ulltveit-Moe (2014), and Richter and Schiersch (2017) analyze the impact of export activities on CO_2 emission intensity at firm-level. They all find that exporting activities can reduce firms' CO_2 emission intensity. This inhibitory effect even goes to the two-digit level (Forslid, Okubo Karen, & Ulltveit-Moe, 2014; Richter & Schiersch, 2017).

Most closely related to this paper is the ARDL-ECM model of Tian, Chen, and Zhu (2017), who also study the impacts of financial factors on carbon intensity in China. However, they focus on financial macro-environment factors, including financial development, financial innovation, and stock market turnover. There are three main differences between this study and theirs. First, the three measures of financial development used in this paper make it possible to capture the impact of financial development on CO_2 emission intensity over a broader range (Zhang, 2011). Second, the possible role of human capital in CO_2 emission intensity is also considered. Last, the asymmetric effects of the selected variables on CO_2 emission intensity in different stages of development are also considered in this study.

2. Methodology and data

2.1. Methodology

This paper employs an ARDL approach to capture the short-run dynamics and the long-run relationships among the variables under concern due to the following three considerations (Pesaran & Shin, 1998; Pesaran, Shin, & Smith, 2001): First, the ARDL approach can avoid the problem of spurious regression and preserve the long-run relationships among variables by integrating all variables with mixed orders in a unified framework. Second, by selecting an appropriate lag structure, this approach can provide consistent estimates for endogenous regressors and report unbiased test statistics for small-size samples, which is especially adequate for this study (38 observations). Third, the long-run equilibrium and short-run error-correction model (ECM) of the series can be calculated easily from this method through a simple linear transformation.

Following Tian, Chen, and Zhu (2017), the ARDL model for this study is specified as follows:[7]

$$\begin{aligned}\Delta CO_2\_IN_t = {} & \beta_0 + \sum_{i=1}^{k}\beta_{1i}\Delta CO_2\_IN_{t-i} + \sum_{i=1}^{k}\beta_{2i}\Delta LNINC_{t-i} + \sum_{i=1}^{k}\beta_{3i}\Delta M2GDP_{t-i} + \\ & \sum_{i=1}^{k}\beta_{4i}\Delta DCPS_{t-i} + \sum_{i=1}^{k}\beta_{5i}\Delta LRFDI_{t-i} + \sum_{i=1}^{k}\beta_{6i}\Delta EPEP_{t-i} + \\ & \alpha_0 CO_2\_IN_{t-1} + \alpha_1 LNINC_{t-1} + \alpha_2 M2GDP_{t-1} + \\ & \alpha_3 DCPS_{t-1} + \alpha_4 LRFDI_{t-1} + \alpha_5 EPEP_{t-1} + \mu_t, \qquad (1)\end{aligned}$$

where Δ represents the first difference operator, k stands for the maximum lag length, β_{ji} and α_i denote the short-term and the long-term cointegration coefficients to be estimated, respectively. μ_t is the white noise residual. The explained variable is CO_2 emission intensity (CO_2_IN), and the explanatory variables include economic growth (LNINC), human capital (EPEP), and three measures of financial development in the sense of scale (M2GDP), efficiency (DCPS), and openness (LRFDI). The definitions of all the variables are presented along with data sources in the next subsection.

The ARDL bounds test (Pesaran, Shin, & Smith, 2001) is used to examine possible long-run cointegration between the series. The null hypothesis of this test is nonexistence of cointegration among the lagged level variables (i.e., $H_0: \alpha_0 = \alpha_1 = \alpha_2 = \alpha_3 = \alpha_4 = \alpha_5 = 0$). To do this, the calculated F-statistic of the test is compared with the two critical value bounds of $I(0)$ and I(1) (lower bound and upper bound) proposed by Pesaran, Shin, and Smith (2001). The results can be divided into three cases: 1) if the calculated F-statistic is larger than their respective upper bound, H_0 is rejected and there exists cointegration relationship among the variables; 2) if the F-statistic is smaller than their respective lower bound, then H_0 cannot be rejected; 3) if the F-statistic is between lower bound and the upper bound, then the bounds tests results are inconclusive and the cointegration relationship cannot be determined.

[7] Note that the model has two variations. First, it includes the three measures of financial development, rather than the China's financial macro-factors in Tian, Chen, and Zhu (2017). This modification does not cause biasedness because the measures of finance in this study are not correlated with theirs in the finance-CO_2-emission nexus. Second, it includes economic growth and human capital because they are important for CO_2 emission intensity.

2.2. Data

The data used for the estimation are annual observations spanning the period 1978–2015 based on consistency and data availability.[8] CO_2 emission intensity (CO_2_*IN*) is defined as the amount of CO_2 emissions produced per unit GDP, and it is measured by the ratio of total CO_2 emissions (kt) to GDP (constant LCU). As mentioned, financial development is measured in three dimensions: scale, efficiency, and openness. First, following Goldsmith (1969), the scale of financial development (M2GDP) is indicated by the broad money supply (M2) as a share of GDP. Second, as with Zhang (2011), the efficiency of financial development (DCPS) is expressed by the ratio of the private sector credit to GDP.[9] The efficiency of financial development, to a large extent, means the efficiency of allocating money obtained from savers to the most efficient borrowers. Thus, the ratio of private sector credit to GDP can measure the efficiency of financial development because 1) the overall economic performance of the private sector or non-state-owned enterprises is much better than that of state-owned ones, and 2) the private sector takes no non-economic responsibilities and so gets no special care from the Chinese financial sector (Zhou & Zhong, 2004). Thus, the credits to the private sector are based mainly on its economic performances, which reflect the commercialization of financial intermediaries.

Third, net foreign direct investment (FDI) inflows are used as the proxy of financial openness, as net FDI inflows are generally regarded as an important measure for the level of financial development and openness (Sadorsky, 2010). Human capital (EPEP) is indicated by enrollments in secondary education of both sexes (% of gross), as secondary education involves the provision of basic education and lays the foundations for further learning and development (Cohen & Soto, 2007).[10] Moreover, economic growth (LNINC) is incorporated into the model, indicated by the logarithmic form of real GDP per capita (constant LCU), as CO_2 emission intensity might be affected by economic growth and the income effect (Nag & Parikh, 2000).[11] All the aforementioned data sets are derived from the World Bank Development Indicators, except for the data set for net FDI flows, which is obtained from the China Statistical Yearbook. Further, the raw series of net FDI inflows is first deflated by the consumer price index in the corresponding periods and then converted into logarithm form (LRFDI). Table 1 summarizes the descriptive statistics of all the variables.

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[8] 978 is the year that market-oriented reform was launched in China, before then China was a planned economy.

[9] On the other hand, some studies also use the ratio of total loans to deposits because the ratio of private sector credit to GDP neglects the vital role of state-owned enterprises (Wang & Sun, 2003). Therefore, the robustness of these results is also tested by using the ratio of loans to deposits. The results show that these qualitative results are robust. Also, the results of the tests are available from the author upon request.

[10] These qualitative results are robust when the proxy of human capital is replaced by the human capital index in Penn World Tables 9.0. The results with this proxy are available from the author upon request.

[11] Note that the level of log GDP per capita is not itself a growth variable, rather the coefficient of log GDP can be interpreted as economic growth. With little abuse of terminology log GDP per capita is also called economic growth. We thank the reviewer for noting this point.

Table 1. Descriptive statistics

	CO_2_IN	LNINC	M2GDP	DCPS	LRFDI	EPEP
Mean	0.19	8.72	1.12	0.96	5.61	10.59
Median	0.16	8.73	1.11	0.97	6.90	10.61
Maximum	0.40	10.27	2.06	1.55	7.42	15.29
Minimum	0.07	7.22	0.24	0.50	1.24	6.81
Std. Dev.	0.10	0.94	0.53	0.28	2.09	2.45
Skewness	0.47	0.05	–0.01	0.00	–0.87	0.29
Kurtosis	1.74	1.79	1.72	2.10	2.29	2.20
Jarque-Bera	3.89	2.35	2.61	1.28	5.59	1.54

2.3. Unit root tests

A precondition for applying the ARDL approach is that all regressors must be either *I* (0) or *I* (1). Therefore, before estimating the ARDL model, the ADF, DF-GLS, and KPSS unit root tests are applied to check the stationarity properties of the sequences. Table 2 shows that all the variables consistently exhibit unit roots at their level form, but become stable after first-difference at the 5% significance level. This indicates that all the series are either *I* (0) or *I* (1). Thus, the ARDL model applies to the estimation.

Table 2. Unit root tests

Variables	Intercept		Intercept with trend	
	Level	1st Diff.	Level	1st Diff.
ADF unit root test				
CO_2_IN	–1.525	–3.894***	–1.587	–3.442**
LNINC	0.103	–3.687***	–3.066	–3.573**
M2GDP	0.014	–6.412***	–3.152	–6.337***
DCPS	0.004	–5.398***	–4.055**	–4.06**
LRFDI	–2.799*	–2.564	–2.111	–3.294**
EPEP	–1.423	–2.038**	–3.206*	–2.340
DF-GLS unit root test				
CO_2_IN	0.125	–3.202***	–1.595	–4.025**
LNINC	0.828	–2.765***	–2.186	–3.456***
M2GDP	1.649	–5.839***	–3.261	–6.217***
DCPS	0.955	–5.441***	–2.613	–5.392***
LRFDI	–0.855	–2.511**	–1.984	–3.028*
EPEP	–0.391	–2.298**	–2.984*	–2.376
KPSS unit root test				
CO_2_IN	0.717	0.344***	0.180	0.057***

End of Table 2

Variables	Intercept		Intercept with trend	
	Level	1st Diff.	Level	1st Diff.
LNINC	0.744	0.144***	0.114***	0.097***
M2GDP	0.747	0.076***	0.088***	0.067***
DCPS	0.743	0.111***	0.077***	0.077***
LRFDI	0.660	0.452**	0.192*	0.057***
EPEP	0.713	0.124***	0.096***	0.079***

Note: **** significance at 1% level;** significance at 5% level; * significance at 10% level.

Furthermore, to consider possible asymmetric effects of the selected variables on CO_2 emission intensity at different stages of development, the Zivot–Andrews breakpoints test is also conducted to check for a possible structural breakpoint of all the series. Figure 1 presents the result of the net FDI inflows series, and it shows clearly that a structural breakpoint exists only in 1992.[12] Therefore, the analysis below is divided into two samples: a full sample with all the observations and a reduced sample with the observations from 1992 to 2015.

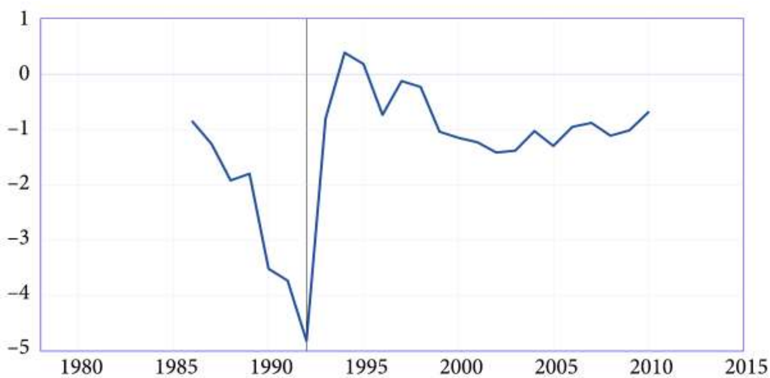


Figure 1. Zivot-Andrews breakpoints test (LRFDI)

3. Empirical results

3.1. ARDL bounds test

As a first step, the ARDL bounds tests are applied to check the long-run cointegration relationship among the series. To determine the optimal lag structure as well as preserving adequate degrees of freedom, the Akaike information criterion (AIC) is used by restricting the maximal lag length to two. Table 3 presents the ARDL bounds test results. The F-statistics derived from the full sample and the reduced sample are 10.040 and 5.905,

[12] Only this result is presented out of consideration of space, but others are available from the author upon request.

respectively, both of which exceed the corresponding upper bound at the 1% significance level. Therefore, the bounds test implies that there indeed exist long-run integration relationships among the variables in China over the 1978–2015 and the 1992–2015 periods.

Table 3. ARDL bounds test

	Full Sample				Reduced Sample			
Test statistics	Value	Signif.	I(0)	I(1)	Value	Signif.	I(0)	I(1)
F-statistics	10.04	10%	2.331	3.417	5.905	10%	2.407	3.517
		5%	2.804	4.013		5%	2.91	4.193
		1%	3.9	5.419		1%	4.134	5.761

3.2. Long-run results

Based on the long-run cointegration relationship among the variables established above, the ARDL model in equation (1) is estimated with both the full sample data and the reduced sample data. The optimal lag structures determined by the AIC criterion for the full sample and the reduced sample are ARDL (2, 0, 0, 0, 0, 2) and ARDL (1, 2, 1, 0, 2, 2), respectively.[13] Table 4 reports the long-run estimates of both samples, where most of the long-run equilibrium coefficients are statistically significant. Three key results are highlighted: First, contrary to Nag and Parikh (2000), it reveals a pronounced negative correlation between per capita income and CO_2 emission intensity in both samples at the 1% significance level. Quantitatively, a 1% increase in per capita income, ceteris paribus, reduces CO_2 emission intensity by 0.063% in the full sample, and by 0.194% in the reduced sample. Hence, the inhibitory effect of per capita income on CO_2 emission intensity has been enhanced distinctly in recent years. The reason for this might be that, in recent years, per capita income in China has increased significantly. Consumers with higher per capita incomes demand and consume more environmental-friendly products, and the significant progress of technology innovations also makes such products available.[14] For instance, low energy-intensity household appliances have become increasingly popular among consumers. Therefore, this result also stands in sharp contrast to Zhang (2009), who finds that the demand pattern in China changes in the direction of high carbon-intensity consumption.

Second, improving human capital is significantly conducive to the reduction of CO_2 emission intensity at all conventional levels in the two samples. Moreover, the negative nexus is much more prominent in the reduced sample (–0.038%) than in the full sample (–0.021%). This result confirms the conjunction above. Human capital not only contributes to the efficient use of energy and capital as an essential input for production but also plays a catalytic

[13] Alternatively, the lag structure determined by the SBC criterion is identical for the reduced sample, but it is different for the full sample, being ARDL (1, 0, 0, 0, 0). However, this different lag structure does not change the main results.

[14] In a survey of China's middle-class consumers, conducted by the Hong Kong Trade Development Council in 2017, 71% of respondents claimed that they had been spending more on green products. See more at http://economists-pick-research.hktdc.com/business-news/article/Research-Articles/China-s-Middle-Class-Consumers-Attitudes-towards-Green-Consumption/rp/en/1/ 1X000000/1X0AB4QY.htm

role in taking in FDI technology spill-overs (Lan, Kakinaka, & Huang, 2012) and developing low-carbon technologies. Furthermore, a higher level of human capital might also promote enterprises to strictly follow related environmental standards, which will also help reduce CO_2 emission intensity.

Table 4. ARDL long-run estimates

	Full Sample		Reduced Sample	
Variable	Coef.	t-ratio	Coef.	t-ratio
LNINC	–0.063***	–2.871	–0.194***	–3.961
EPEP	–0.021***	–6.243	–0.038***	–4.174
LRFDI	–0.030***	–15.018	–0.047***	–4.205
M2GDP	–0.080*	–1.796	0.111	1.192
DCPS	0.044	1.274	0.05	0.889
Constant	1.182***	5.786	2.368***	5.061
R2	0.997		0.996	
F-statisitics	841.48		185.47	
D.W	2.199		2.121	

Note: **** significance at 1% level; ** significance at 5% level; * significance at 10% level.

The last result relates to the effect of financial development on CO_2 emission intensity in the three dimensions. First, financial openness, measured by net FDI inflows, exerts a notably adverse impact on CO_2 emission intensity in both samples at the 1% significance level. Specifically, a 1% increase in net FDI inflows is linked to decreases of CO_2 emission intensity by 0.03% in the full sample, and 0.047% in the reduced sample. So, the inhibitory effect produced by net FDI inflows is also much more striking in the past two decades, indicating that net FDI inflows have been progressively more effective in protecting the environment. Therefore, consistent with the Pollution Halo Hypothesis (Zarsky, 1999), net FDI inflows can decrease CO_2 emission intensity through the application of better management practices and advanced technologies in host countries. This decreasing effect dominates the positive effect of more aggregate investments in CO_2 emissions, despite a relatively higher ratio of FDI pouring into China's carbon-intensive industries (Zhang, 2011).[15] Indeed, FDI in carbon-intensive industries does not necessarily mean high carbon intensity, as Doytch and Narayan (2016) show that FDI concentrated on non-renewable energy sectors saves energy. However, this contradicts with Zhang, Liu, Zhang, and Tan (2014) and Tian, Chen, and Zhu (2017) who show that net FDI inflows increase CO_2 emission intensity. This might be attributed to different estimation models and data processing methods. Therefore, this finding provides further evidence against the Pollution Heaven Hypothesis (Acharyya, 2009; Husain, 2016; Leitão, 2013; Zomorrodi, Zhou, & others, 2016).

[15] Note further that more investment with FDI will not increase CO_2 emissions by much since China's net inflow of FDI accounts for less than 5% of GDP (Zhang, 2011).

Second, the scale of financial development depresses the increase of CO_2 emission intensity only in the full sample at the 10% significance level. One possible interpretation of this is that, with the expansion of financial sector enterprises, more credits necessary for improving energy efficiency and introducing high-level renewable energy technology can be obtained (Jalil & Feridun, 2011). Nevertheless, this beneficial influence turns out to be insignificant in the reduced sample. Intuitively, this phenomenon can be explained by a much weaker linkage between financial scale and CO_2 emission intensity in recent years. Since 1992, China has experienced two great financial crisis (in 1997 and 2008), during which the monetary base expanded rapidly with frequent uses of expansionary monetary policies by the government. For instance, in 2008, the government carried out a 4 trillion RMB bailout plan.

Finally, in tandem with Zhang, Liu, Zhang, and Tan (2014), the efficiency of financial development is not significantly related to CO_2 emission intensity in either sample. This may be because financial efficiency in China is still not substantial, as the financial sector is heavily burdened by supporting inefficient state-owned enterprises and reducing poverty under administrative orders and government policies (Boyreaudebray, 2003; Guariglia & Poncet, 2008; Hasan, Wachtel, & Zhou, 2009).[16]

3.3. Short-run results

Panel A of Table 5 presents the short-run results. The estimates derived from the full sample reveal that CO_2 emission intensity exhibits path dependence: CO_2 emission intensity in the previous year exerts a significant positive impact on the current year. Similarly, three key findings are underlined. First and foremost, in the short-run, human capital is positively related to CO_2 emission intensity, with a one-time lag after 1992 in the reduced sample. This may be because increasing human capital after 1992 involves very high CO_2 emission intensity activities, such as building new and modern schools with concrete and steel. Combining this finding with the long-run one above, one can notice that there exists an inverted N-shaped relationship between human capital and CO_2 emission intensity: improving human capital first reduces CO_2 emission intensity (before 1992), then increases it in the short-run (after 1992), and, finally, alleviates the intensity in the long-run. Second, the impacts of all three measures of financial development on CO_2 emission intensity in the short-run period are analogous to that in the long term. Thus, finance-carbon nexus shows some consistency over time. Last, the inhibitory effect of per capita income on CO_2 emission intensity persists with the full sample in the short-run, but a reverse effect emerges after 1992 in the reduced sample. This is similar to the effect of human capital: an inverted N-shaped relationship exists between per capita income and CO_2 emission intensity. Intuitively, changing consumption patterns requires time, so the inhibitory effect appears in the long-run.

[16] For instance, the Chinese stock market is immature and subject to problems of incomplete information, lack of transparency, and disclosure deficiencies, experiencing mania once and market panic twice in only two years: 2015 and 2016 (Ouyang & Li, 2018).

Table 5. ARDL short-run estimates

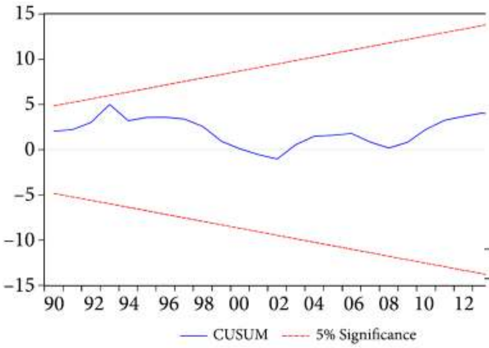
Panel A. ARDL short run error correction representation				
	Full Sample		Reduced Sample	
	Coef.	t-ratio	Coef.	t-ratio
D(CO_2_IN(-1))	0.241**	2.165	–0.175	–1.163
D(LNINC)	–0.052**	–2.294	0.395**	2.359
D(EPEP)	–0.017***	–3.974	0.004	0.346
D(EPEP(-1))	–0.011	–1.215	0.027*	2.21
D(LRFDI)	–0.025***	–5.803	–0.055***	–3.882
D(LRFDI(-1))			–0.022**	–2.583
D(M2GDP)	–0.066*	–1.94	0.035	0.646
D(DCPS)	0.037	1.332	0.039	0.94
C	0.978***	3.651	1.872***	4.395
ECM(-1)	–0.827***	–6.675	–0.790***	–4.235
Panel B. Diagnostic tests				
	Coef.	p-value	Coef.	p-value
J-B Normality Test	0.41	0.815	0.574	0.75
Ramsey Test	0.336	0.718	0.88	0.452
LM Test	1.521	0.239	1.344	0.314
Heteroscedasticity Test	1.226	0.322	1.085	0.457

Note: **** significance at 1% level; ** significance at 5% level; * significance at 10% level.

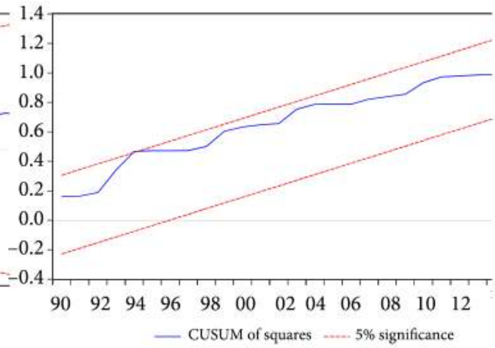
Meanwhile, the coefficients of the ECM are –0.83 and –0.79 in the two samples, respectively, indicating a relatively rapid convergence from short-term deviations to the one-term equilibrium. The short-run diagnostic test results reported in Panel B of Table 5 further imply that the ARDL model is well specified, as there is no heteroscedasticity and no autocorrelations and all white noise residuals are normally distributed. To further examine the stability of the long-term model and short-term ECM parameters, two standard methods are used: Cumulative Sum of Recursive Residuals (CUSUM) and Cumulative Sum of Squares of Recursive Residuals (CUSUMSQ). Figure 2 delineates the results and shows that the residuals in both samples are stable at the 5% significance level.

3.4. Robustness check

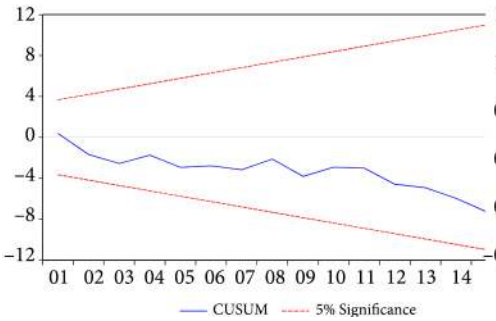
To check the robustness of the results, three alternative estimation methods are employed: fully modified least squares (FMOLS), dynamic least squares (DOLS), and canonical cointegration regression (CCR). Tables 6 and 7 show that the empirical results above are robust in the two samples, including the inhibitory effects of net FDI inflows, human capital, and per capita income on carbon intensity. But the positive linkage between financial efficiency and CO_2 emission intensity becomes significant in some tests in both samples. One possible



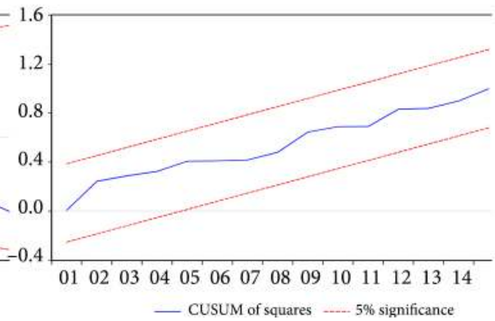
Panel A1 Plot of Cumulative Sum of Recursive Residuals (full-sample model).



Panel A2 Plot of Cumulative Sum of Squares of Recursive Residuals (full-sample model).



Panel B1 Plot of Cumulative Sum of Recursive Residuals (reduced-sample model).



Panel B2 Plot of Cumulative Sum of Squares of Recursive Residuals (reduced-sample model).

Figure 2. Stability tests for the ARDL models

explanation is that the financial sector, especially in terms of the loan, has always been monitored closely by the Chinese central government and is very sensitive to the government's policies. For the reduced sample period, Table 7 shows that the results obtained by the DOLS method are similar to those obtained by the ARDL estimation since the DOLS method is regarded as being more reliable in the sense of including both leads and lags and correcting heteroscedasticity and autocorrelations (Salim, Yao, & Chen, 2017). Therefore, the results in the reduced sample period are also robust.

Table 6. Long-run robustness check in the full sample

Variable	ARDL(Full)	FMOLS	DOLS	CCR
LNINC	–0.063***	–0.030*	–0.039	–0.027
EPEP	–0.021***	–0.015***	–0.017***	–0.015***
LRFDI	–0.030***	–0.030***	–0.030***	–0.030***
M2GDP	–0.080*	–0.127***	–0.116**	–0.133***
DCPS	0.044	0.070**	0.068*	0.078**
C	1.182***	0.864***	0.941***	0.830***

Note: **** significance at 1% level;** significance at 5% level; * significance at 10% level.

Table 7. Long-run robustness check in the reduced sample

Variable	ARDL(Reduced)	FMOLS	DOLS	CCR
LNINC	–0.194***	–0.012	–0.150**	–0.015
EPEP	–0.038***	–0.017***	–0.030***	–0.017***
LRFDI	–0.047***	–0.034***	–0.044***	–0.033***
M2GDP	0.111	–0.195***	0.052	–0.194**
DCPS	0.05	0.125***	0.073	0.131**
C	2.368***	0.776***	1.924***	0.786***

Note: *** significance at 1% level; ** significance at 5% level; * significance at 10% level.

4. Policy implications

The empirical results on the dynamic impacts of financial development and human capital on CO_2 emission intensity in China provide two valuable policy implications for achieving green and sustainable economic growth for China and also for other developing countries.

First, financial development, in the sense of scale and openness, exhibits an inhibitory and significant effect on CO_2 emission intensity in both the short- and the long-term, but financial efficiency has an insignificantly positive effect. Therefore, a higher level of financial development, with greater openness, props up technological innovations, either by taking in low-carbon technologies aboard or by increasing spending on energy conservation R&D. This improves energy efficiency and, hence, lowers CO_2 emission intensity. To transform toward a low-carbon economy and fulfill the 2030 carbon emission intensity target, the Chinese government should further open its financial sector and attract more net FDI inflows and, at the same time, improve financial efficiency to avoid the environment-degrading effect of low financial efficiency.

Second, human capital can also significantly curb CO_2 emission intensity in the long-term. Therefore, the government can also rely on the improvement of human capital to decrease CO_2 emission intensity in the long-run. However, this policy might either not have immediate effects or may even exacerbate the situation in the short-run. Due to the high turnover rate of administrative officers in China, the local government has no incentive to improve human capital in the short-run, and, thus, cannot make use of its long-run inhibitory effect on carbon intensity. Therefore, the central government should take responsibility and invest more resources in improving human capital and cultivating high-tech talents, particularly in the fields relating to low-carbon technologies.

Conclusions

With the looming global warming crisis, the question of how to decrease CO_2 emission intensity is becoming an important issue confronting many developing countries. This study reveals a long-run cointegration linkage between financial development, human capital, economic growth, and CO_2 emission intensity. First, financial development can, in general, reduce CO_2 emission intensity, but the magnitude of this effect varies across different dimensions of financial development. The role of financial openness measured by net foreign direct investment (FDI) inflows is significant, whereas that of financial scale and efficiency is somewhat limited and insignificant. Also, raising human capital is beneficial for decreasing CO_2 emission intensity, but it may have an adverse effect in the short-run. Last, improving per capita income is also found to decrease CO_2 emission intensity in the long-run, but this result is sensitive to different specifications. Therefore, the significant roles of net FDI inflows and human capital are highlighted in reducing CO_2 emission intensity and, thus, ameliorating environmental quality.

These results contribute to the debate on the environmental impact of economic variables. In particular, they provide further evidence that financial development, especially in the sense of net FDI inflows, and human capital are two essential tools for supporting green and sustainable economic growth. This finding has particular significance for China to fulfill the target of reducing CO_2 emission intensity by 60–65% from 2005 levels by 2030. Due to unavailability of data, however, this study is restricted to country-level time series. Studies with province-level or even city-level panels may help us understand further the heterogeneous impacts of financial development and human capital on CO_2 emission intensity across areas and cities. This is because economic development and, consequently, financial development and human capital are unbalanced and vary a lot across areas in China. Also, it is worthwhile to exploit the environmental impact of financial development by further separating it into formal and informal finance, as in Ayyagari, Demirgüç-Kunt, and Maksimovic (2010), or by doing this at firm-level, as in Forslid, Okubo Karen, and Ulltveit-Moe (2014) and Richter and Schiersch (2017). These avenues are left for future research.

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Author contributions

PL and YO conceived the study and were responsible for the design and development of the data analysis. PL was responsible for data collection and analysis. YO was responsible for data interpretation and wrote the first draft of the article.

Disclosure statement

The authors declare that they did not have any competing financial, professional, or personal interests from other parties.

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