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Local finance - carbon neutrality nexus: A quasi-natural experiment of city commercial banks in China

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Abstract: The Chinese government indicated that financial policies are important for sustainable development and that green finance should be developed to achieve carbon peaks by 2030 and carbon neutrality by 2060. This study aimed to detect the nexus of local finance and carbon neutrality by constructing a two-sector (clean and dirty sectors) model to capture the channels from financial development (FD) to energy consumption and carbon emissions (CEs) and by analyzing the scale, structural, and technological effects of the changes in the financial scale, structure, and efficiency. By establishing city commercial banks (CCBs) for a quasi-natural experiment, we used difference-in-differences (DID), instrument variable (IV), and spatial DID methods to test the effects of FD on CEs in China during 2003–2018. The construction of CCBs had a positive effect on the CEs of cities. This was mainly because of the expansion of electricity consumption (scale effect) and reindustrialization (structure effect) caused by establishing CCBs despite the technological effects of stimulating patent creation. Moreover, the nexus varied across different regions with different geographical locations, resource endowments, financial correlation ratios, and environmental regulations. In addition, CCBs construction showed a positive spatial spillover effect on the CEs of neighboring regions. Finally, the study proposed some suggestions for carbon neutrality from the perspective of CCBs management, related policies and regulations, and local carbon reduction efforts.

Keywords: Local financial development; Carbon emissions; City commercial banks; Difference-in-differences; Mixed effect

1. Introduction

To achieve a carbon peak by 2030 and carbon neutrality by 2060, the government, social organizations, and other stockholders of China have made continuous efforts through different aspects. On October 24, 2021, the Central Committee of Communist Party of China and State Council Issued “Opinions” to “completely, accurately, and comprehensively implement a new development concept, and do a good job in carbon peaking and carbon neutralization.” As the “1” of the “1+N” policy system on carbon peaking and carbon neutralization, the proposed “opinions” provided systematic plans and management provisions to achieve the said carbon peak and carbon neutralization goals. It is a top guidance document that explicitly highlights that one of the key tasks of carbon peaking and neutralization is improving policy mechanisms. The financial sector, especially green finance, is a vital part of the policy mechanisms. Generally, financial development (FD), which provides capital and financial services to an economy, is essential for both carbon markets and carbon neutrality policies [1]. A comprehensive understanding of the nexus of local FD and carbon emissions (CEs) is a prerequisite for efficiently utilizing financial resources to promote carbon neutrality [2,3].

FD has been gaining attention recently because of its role in reducing CEs. In particular, with the increase in the importance of carbon neutrality, research focusing on the relationship between FD and CEs has been correspondingly increasing. The existing research on the nexus between FD and CE includes three perspectives: positive effects [4-8], negative effects [1,9,10], and non-monotonic effects, including U-shaped [11,12], inverted U-shaped [13,14], M-shaped, W-shaped, and N-shaped effects [15], which are alternatively called time-variant effects[16,17]. Most researchers believed that the financial sector has a direct CE reduction effect because it is a part of the tertiary industry. These controversial conclusions mainly arise from the diverse indirect channels, including positive and negative channels, from FD to CEs [1-3,18]. These channels cover technological progress, which is associated with CE reduction [2,3], industrial structural change, which is considered a negative channel [1], and foreign direct investment (FDI) and economic growth/energy consumption, all of which increase CEs [2]. A theoretical mechanism analysis of the channels between FD and CE is a prerequisite to understand the inconclusive nexus between FD and CE. Therefore, in this study, we constructed a two-sector model to gain insights into the channels between FD and CE.

Existing studies have measured FD using many indices from different perspectives, such as financial access, financial depth, and financial efficiency [19], and explained FD in stock market development and bank system development using comprehensive proxies [20]. In addition, some indexes described FD from a unique perspective [3]. However, it is sparse to evaluate the effect of FD from the viewpoint of the construction of CCBs. To the best of our knowledge, few studies have documented the effect of FD on CEs from the perspective of CCBs. Unlike the US financial system, which is mainly equity market-oriented, China's financial system is dominated by the banking sector [21]. Bank financing directly influences firms. In areas with low financial development, the development of the firms is more dependent on bank credit. With the expansion of assets and credit, CCBs have become more crucial for firms' financing, especially for small- and medium-sized enterprises' (SMEs) [22]. Moreover, CCBs, being regional financial institutions, are closely connected to the local economy [23]. Contrary to state-owned banks, CCBs are a more representative index of local FD in the context of loose feet capital. By comprehensively considering the characteristics of China's financial and enterprise systems, detecting the CE reduction effect of FD from the perspective of CCBs is practical and useful [24]. Therefore, using a theoretical mechanism analysis along with a two-sector model, this study attempted to reveal the exact impacts of FD on CEs using CCB information.

With the aforementioned analysis, research on the association between CCBs and regional CEs is vital to achieve carbon neutrality. Especially, in China, the top carbon emitter, banking-related policies is essential and seminal for the "30+60" carbon reduction commitment. The present study constructed a two-sector (clean and dirty) model by introducing energy and the environment as input factors. The theoretical analysis and corresponding hypothesis were presented by debating the effects of changes in the financial scale, structure, and efficiency. An empirical test was conducted on a dataset of 285 cities in China from 2003 to 2018. Considering the potential endogeneity in the influence of FD on CEs [25,26], difference-in-difference (DID) model was considered a technically feasible method to alleviate endogenous problems [27,28]. By constructing CCBs as a quasi-natural experiment, we established a multi-period DID model and an instrument variable (IV) method to study the effects of CCBs on CEs.

This study makes three significant contributions to the literature. First, a two-sector model was established to discuss the theoretical routes and provide a micro-mechanism responsible for the effects of FD on CEs. Many studies have reported the channels from FD to CEs using different routes, including economic growth, industrialization, FDI, technological innovation, energy consumption [1-3], direct and indirect effects [8,29], scale effect, and efficiency effect [12]. However, the descriptions of the micro-theoretical mechanisms are scarce, especially in empirical papers. Therefore, this study identified the effects of financial scale, structure, and efficiency on CEs, thereby distinctly achieving the routes of the effects of FD on CEs, and successfully combining macro and micro discussions. Second, information on the establishment and distribution of CCBs was collected to describe local FD for the empirical tests. Existing research has extensively constructed a comprehensive FD index [5,18,30,31], or variable dimensions of proxies to detect the connection between FD and CEs [6-8,12,14,16,20,29,31,32]. However, research on the nexus of CCBs with pollution emissions is still lacking [24], particularly for the effects of CCBs on CEs. Given that China has a bank-dominated financial system, and large banks operate in wide locations, measuring the efficiency of large banks that operate their businesses in a wide area is difficult [33]. With the demonstration of the background and development course of CCBs, it can be considered as a quasi-natural experiment and used to test the effect of FD on CEs [24]. Third, using city-level data, we provided a suite of empirical studies, including direct effect tests and mechanism analysis on the effects of FD on CEs using the DID and IV methods, which alleviate the endogeneity problem to some degree. Further, mutually verifiable empirical analysis (including propensity score matching-DID and spatial DID, excluding special samples, changing the measurement of variables, and considering the hysteresis and expectancy effects) proved the robustness of our conclusions, and the test on the mechanisms provided in-depth and reliable results.

The remainder of this paper is structured as follows: Section 2 presents the policy background and theoretical hypothesis. Empirical strategy and findings are presented in Sections 3 and 4, respectively. Section 5 describes the analysis results of the mechanism, heterogeneity, and spatial spillover effects. Finally, Section 6 presents the conclusions and policy implications.

2. Policy background and theoretical hypothesis

2.1. Policy background

The development of the financial sector not only increases financial assets, but also represents an institutional reform of the financial system. The emergence of CCB replaced the conventional system of “strong public finance and weak local finance” with increasingly important contribution of the local government in capital structure [25]. In 1995, with the support from the central government and central bank, CCBs were fostered by restructuring urban credit cooperatives. In 1998, CCBs were first officially announced. They were originally positioned to provide financial services for SMEs and support local economic growth [22], and were created following the rule of a one-city-one-commercial bank. Until 2006, the China Banking Regulatory Commission permitted CCBs to establish branches in other provinces. Since 2007, several CCBs have extended exponentially outside their own provinces. After more than 20 years of development, CCBs rank third in business development among all categories of Chinese financial institutions. The City Commercial Bank Development Report (2021) indicated that by the end of 2020, national urban commercial banks reached 41.1 trillion yuan (up 10.2% year-on-year), accounting for 12.85% of the total assets of China's banking system.

Against this background, three aspects support us to analyze the local financial level and CE nexus from the CCB perspective. First, the scale and business expansion of CCBs reflect the scale expansion of China's financial industry to a certain extent. Since the establishment of CCBs, their number and scale have been gradually increasing. Until 2020, CCBs achieved an operating revenue of 885.6 billion yuan (up 3.2% year-on-year), thus, ranking third in the banking industry. The asset scale and growth rate of CCBs have been consistent with the expanding scale of China's FD (Figure 1). In addition, contrary to state-owned commercial banks, whose business lies predominantly in the most developed area of China, CCBs operate their businesses widely across the country [23]. Hence, from the perspective of scale, discussing FD through the lens of CCBs is practically possible. Second, since their establishment and development, CCBs have continually improved and showed a gradual transition, reflecting the evolution of the structure of China's financial system to some degree. CCBs are a significant change in China's banking industry [22]. Additionally, the diversified stakeholders of CCBs, mainly including local government, urban collective-owned firms, urban private-owned firms, and shareholders of former credit cooperatives rather than only the central government, embody the will of many shareholders and tie-down the connection of CCBs with the regional economic system [25,33]. From a structural perspective, the evolution of CCBs is appropriate to state the endeavor of FD to reduce regional CEs. Third, the priority of CCBs in simple organization and stable operation contributes to their high efficiency and, to some extent, reflects the increasing efficiency of China's financial system. As seen in Figure 1, the non-performing loan ratio of CCBs has been consistent with the growth of China's banking system during 2011–2020. By the end of 2020, it was 1.81%, which was 1.01% higher than that in 2011 (0.8%) and slightly lower than that of China's commercial banks (1.84%). To some extent, the volatility of the efficiency of CCBs reflects the continuous improvement in the efficiency of China's financial industry through policy adjustment and mechanism improvement. Thus, investigating the effects of FD on CEs from the perspective of CCBs is practical. Moreover, this study scrutinized the theoretical channels from FD to CEs by discussing the effects of financial scale expansion, financial structure adjustment, and financial efficiency improvement.

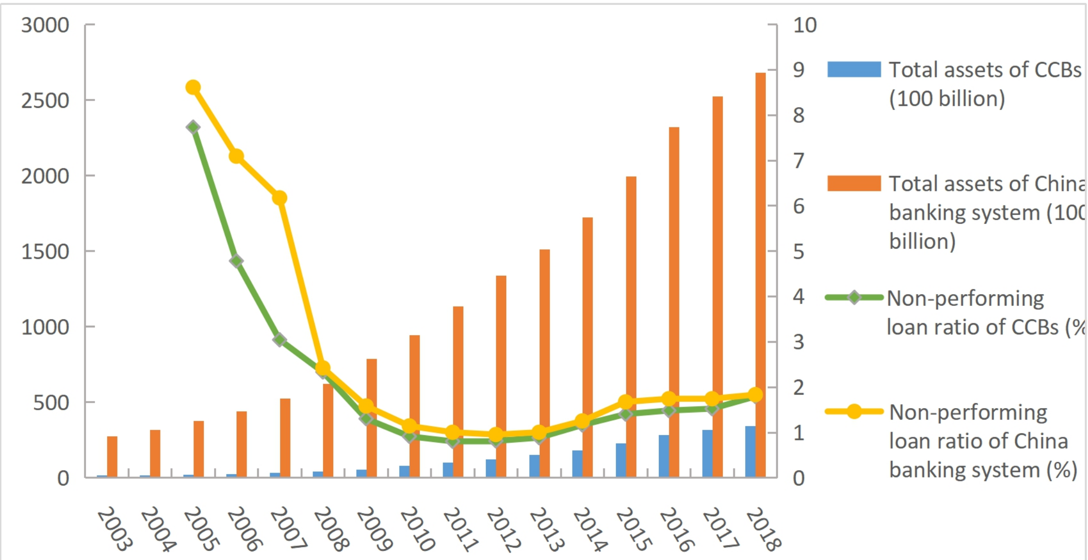

Figure 1 Total assets and non-performing loan ratio of city commercial banks (CCBs) and banking system of

2.2. Theoretical hypothesis

Referring to Acemoglu et al. [34] and Zhou et al. [35], we constructed a two-sector model, using "clean sector" (sector *c* with no energy consumption and CE) and "dirty sector" (sector *d* with energy input and CEs). The model was as follows:

$$U_t = f_{t,c}\left[\left(A_{t,k_c} \times k_{t,c}\right), \left(A_{t,l_c} \times l_{t,c}\right)\right] + f_{t,d}\left[\left(A_{t,k_d} \times k_{t,d}\right), \left(A_{t,l_d} \times l_{t,d}\right), \left(A_{t,e} \times e_t\right), \left(A_{t,h} \times h_t\right)\right]$$

Here, $k_{t,c} + k_{t,d} = K_t$ and $l_{t,c} + l_{t,d} = L_t$. K_t and L_t represent the total capital and total labor in the economy at time *t*, respectively. We assumed $K_{t1} = (1+\varphi)K_{t0}$, implying that the current capital growth with time was based on the front capital and without considering consumption, K_{t1} was used for production, and $\varphi > 0$[1]. In sector *c*, the inputs were capital (k_c) and labor (l_c), whereas in sector *d*, the inputs included not only capital (k_d) and labor (l_d), but also energy (e) and a clean environment[2] (h). Because over 80% of CEs originate from fossil energy consumption, we set $h = h(e)$ to represent the linkage between environmental pollution and energy consumption [36]. Further, A_* represents the index of technological progress and denotes the efficiency of input *. For example, $A_e \times e$ represents total effective energy. In the original generation, the *t0* period, local equilibrium conditions for each sector were as follows:

$$\frac{\partial f_{t0,c}\left[\left(A_{t0,k_c}\times k_{t0,c}\right),\left(A_{t0,l_c}\times l_{t0,c}\right)\right]}{\partial k_{t0,c}} = \frac{\partial f_{t0,d}\left[\left(A_{t0,k_d}\times k_{t0,d}\right),\left(A_{t0,l_d}\times l_{t0,d}\right),\left(A_{t0,e}\times e_{t0}\right),\left(A_{t0,h}\times h_{t0}\right)\right]}{\partial k_{t0,d}}$$

$$\frac{\partial f_{t0,c}\left[\left(A_{t0,k_c}\times k_{t0,c}\right),\left(A_{t0,l_c}\times l_{t0,c}\right)\right]}{\partial l_{t0,c}} = \frac{\partial f_{t0,d}\left[\left(A_{t0,k_d}\times k_{t0,d}\right),\left(A_{t0,l_d}\times l_{t0,d}\right),\left(A_{t0,e}\times e_{t0}\right),\left(A_{t0,h}\times h_{t0}\right)\right]}{\partial l_{t0,d}}$$

$$\frac{\partial U_{t0}}{\partial e_{t0}} = \frac{\partial f_{t0,d}\left[\left(A_{t0,k_d}\times k_{t0,d}\right),\left(A_{t0,l_d}\times l_{t0,d}\right),\left(A_{t0,e}\times e_{t0}\right),\left(A_{t0,h}\times h_{t0}\right)\right]}{\partial e_{t0}} = 0$$

$$\frac{\partial U_{t0}}{\partial h_{t0}} = \frac{\partial f_{t0,d}\left[\left(A_{t0,k_d}\times k_{t0,d}\right),\left(A_{t0,l_d}\times l_{t0,d}\right),\left(A_{t0,e}\times e_{t0}\right),\left(A_{t0,h}\times h_{t0}\right)\right]}{\partial h_{t0}} = 0$$

The above equilibrium states vary with the changes in capital caused by FD in the new generation, i.e., the *t1* period. The comprehensive analyses with different assumptions under different contexts were as follows:

(1) With the endeavor of related policies and financial institutions and markets, $K_{t1} = (1+\varphi)K_{t0}$ and $\varphi > 0$, implying that the financial scale increases in the *t1* generation. Discussions of different financial structure distributions without technological progress are as follows:

(1.1) $\Delta k_c = k_{t1,c} - k_{t0,c}$, $\Delta k_d = k_{t1,d} - k_{t0,d}$, and $\Delta k_c > \Delta k_d$, implying that in the *t1* period, increased added capital flows into the clean sector by some driving forces from related policies and/or institutional adjustments, such as green finance, and/or strategy adjustment of financial institutions. To clearly observe the changes in the corresponding variables, we set a special condition, $\Delta k_c > \Delta k_d = 0$, implying that all added capital flows into the clean sector driven by the green financial policies. When $k_{t0,c} \rightarrow k_{t1,c}$ and $k_{t1,c} > k_{t0,c}$, $\frac{\partial f_{t1,d}}{\partial l_{t1,d}} < \frac{\partial f_{t0,c}}{\partial l_{t0,c}} = \frac{\partial f_{t0,d}}{\partial l_{t0,d}} < \frac{\partial f_{t1,c}}{\partial l_{t1,c}}$; that is, the marginal utilities of labor in sector *c* will increase along with the expansion of the financial scale (a dimension of FD). Subsequently, with the free flow of factors, labor will gradually flow

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[1] $\varphi < 0$, and vice versa, is not discussed in the paper. If $\varphi = 0$, there is no change caused by the financial scale, but changes caused by the change of the financial structure in the new equilibrium occur. It is similar to the discussion with $\varphi > 0$, which is not discussed here.

[2] Here, we consider that the CO_2 consumption can be considered as the consumption of environmental resources (h).

into the efficient sector (sector *c*) from the inefficient sector (sector *d*) until a new equilibrium state is achieved ($\frac{\partial f_{t1,c}}{\partial k_{t1,c}} = \frac{\partial f_{t1,d}}{\partial k_{t1,d}}$ and $\frac{\partial f_{t1,c}}{\partial l_{t1,c}} = \frac{\partial f_{t1,d}}{\partial l_{t1,d}}$) in the *t1* generation. Further, $f_{t1,c} > f_{t0,c}$, $f_{t1,d} < f_{t0,d}$, $|\Delta f_c| > |\Delta f_d|$, and $U_{t1} > U_{t0}$, indicating that the corresponding sector structure will change from the initial equilibrium state $\frac{f_{t0,c}}{f_{t0,d}}$ to the new states $\frac{f_{t1,c}}{f_{t1,d}}$ and $\frac{f_{t1,c}}{f_{t1,d}} > \frac{f_{t0,c}}{f_{t0,d}}$. Moreover, with the labor flowing out from sector *d*, the labor force per unit of energy or environmental resources declines, and the marginal production of *e* and *h* decline. To gain a new equilibrium, $\frac{\partial f_{t1,d}}{\partial e_{t1}} = \frac{\partial f_{t1,d}}{\partial h_{t1}} = 0$, the consumption of resources *e* and *h* will decrease; thus, the CEs decrease. Once sectors *c* and *d* were consistent with manufacturing and service industries, respectively, we confirmed the "**structural effect**," with factors flowing free, and FD leading to industrial structural upgrading, consequently, promoting the decrease of CE.

(1.2) $\Delta k_c = k_{t1,c} - k_{t0,c}$, $\Delta k_d = k_{t1,d} - k_{t0,d}$, and $\Delta k_c = \Delta k_d$ imply that in the *t1* period, the added capital flows on average into the two sectors. With $k_{t0,c} \to k_{t1,c}$, $k_{t1,c} > k_{t0,c}$ and $k_{t0,d} \to k_{t1,d}$, and $k_{t1,d} > k_{t0,d}$, the capital per efficient energy and environmental resource increases. Subsequently, the increase in the marginal production of *e* and *h* results in new local equilibrium states, $\frac{\partial f_{t1,d}}{\partial e_{t1}} = 0$ and $\frac{\partial f_{t1,d}}{\partial h_{t1}} = 0$. Moreover, the scale of the dirty sector increases as $f_{t1,d} > f_{t0,d}$ and aggregate utility increases as $U_{t1} > U_{t0}$. Thus, without technological progress of inputs *e* and *h*, the scale expanding of the dirty sector will increase energy consumption and CEs, viz., $e_{t1} > e_{t0}$ and $h_{t1} > h_{t0}$. We confirmed the "**scale effect**," with the factors flowing free and FD leading to economic growth, consequently, stimulating energy consumption and CE.

(1.3) $\Delta k_c = k_{t1,c} - k_{t0,c}$, $\Delta k_d = k_{t1,d} - k_{t0,d}$, and $\Delta k_c < \Delta k_d$ indicates that in the *t1* period, increased added capital flows into the dirty sector that is promoted by some policies and/or institutional adjustments, such as reindustrialization and/or strategy adjustment of financial institutions. To clearly observe the changes in the corresponding variables, we set a special condition, $\Delta k_d > \Delta k_c = 0$, implying that all added capital flows into the dirty sector driven by reindustrialization. Using $k_{t0,d} \to k_{t1,d}$ and $k_{t1,d} > k_{t0,d}$, we can obtain $\frac{\partial f_{t1,d}}{\partial e_{t1}} > \frac{\partial f_{t0,d}}{\partial e_{t0}} = 0$, $\frac{\partial f_{t1,d}}{\partial h_{t1}} > \frac{\partial f_{t0,d}}{\partial h_{t0}} = 0$, and $\frac{\partial f_{t1,c}}{\partial l_{t1,c}} < \frac{\partial f_{t0,c}}{\partial l_{t0,c}} = \frac{\partial f_{t0,d}}{\partial l_{t0,d}} < \frac{\partial f_{t1,d}}{\partial l_{t1,d}}$; that is, the marginal utilities of *l, e*, and *h* in sector *d* increase with FD. With the free flow of factors, labor will gradually flow into the more efficient sector *d* until a new equilibrium state is reached ($\frac{\partial f_{t1,d}}{\partial e_{t1}} = 0$, $\frac{\partial f_{t1,d}}{\partial h_{t1}} = 0$, $\frac{\partial f_{t1,c}}{\partial k_{t1,c}} = \frac{\partial f_{t1,d}}{\partial k_{t1,d}}$ and $\frac{\partial f_{t1,c}}{\partial l_{t1,c}} = \frac{\partial f_{t1,d}}{\partial l_{t1,d}}$) in the *t1* period. When $f_{t1,c} < f_{t0,c}$, $f_{t1,d} > f_{t0,d}$, $|\Delta f_c| < |\Delta f_d|$, and $U_{t1} > U_{t0}$, the corresponding sector structure will transform to $\frac{f_{t1,c}}{f_{t1,d}}$ and $\frac{f_{t1,c}}{f_{t1,d}} < \frac{f_{t0,c}}{f_{t0,d}}$ (which can be described as industrialization). Moreover, to gain a new equilibrium, $\frac{\partial f_{t1,d}}{\partial e_{t1}} = \frac{\partial f_{t1,d}}{\partial h_{t1}} = 0$, the consumption of resources *e* and *h* will increase and consequently, increase CEs. From a macro perspective, under reindustrialization, FD leads to an industrial structural solidification and economic growth and subsequently, drives the increase in CEs, thereby resulting in a "**structural effect**."

(2) With the endeavor of related policies, financial institutions, and markets, $A_{t1,k} = \theta A_{t0,k}$ and $\theta \geq 1$[3], implying that the efficiency of the financial sector (or the utility of capital) is proven in the *t1* generation.

(2.1) $A_{t1,k_c} = \theta_c A_{t0,k_c}$, $A_{t1,k_d} = \theta_d A_{t0,k_d}$, and $\theta_c > \theta_d$, indicating that in the *t1* period, with some comparative advantages from sector distinctions, the efficiency of *k* in the clean sector increases faster than that in the dirty sector. To clearly observe the changes in the corresponding variables, we set a special condition, $\theta_c > \theta_d = 1$, implying that with the exogenous driving force (from corresponding policies or institutions), only the clean sector showed an increase in the financial efficiency. In the beginning, $A_{t0,k_c} \rightarrow A_{t1,k_c}$ and $A_{t1,k_c} > A_{t0,k_c}$ lead to $\frac{\partial f_{t1,d}}{\partial k_{t1,d}} < \frac{\partial f_{t1,c}}{\partial k_{t1,c}}$ and $\frac{\partial f_{t1,d}}{\partial l_{t1,d}} < \frac{\partial f_{t1,c}}{\partial l_{t1,c}}$, respectively. With the factors flowing free, the capital and labor in the dirty sector will flow into the clean sector to gain a higher efficiency. A new equilibrium state is achieved ($\frac{\partial f_{t1,c}}{\partial k_{t1,c}} = \frac{\partial f_{t1,d}}{\partial k_{t1,d}}$ and $\frac{\partial f_{t1,c}}{\partial l_{t1,c}} = \frac{\partial f_{t1,d}}{\partial l_{t1,d}}$) in the *t1* generation. Here, we have new sector structures $\frac{f_{t1,c}}{f_{t1,d}}$ and $\frac{f_{t1,c}}{f_{t1,d}} > \frac{f_{t0,c}}{f_{t0,d}}$. In this new equilibrium, the consumption of resources *e* and *h* will decrease and finally lead to CE reduction, thereby resulting in the "**structural effect**."

(2.2) $A_{t1,k_c} = \theta_c A_{t0,k_c}$, $A_{t1,k_d} = \theta_d A_{t0,k_d}$, and $\theta_c = \theta_d > 1$[4], implying that in the *t1* period, the promotion of capital efficiency can be found in the two sectors simultaneously. With $A_{t0,k_c} \rightarrow A_{t1,k_c}$, $A_{t1,k_c} > A_{t0,k_c}$, $A_{t0,k_d} \rightarrow A_{t1,k_d}$, and $A_{t1,k_d} > A_{t0,k_d}$, the efficient capital per unit of efficient energy and environmental resource increases. Subsequently, the increase in the marginal production of *e* and *h* expands the scale of the dirty sector until a new local equilibrium state is reached as $\frac{\partial f_{t1,d}}{\partial e_{t1}} = 0$ and $\frac{\partial f_{t1,d}}{\partial h_{t1}} = 0$. As $f_{t1,d} > f_{t0,d}$ and $U_{t1} > U_{t0}$, the expanding scale of the dirty sector will increase energy consumption and CEs, viz., $e_{t1} > e_{t0}$ and $h_{t1} > h_{t0}$. Thus, we confirmed the "**scale effect**" with the factors flowing free and FD leading to economic growth, thereby subsequently, stimulating energy consumption and CEs. Moreover, $\frac{\partial f_{t1,d}}{\partial e_{t1}} = \frac{\partial f_{t1,d}}{\partial A_e e_{t1}} * \frac{\partial A_e e_{t1}}{\partial e_{t1}} = 0$ and $\frac{\partial f_{t1,d}}{\partial h_{t1}} = \frac{\partial f_{t1,d}}{\partial A_h h_{t1}} * \frac{\partial A_h h_{t1}}{\partial h_{t1}} = 0$ can be reached by $\frac{\partial f_{t1,d}}{\partial A_e e_{t1}} = 0$ and $\frac{\partial f_{t1,d}}{\partial A_h h_{t1}} = 0$. With the technological progress in *e* and *h*, $\frac{\partial f_{t1,d}}{\partial A_e e_{t1}} = 0$ and $\frac{\partial f_{t1,d}}{\partial A_h h_{t1}} = 0$ can be achieved by $A_{t0,e} \rightarrow A_{t1,e}$, $A_{t1,e} > A_{t0,e}$, and $A_{t0,h} \rightarrow A_{t1,h}$, $A_{t1,h} > A_{t0,h}$; that is, the scale effect caused by the increase in the financial efficiency can be offset by the efficiency amelioration of energy and environmental resources, thereby resulting in the "**technological effect**." Moreover, as $A_{t1,e}$ increases over $A^*_{t1,e}$ (and/or $A_{t1,h}$ increases over $A^*_{t1,h}$), where $A^*_{t1,e}$ and $A^*_{t1,h}$ denote the technological level of *e* and *h*, respectively, with the new equilibrium in the *t1* period, the CE changes caused by the scale effect can be covered by the CE decrease caused by the technological effect, consequently, reducing CE.

(2.3) $A_{t1,k_c} = \theta_c A_{t0,k_c}$, $A_{t1,k_d} = \theta_d A_{t0,k_d}$, and $\theta_c < \theta_d$ imply that in the *t1* period, the

[3] Considering the path dependence of technological progress, the context of $\theta < 1$ is scarce and thus, its analysis is not useful.
[4] If $\theta_c = \theta_d = 1$, no change is caused by FD in the new equilibrium and is thus, not discussed here.

efficiency of k in the dirty sector increases faster than that in the clean sector. To clearly observe the changes in the corresponding variables, we set a special condition, $\theta_d > \theta_c = 1$, implying that with the exogenous driving force, only the dirty sector shows an increasing financial efficiency. Initially, $A_{t0,k_d} \rightarrow A_{t1,k_d}$ and $A_{t1,k_d} > A_{t0,k_d}$ lead to $\frac{\partial f_{t1,d}}{\partial k_{t1,d}} > \frac{\partial f_{t1,c}}{\partial k_{t1,c}}$ and $\frac{\partial f_{t1,d}}{\partial l_{t1,d}} > \frac{\partial f_{t1,c}}{\partial l_{t1,c}}$. With the factors flowing free, the dirty sector with a higher efficiency will absorb more capital and labor. Thus, a new equilibrium state is achieved ($\frac{\partial f_{t1,c}}{\partial k_{t1,c}} = \frac{\partial f_{t1,d}}{\partial k_{t1,d}}$ and $\frac{\partial f_{t1,c}}{\partial l_{t1,c}} = \frac{\partial f_{t1,d}}{\partial l_{t1,d}}$) in the *t1* generation. Here, we have new sector structures $\frac{f_{t1,c}}{f_{t1,d}}$ and $\frac{f_{t1,c}}{f_{t1,d}} < \frac{f_{t0,c}}{f_{t0,d}}$. In the new equilibrium, the consumption of resources *e* and *h* will increase and finally lead to CE reduction, thus, resulting in the "**structural effect**." Moreover, when $\frac{\partial f_{t1,d}}{\partial e_{t1}} = \frac{\partial f_{t1,d}}{\partial A_e e_{t1}} * \frac{\partial A_e e_{t1}}{\partial e_{t1}} = 0$, $\frac{\partial f_{t1,d}}{\partial h_{t1}} = \frac{\partial f_{t1,d}}{\partial A_h h_{t1}} * \frac{\partial A_h h_{t1}}{\partial h_{t1}} = 0$ can be achieved using $\frac{\partial f_{t1,d}}{\partial A_e e_{t1}} = 0$ and $\frac{\partial f_{t1,d}}{\partial A_h h_{t1}} = 0$. With the technological progress of *e* and *h*, $\frac{\partial f_{t1,d}}{\partial A_e e_{t1}} = 0$ and $\frac{\partial f_{t1,d}}{\partial A_h h_{t1}} = 0$ can be achieved using $A_{t0,e} \rightarrow A_{t1,e}$, $A_{t1,e} > A_{t0,e}$, $A_{t0,h} \rightarrow A_{t1,h}$, and $A_{t1,h} > A_{t0,h}$. Similarly, the structural effect caused by the increase in the financial efficiency could be offset by the efficiency amelioration of energy and environment resources, that is, the "technological effect." Once $A_{t1,e}$ increases more than $A^*_{t1,e}$ (and/or $A_{t1,h}$ rise over $A^*_{t1,h}$) with the new equilibrium in the *t1* period, where $A^*_{t1,e}$ and $A^*_{t1,h}$ denote the technological level of *e* and *h*, respectively, the CE changes caused by the structural effect can be offset by the CE decreases caused by the technological effect, consequently, reducing CEs.

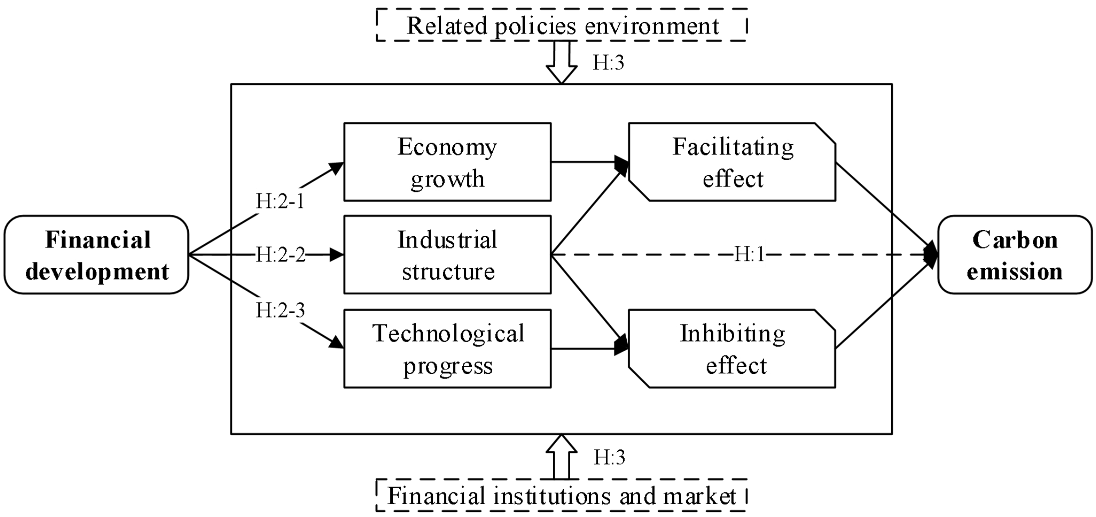

Figure 2. Conceptual framework

Based on the changes in capital and its efficiency as the expression of the variables on the financial scale, structure, and efficiency, it can be concluded that FD can affect energy consumption and CEs by driving economic growth, industrial structure change, and technological progress. Finally, it shows an interaction of facilitating and inhibiting effects on CEs (Figure 2). Based on the above discussions and conceptual framework, the following hypotheses were proposed in the present study:

Hypothesis 1: FD has both positive and negative effects on CEs and represents shows the results of a two-force interaction.

Hypothesis 2-1: FD can promote CEs by driving economic growth.

Hypothesis 2-2: FD has a mixed effect on CEs by influencing the direction of industrial structural changes.

Hypothesis 2-3: FD inhibits CE by forcing technological progress.

In the above discussion, we provided the assumptions that the unique direction of local FD is driven by the context of related environmental policies and financial institutions. We further deduced the corresponding conclusions based on these assumptions. However, under fiscal and environmental decentralizations, not all cities have the same level of policy enforcement, institutional arrangements, resource endowments, and other characteristics [2,3,22]. In fact, these pathways may play different roles in regions under varying circumstances. Thus, whether the CE effect of FD varies among cities with different comparative advantages should be further analyzed. According to the aforementioned analysis and existing discussions [3,13,17,20], we discussed the heterogeneity of the effect of FD among cities with different geographical locations, resource endowments, financial correlation ratios, and environmental regulations. Therefore, Hypothesis 3 was proposed as follows:

Hypothesis 3: The effect of FD on CEs varies among cities with different features.

3. Empirical strategy

3.1. Empirical framework

Owing to its advantage in addressing biases in endogeneity and missing variables, the DID model has been commonly used in recent years. Referring to Chen et al. [24], we constructed a DID model to demonstrate the effects of CCB on local CEs. As the time point and treatment group varied during the establishment and construction of CCBs, we built a multi-period DID model as given in Eq. (1) for the baseline regression.

$$CE_{it} = \alpha_0 + \beta_0 CCB_i * Post_{it} + \gamma Z_{it} + \mu_t + \lambda_i + \varepsilon_{it} \tag{1}$$

Here, i and t denote the city and year, respectively, CE_{it} represents the CEs of city *i* in year *t*, CCB_i is a grouping variable and is equal to 1 if city *i* establishes at least one commercial bank in year *t*, otherwise it is 0. Further, $Post_{it}$ is a state variable and a dummy variable that equals 1 when a city is still operating a commercial bank, otherwise it is 0. Z_{it} covers all control variables. μ_t, λ_i, and ε_{it} represent the time-fixed effect, individual-fixed effect, and standard error, respectively.

To pursuit the fixed difference, absence of systematic difference in CCB and non-CCB cities is the prerequisite to effectively use the DID model. Following Beck et al. [37] and Chen et al. [24], we probed the validity of parallel trend assumption by event study. The econometric model was constructed as follows:

$$CE_{it} = \alpha + \sum_{k\geq -6}^{6} \varphi_k D_{it}^k + \gamma Z_{it} + \mu_t + \lambda_i + \varepsilon_{it} \tag{2}$$

Here, D_{it}^k is a dummy variable, which represents the "event" CCB establishment. Considering the data interval 2003–2018, we documented the setting year of CCB of a city with s_i, if $t - s_i \leq -6$ $D_{it}^{-6} = 1$, otherwise, $D_{it}^{-6} = 0$. In general, if $t - s_i = k$, $D_{it}^k = 1$, otherwise, $D_{it}^k = 0$ (k $\in [-6,6]$). When $t - s_i \geq 6$, $D_{it}^{6+} = 1$, otherwise, $D_{it}^{6+} = 0$. The coefficient φ_k captures the effect of CCB construction on local CEs. Other variables in Eq. (2) are the same as that in Eq. (1).

The regression equation as given in Eq. (2) could document the validity of the parallel trend assumption and the effect of dynamic DID.

To distinguish the channels from CCB construction to local CEs, a system of mediating models was used to test the scale, structure, and technological effects [2,3].

$$scale\ variable_{it} = \alpha_1 + \beta_1 CCB_i * Post_{it} + \gamma Z_{it} + \mu_t + \lambda_i + \varepsilon_{it} \tag{3-1}$$

$$structure\ variable_{it} = \alpha_2 + \beta_2 CCB_i * Post_{it} + \gamma Z_{it} + \mu_t + \lambda_i + \varepsilon_{it} \tag{3-2}$$

$$technology\ variable_{it} = \alpha_3 + \beta_3 CCB_i * Post_{it} + \gamma Z_{it} + \mu_t + \lambda_i + \varepsilon_{it} \tag{3-3}$$

Here, $scale\ variable_{it}$, $structure\ variable_{it}$, and $technology\ variable_{it}$ are the mediation variables and denote economic growth, industrial structural adjustment, and technological progress, respectively. A significantly positive estimator of β_1 indicates that establishing a CCB can promote CEs by stimulating local economic growth. A significant β_2 value indicates that CCB construction can influence local CEs by changing the industrial structure. Further, a significantly positive estimator of β_3 indicates that establishing a CCB can reduce CEs by promoting technological progress.

Moreover, considering the probable spatial effect of establishing and constructing CCBs [10,38], we constructed a spatial DID model as follows:

$$CE_{it} = \alpha_4 + \beta_4 CCB_i * Post_{it} + \delta W_{it} * CCB_i * Post_{it} + \gamma Z_{it} + \mu_t + \lambda_i + \varepsilon_{it} \tag{4}$$

Here, W_{it} is the spatial weight matrix, and δ captures the spatial spillover effect of the neighboring CCB construction on local CEs. A matrix based on geographical distance is widely regarded as a spatial weight matrix [10,38]. Preventing the disturbance from the priority of the spatial weight matrix setting, we provided three types of spatial weight matrices: W_{cont}, W_{dist}, and W_{pgdp}. Specifically, in the geographical location-type spatial weight matrix (W_{cont}), $W_{ij} = 1$ when cities i and j belong to the same province, otherwise, $W_{ij} = 0$. In the geographical distance-type spatial weight matrix (W_{dist}), $W_{ij} = 1/d_{ij}^2$, where d_{ij} is the spherical distance between cities i and j calculated according to the geographical coordinates of the city government location. In the economic distance-type spatial weight matrix (W_{pgdp} , $W_{ij} = [1/|pgdp_i - pgdp_j + 1|] \times exp(-d_{ij})$, where $pgdp_i$ represents the average value of the economic development level in city i during the sample period, and d_{ij} is the spherical distance between cities i and j.

3.2. Data and variables

The data for the empirical test were China's city-level panel data covering 285 prefecture-level and higher-level cities for 2003–2018. The information on CCBs was acquired from "Selected Statistical Data of Modern Economic History of China," "China Financial Statistical Yearbook," and the websites of each CCB. The data of other variables were acquired from the "China Statistical Yearbook," "China City Statistical Yearbook," "China Urban Construction Statistical Yearbook," and other related official websites. To avoid the disturbance from inflation, all variables involving price were deflated into the year 2000 with provincial annual price indices.

3.2.1. Dependent variable

According to Xie et al. [39], city CEs included direct CEs, which mainly originated from the consumption of natural gas and liquefied petroleum gas, and indirect CEs, which mainly originated from the consumption of electricity and heat energy. The direct and indirect CEs were calculated based on the CE factors listed in the Intergovernmental Panel on Climate Change 2006, while the 70% thermal efficiency was calculated according to the "GB/T15317 - 2009 Energy conservation monitoring of coal-fired industrial boilers." The calculations were consistent with those of Xie et al. [39] and were not included in this paper. In this study, the logarithm of total CEs was the main dependent variable, and the per capita CEs were used as a subsidiary index for the robustness test.

3.2.2. Key independent variable

This study considered the establishment and construction of CCBs as a quasi-natural experiment and displayed the performance of CEs in cities with CCB (treatment group) and without CCB (control group), as shown in Figure 3. From the figure, it can be seen that although both treatment and control groups showed an increase in CEs during the study period, the CEs showed an evident difference between the two groups, with the CEs of the treatment group being higher than those of the control group. Thus, the construction of CCBs increased CEs. To achieve an accurate association between the CCBs and CEs, identifying the nexus is necessary using various empirical tests. Referring to Chen et al. [24], we selected the DID method and constructed dummy variables to capture the information on CCB establishment. Specifically, CCB_i is a grouping variable and is equal to 1 if city *i* sets at least one commercial bank in year *t*, otherwise it is 0. $Post_{it}$ is a state and dummy variable equal to 1 when a city is still operating a commercial bank; otherwise, it is 0. Subsequently, the cross-term *CCB×Post* captured the information on CCB construction.

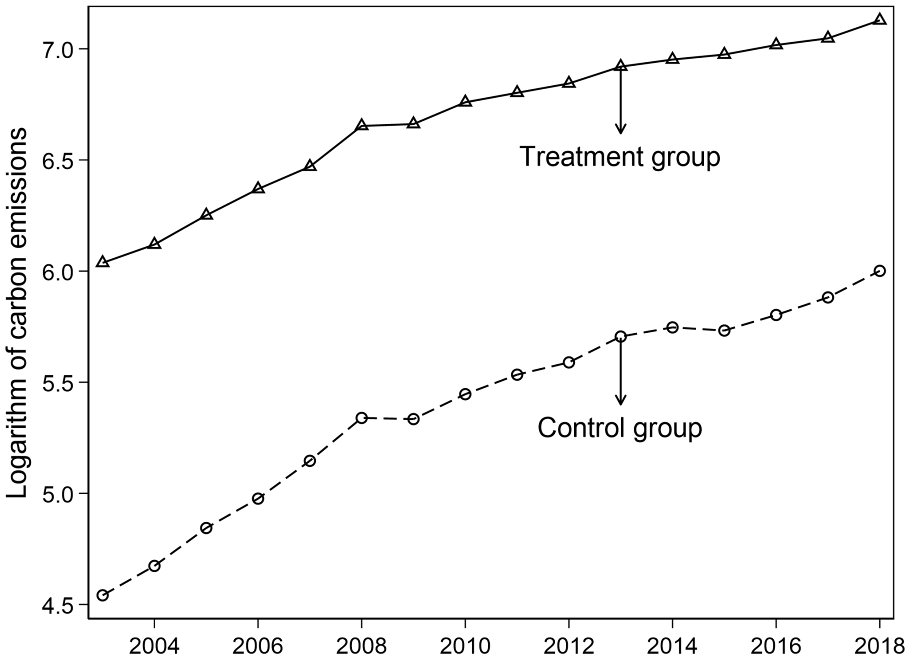

Figure 3 Carbon emission of the treatment group and control group during 2003–2018

3.2.3. Control variables

Based on Wen et al. [1], Xu et al. [2,3], Lv and Li [10], Li [22], and Khan and Ozturk [29], we considered financial interrelation ratio (FIR), industrialization (SecIS), population density (PopD), research and development (R&D), FDI, fiscal decentralization (FisD), per capita income (PGDP), and its quadratic term in the model to avoid omitted variable bias. The details of the control variables are listed in Table 1.

Table 1

Summary statistics.

Variables	Label	Definition	Obs.	Mean	S.D.	Min	Max
Carbon emission	*CE*	Logarithm of total carbon emissions	4560	6.11	1.22	2.09	9.92
Construction of city commercial bank	*CCB×Post*	=1 when the city establishes a commercial bank, otherwise =0	4560	0.53	0.50	0.00	1.00
Financial interrelation ratio	*FIR*	Sum of deposits and loans of financial institutions / GDP	4554	2.12	1.03	0.51	12.51
Industrialization	*SecIS*	Added value of the secondary industry / GDP	4560	48.02	10.99	14.84	90.97
Population density	*PopD*	Logarithm of total population per unit area	4556	5.72	0.91	1.55	7.88
FDI ratio	*FDI*	FDI / GDP	4315	2.09	2.31	0.00	37.58
Fiscal decentralization	*FisD*	Fiscal expenditure decentralization	4556	0.39	0.10	0.14	0.91
Tech spending	*R&D*	Proportion of science and technology expenditure in financial expenditure	4553	1.21	1.37	0.03	20.68
Per capita income	*PGDP*	Logarithm of real GDP per capita	4554	9.00	0.69	7.26	11.89

Note: *FisD* = per capita fiscal expenditure of prefecture-level cities / (per capita fiscal expenditure of prefecture-level cities + per capita provincial financial expenditure + per capita central government expenditure)

4. Empirical findings

4.1. Baseline results

Table 2 presents the regression results of the baseline model. Columns (1) and (2) present the results based on the total samples, Columns (3) and (4) are the results based on the sample cities without their municipalities directly under the central government, Columns (5) and (6) are the results based on the sample cities without their municipalities directly under the central government, provincial capital cities, and cities with separate state planning. It can be seen that in the fixed effect regressions, the coefficients were consistent, indicating that the results cannot be disturbed by the special samples. Notably, whether control variables were used or not, the coefficients of the dummy variable *CCB×Post* were positive and significant at the 1% significance level. In other words, the construction of CCBs profoundly stimulated an increase in CEs, which was consistent with the findings of Wen et al. [1], Shen et al. [7], and Shahzad et al. [13]. Regarding Hypothesis 1, we could conclude that the effect of FD on CEs was dominated by the positive force and appeared to be the facilitating effect in China.

Regarding the control variables, the following discussion is mainly based on the results of Column (2). The positive coefficients indicated that the FIR, PopD, and FisD were the main driving forces of local CEs. Additionally, secondary industry was the chief culprit of CEs [2]. Bank deposits and credit are vital to the actions of regional firms, including innovation and production [21,40,41]. A higher FIR indicates that local firms have more capital to expand production and ultimately increase energy consumption and CEs [7]. Aluko and Obalade [18] and Acheampong et al. [31] indicated that without green consumption, population increase further increases CEs. Regarding FisD, without appropriate environment regulation, higher FisD may lead to "race to the bottom" among the local governments, followed by environmental deterioration. Regarding FDI, the insignificant coefficient corroborated the findings of Zhang [14], who demonstrated that China marginally uses the real FDI compared with gross domestic product (GDP), and its effect on CE is small. Similarly, lower R&D investment does not promote an innovation effect on CEs [4]. The coefficients of per capita income (PGDP) and its quadratic term showed an inverse U-shaped nexus between PGDP and CEs, thus, validating the existence of the EKC in China [3]. The turning point of the inverse U-shaped curve was per capita 33843.42 at constant 2000 RMB￥. Compared with the sample mean - per capita (8135.56 at constant 2000 RMB￥) as shown in Table 1, the turning point was far; that is, most regions were still in the incline stage of the curve and thus, increasing the per capita income could increase CEs.

Table 2

Baseline results: Effects of CCBs on CEs

	All samples		Excluding municipalities directly under the central government		Excluding all the special cities#	
	(1)	(2)	(3)	(4)	(5)	(6)
CCB×Post	0.1337***	0.1530***	0.1338***	0.1531***	0.1191**	0.1529***
	(0.0510)	(0.0512)	(0.0510)	(0.0512)	(0.0517)	(0.0518)
FIR		0.0312*		0.0325*		0.0665**
		(0.0173)		(0.0180)		(0.0290)
SecIS		0.0039**		0.0039**		0.0029
		(0.0017)		(0.0017)		(0.0018)
PopD		0.4536***		0.4541***		0.6130***
		(0.1209)		(0.1210)		(0.1482)
FDI		0.0030		0.0031		0.0057*
		(0.0028)		(0.0028)		(0.0030)
FisD		0.6027***		0.5968***		0.4097*
		(0.1957)		(0.1981)		(0.2257)
R&D		0.0018		0.0014		0.0022
		(0.0058)		(0.0059)		(0.0069)
PGDP		2.7972***		2.8034***		3.0844***
		(0.6308)		(0.6333)		(0.7238)
$PGDP^2$		-0.1341***		-0.1343***		-0.1474***
		(0.0335)		(0.0336)		(0.0391)
CVs	6.0361***	-11.3239***	5.9939***	-11.3989***	5.8141***	-13.8327***
	(0.0275)	(2.9330)	(0.0272)	(2.9437)	(0.0249)	(3.3565)
City/Year FE	Yes/ Yes	Yes/ Yes	Yes/ Yes	Yes/ Yes	Yes/ Yes	Yes/ Yes
Province-specific time trends	Yes	Yes	Yes	Yes	Yes	Yes
Obs.	4560	4310	4496	4246	4000	3759

R-squared	0.9481	0.9539	0.9431	0.9492	0.9286	0.9357

Notes: ***, **, and * denote significance at the 1%, 5%, and 10% levels, respectively. Robust standard errors for the coefficients are given in parentheses. # refers to special cities, including municipalities directly under the central government, provincial capital cities, and cities with separate state plans. CVs: control variables, Obs: observations, city/year FE: fixed effect on city and year. The abbreviations in the following tables (Table 3, 4, 5, 6, 7 and 8) keep in line with that in Table 2.

4.2. The validity of parallel trend assumption and dynamic DID

Figure 4 depicts the regression results of the dynamic DID model (2). Three conclusions can be inferred from the results of this model: First, system difference did not exist among cities before the construction of CCBs because the confidence interval of the coefficient included 0. Second, the facilitating effect of CCBs was immediately evident because after establishing CCBs, as the confidence interval of the coefficient no longer included 0. Third, the promotion on CE from CCBs construction was stabilized in the long term. In the following six years after constructing CCBs, the corresponding dummy variables showed relatively stable coefficient values and similar confidence intervals.

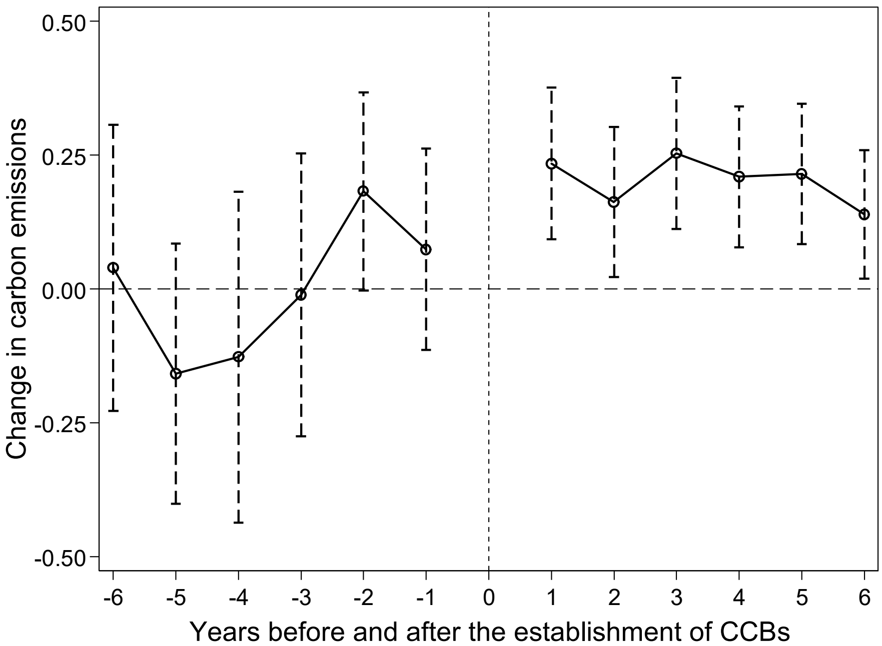

Figure 4 Results of the parallel trend test

Notes: The small circle in the figure is the estimated coefficient, and the dotted line represents the 95% confidence interval of the estimated coefficient.

4.3. Results of the IV method

IV was constructed based on the slope of the regions. For the relativity of IV, a higher slope of a region indicated a more rugged landform and a less active economy that required less financial support, thereby reducing the probability of CCB occurrence, and vice versa. Regarding the exogeneity of IV, as a geographical variable, the slope was the result of geological movement and had no direct relationship with current urban CEs. However, the slope of the city cannot be directly used as the IV of *CCB×Post* because the latter represents panel data and the former represents only cross-sectional data. Nunn and Qian [42] provided a solution by finding a time-varying variable and converting it to an interaction term with the cross-sectional variable. Accordingly, we selected the amount of RMB credit funds from financial institutions during 2003–2018, which reflected the overall development and growth of credit as a time-varying variable. Consequently, the cross-term of the reciprocal of the region's slope (cross-section data) and credit growth (time series data) was considered as the IV of *CCB×Post*. Table 3 shows the results of the IV method. With (or without) the control variables, the correlation coefficients of *CCB×Post* and *reciprocal slope× credit growth* were significant and positive, implying that the establishment of CCBs promoted regional CEs, thus, confirming the abovementioned major conclusion.

Table 3

Regression results of the IV method.

	Model I		Model II	
	(1)	(2)	(3)	(4)
	IV first stage	IV second stage	IV first stage	IV second stage
CCB×Post		1.1360***		1.1297***
		(0.2781)		(0.2694)
Reciprocal slope×Credit growth	0.0068***		0.0069***	
	(0.0012)		(0.0012)	
First-stage F value	34.000		33.910	
CVs	No	No	Yes	Yes
City/ Year FE	Yes/Yes	Yes/Yes	Yes/Yes	Yes/Yes
Province-specific time trends	Yes	Yes	Yes	Yes
Obs.	4560	4560	4310	4310
R-squared	0.9503	0.9396	0.9520	0.9460

4.4. Placebo test

To avoid bias in sort of missing variables, we randomly selected CCB cities as the basis of the placebo test, according to Li et al. [43]. In this study, we constructed a new dummy variable, " CCB_{it}^{false}" by randomly selecting the same number of cities as the treatment group according to the number of cities with established CCBs in the same year. With the new samples, large-scale simulations were aligned with the baseline model (1) (defined in Section 3.1). Figure 5 shows the estimation results of the random samples with 500 and 1000 simulations. The estimates of β_0 were spread around 0. Further, the means of the estimations in Figures 5a and 5b were -0.003757 and -0.003244, respectively. Moreover, most estimates in the simulations were smaller than the true estimates, indicating that the results cannot be disturbed by the occurrence.

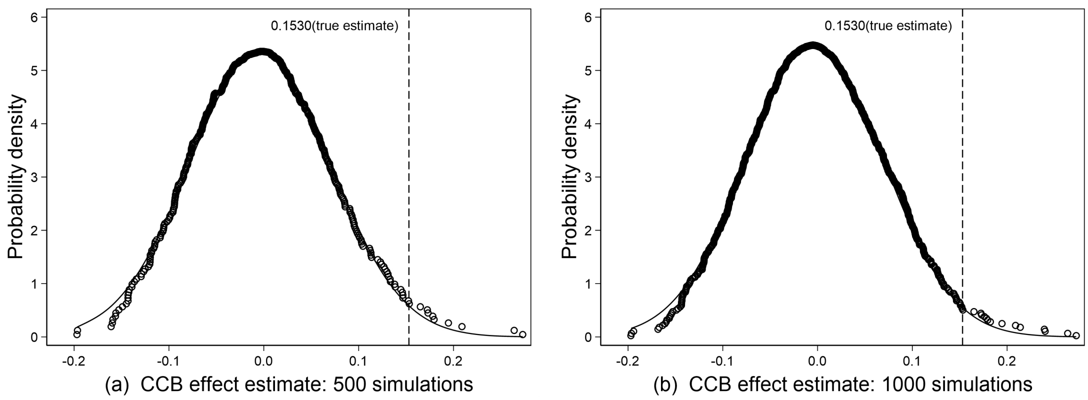

Figure 5 Simulation results of randomly assigned treatment group cities

4.5. Robustness tests

Referring to Zhou and Du [44] and Chen et al. [24], we used seven regressions for the robustness test. Table 4 presents the corresponding results. Column (1) shows the results for per capita CEs as the explained variable. Column (2) shows the results based on the sample without outliers to deter the disturbance of the outliers. Sample results by eliminating cities that did not establish CCBs during the study period to ameliorate the loss from heterogeneous samples are shown in Column (3). Considering the probable lag effect of establishing CCBs, Column (4) presents the results by considering a one-period lag of all explanatory variables as the main explanatory variables. Further, Column (5) reflects the expectancy effect of establishing CCBs by introducing the cross-term of the one-period-ahead of the CCB construction with the dummy variable into the regression. Column (6) demonstrates the results of the samples by simultaneously controlling the combined fixed effects of province and year. Finally, Column (7) presents the results of the PSM-DID method. The treatment group received the k-nearest neighbor similar to that in the calipers based on the 2003 data.

All the coefficients of $CCB \times Post$ were significant and positive, indicating that establishing CCBs had a positive effect on local CEs, thus, conforming to the robustness of the abovementioned main conclusion. Moreover, the data in Column (5) indicates that the coefficient of $CCB \times D^{-1}$ was insignificant, implying the absence of the expectancy effect of establishing CCBs. These results increased the robustness of the main conclusion.

Table 4

Results of the robustness test

	(1)	(2)	(3)	(4)	(5)	(6)	(7)
	Per capital carbon emission	Without the outliers	Excluding cities that did not set up CCBs	One-period lag of explanatory variables	Considering expectancy effect	Combined fixed effect of province and year	PSM-DID
$CCB \times Post$	0.1436***	0.1504***	0.1863***	0.1439***	0.1683***	0.1224**	0.1494***
	(0.0515)	(0.0460)	(0.0526)	(0.0451)	(0.0608)	(0.0491)	(0.0512)
$CCB \times D^{-1}$					0.0526		
					(0.0967)		
CVs	Yes	Yes	Yes	Yes	Yes	Yes	Yes

City/Year FE	Yes/Yes	Yes/Yes	Yes/Yes	Yes/Yes	Yes/Yes	Yes/Yes	Yes/Yes
Province-specific time trends	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Obs.	4310	4310	2444	4042	4310	4207	4168
R-squared	0.9547	0.9508	0.9487	0.9553	0.9540	0.9541	0.9545

5. Further analysis

5.1. Mechanism

To understand the underlying mechanism of the effects of CCBs on local CEs, according to the theoretical analysis mentioned in Section 2.2, we investigated the scale, structural, and technological effects. Referring to Salahuddin et al. [45], we used electricity consumption (i.e., total consumption of electricity and per capita electricity consumption) as an index of the scale effect. Additionally, similar to Chen et al. [24], we used the proportion of the industry on GDP (including output value of primary industry / GDP, value of secondary industry / GDP, and value of tertiary industry / GDP) as proxy for the industrial structure. Patent-related indices are commonly used for measuring technological progress [3]. Green technology effectively obstructs CEs [46]. In this study, green patents (i.e., the number of green patent applications and acquisitions) were used as indicators of the technological effect. Details of the mechanism presented in Table 5 facilitate effective acquisition of the exact channels from CCB construction to CEs.

The coefficients of $CCB \times Post$ in the scale effect regressions were significantly positive (Table 5), implying that establishing CCBs promotes regional electricity consumption, which subsequently, increases local CEs [7,45]. Thus, Hypothesis 2-1 was verified and confirmed. Regarding the structural effect, only the regressions having the ratio of secondary industry to GDP [Column (4)] as the explained variable showed a positive and significant coefficient for $CCB \times Post$. The coefficients of $CCB \times Post$ in Column (3) were insignificant but that in Column (5) were apparently negative, that is establishing CCBs would not only promote industrialization [2,3], followed by an increase in the CEs but also actuate industrial upgrading [1] to ensure further carbon reduction. Several previous studies have shown that industrialization causes CEs [2] and the dampening effect of the tertiary industry is common [24]. Consequently, the structural effect showed controversial results, as discussed in Section 2.2. These results indicated that establishing CCBs not only boosted the service industry (clean sector), but also industrialization, which increases CEs, serve as a warning sign to economic and environmental policymakers. Thus, Hypothesis 2-2 was confirmed that supported the tendencies of industrial structural transformation and upgrading to ensure further CE reduction. Regarding the technological effect, the coefficients of $CCB \times Post$ in Columns (6) and (7) (0.0935, 0.1512) were both positive and significant at the 10% level, thus, supporting that CCB construction would promote technological progress [40,41,47], especially green innovation, and further contribute towards reducing CEs. This result was consistent with that of Xu et al. [3], Chen et al. [24], and Acheampong et al. [31], who stated that innovation is one of the positive channels connecting FD and CE reduction. In summary, Hypothesis 2-3 was validated in China.

Table 5

Results of the mechanism analysis

	Scale effect		Structural effect			Technological effect	
	Total electricity consumption	Per capita electricity consumption	Ratio of primary industry to GDP	Ratio of secondary industry to GDP	Ratio of tertiary industry to GDP	Green patent application	Green patent acquisition
	(1)	(2)	(3)	(4)	(5)	(6)	(7)
CCB×Post	0.1628***	0.1527***	-0.1700	1.1060**	-0.9363**	0.0935*	0.1512***
	(0.0497)	(0.0495)	(0.2993)	(0.4973)	(0.4158)	(0.0534)	(0.0554)
FIR	0.0278	0.0394*	-0.1523	-0.5612***	0.7133***	0.0367**	0.0370**
	(0.0192)	(0.0202)	(0.1182)	(0.2126)	(0.2434)	(0.0160)	(0.0172)
PopD	0.7101***	0.3360**	-4.6465***	1.9710	2.6889	0.2089	0.2330
	(0.1339)	(0.1439)	(0.9101)	(2.0099)	(1.7289)	(0.1488)	(0.1651)
FDI	0.0056*	0.0057*	-0.0071	0.1382***	-0.1310***	-0.0178***	-0.0104*
	(0.0031)	(0.0031)	(0.0446)	(0.0447)	(0.0490)	(0.0051)	(0.0063)
FisD	0.5852***	0.9818***	-13.1702***	13.2098***	-0.0384	0.5764**	-0.1329
	(0.2200)	(0.2200)	(1.8903)	(2.6747)	(2.2962)	(0.2660)	(0.3008)
R&D	-0.0008	-0.0099**	0.4031***	-0.5513***	0.1479*	0.0582***	0.0546***
	(0.0053)	(0.0050)	(0.0948)	(0.1552)	(0.0820)	(0.0121)	(0.0114)
PGDP	0.5224***	0.6136***	-7.5786***	16.3374***	-8.7595***	0.1109	-0.0148
	(0.0707)	(0.0705)	(0.5076)	(0.9769)	(0.8334)	(0.0775)	(0.0828)
Constants	3.6319***	-1.0957	114.2205***	-114.8421***	100.5509***	1.5477	2.3075*
	(0.9683)	(0.9988)	(6.9494)	(14.1930)	(12.0472)	(1.0985)	(1.2467)
City/Year FE	Yes/Yes	Yes/Yes	Yes/Yes	Yes/Yes	Yes/Yes	Yes/Yes	Yes/Yes
Province-specific time trends	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Obs.	4241	4241	4310	4310	4310	4243	4176
R-squared	0.9488	0.9479	0.9565	0.9106	0.9110	0.9627	0.9564

5.2. Heterogeneous effects

Similar to Xu et al. [2,3], Thampanya et al. [17], Guo et al. [20], Chen et al. [24], we assessed the heterogeneity of the CE effect of CCBs, and also differentiated them. We only analyzed the heterogeneous effects among cities with different geographic locations, financial correlation ratios, resource endowments, and environmental regulations. Specifically, according to the standards of the National Bureau of Statistics of China, the sample cities were divided into eastern, middle, and western cities. According to Zhou and Du [44], the sample cities were grouped into resource-based and non-resource-based cities. According to the FIR level, the samples were divided into three equal divisions: low-, middle-, and high-FIR regimes. Referring to the "National 11th Five-Year Plan for Environmental Protection" published by the State Council of the People's Republic of China 2007, we further classified the sample cities as key environmental protection cities and others. Tables 6 and 7 show the corresponding results based on the heterogeneous subsamples.

The coefficients of *CCB×Post* in the eastern, middle, and western cities (-0.1408, 0.0362, 0.6058) were significantly negative, insignificant, and significantly positive, respectively (Table 6), indicating that CCB construction had a limited impact on CEs in the eastern cities, no significant influence on the middle cities, and a positive impact on the western cities. These results demonstrated an EKC between FD and CEs, implying that banking development alleviated CEs in developed regions, but enhanced CEs in developing regions. This was consistent with the results of Thampanya et al. [17]. Further, Huang et al. [41] indicated that banking competition evidently promoted innovation in the eastern regions. Regarding the estimations with different contexts of resource endowment, resource-based samples showed a significantly positive coefficient (0.3018) on *CCB×Post*, while non-resource-based cities showed an insignificant estimation (-0.0380). Thus, establishing CCBs promoted CEs in resource-based cities, but did not influence non-resource-based cities. This could be explained by the overweight dependence on resource-intensive industries in these areas that promotes the credit potential of the financial sector, which is not used predominantly for environmentally friendly industries, but results in path dependence.

Table 6

Heterogeneous results considering different geographic locations and resource endowments

	Different geographic location			Different resource endowment	
	Eastern cities	Middle cities	Western cities	Resource-based cities	Non-resource-based cities
	(1)	(2)	(3)	(4)	(5)
CCB×Post	-0.1408**	0.0362	0.6058***	0.3018***	-0.0380
	(0.0702)	(0.0486)	(0.1302)	(0.1031)	(0.0394)
CVs	Yes	Yes	Yes	Yes	Yes
City/Year FE	Yes/Yes	Yes/Yes	Yes/Yes	Yes/Yes	Yes/Yes
Province-specific time trends	Yes	Yes	Yes	Yes	Yes
Obs.	1613	1579	1118	1699	2611
R-squared	0.9675	0.9446	0.9327	0.9278	0.9687

The estimations of β were different in the regression analyses with different FIR-level cities (Table 7). Specifically, the coefficients of *CCB×Post* in the low-FIR cities were negative but insignificant, whereas those in the middle- and high-FIR cities were positive and significant. Notably, the coefficient was more pronounced in Column (3) than in Column (2), indicating that establishing CCBs had no profound impact on the low-FIR cities, while it promoted CEs in the middle-and high-FIR cities; additionally, the positive effect of CCBs was more severe in the high-level FIR cities. These conclusions were consistent with the above baseline analysis results and were consistent with the findings of Xu et al. [3] and Guo et al. [20]. The results indicated that a shift toward higher energy efficiency and less CEs further requires correct financial support. When environmental regulation was selected as the criterion for sample divisions, the coefficients of *CCB×Post* in the key environmental protection cities were positive but insignificant, indicating that CCB establishment had no effect on the CEs of cities with strict environmental regulations. Subsequently, the corresponding coefficient of the non-key environmental protection cities was positive at the 10% level, validating that CCB construction promoted CEs in cities with lenient environmental regulations. In other words, environmental regulations could alleviate the promoting effect of CCBs to some extent. As environmental regulation can promote the agglomeration of financial resources for green innovation [44], key environmentally regulated cities showed a relatively satisfactory nexus between FD and CEs. To ensure, a sustainable development pattern, strict environmental regulations are further required to correct financial support. Overall, based on the preceding arguments, it can be concluded that a striking heterogeneity exists in the nexus between CCB construction and CEs among different city types. Therefore, Hypothesis 3 was proved.

Table 7

Heterogeneous results considering different financial interrelation ratios and environmental constraints

	Different financial interrelation ratio (FIR)			Different environmental constraints	
	Low-level FIR cities	Middle-level FIR cities	High-level FIR cities	key environmental protection cities	Non-key environmental protection cities
	(1)	(2)	(3)	(4)	(5)
CCB×Post	-0.0461	0.1571**	0.5491***	0.1002	0.1003*
	(0.0721)	(0.0759)	(0.1615)	(0.0820)	(0.0609)
CVs	Yes	Yes	Yes	Yes	Yes
City/Year FE	Yes/Yes	Yes/Yes	Yes/Yes	Yes/Yes	Yes/Yes
Province-specific time trends	Yes	Yes	Yes	Yes	Yes
Obs.	1467	1417	1372	1727	2583
R-squared	0.9382	0.9495	0.9791	0.9570	0.9179

5.3. Spatial spillover effects

Based on the framework in Section 3.1, this study probed the interactions of CCB construction with local and neighboring CEs using six groups of spatial regressions. The corresponding results are presented in Table 8. All coefficients of *CCB×Post* were significantly positive and consistent with the aforementioned conclusion that constructing CCBs promotes regional CEs. Based on the coefficients of the special term W_i×*CCB×Post*, all estimations in the regressions without control variables were positive, while the estimations in the regressions with control variables was positive and significant only under the matrix of spatial weight matrices W_{cont}. In other words, the spillover promoting effect of FD on neighbors' CEs could be ameliorated by the involvement of other influences. These results were contrasting to those of Lv and Li [10] and Liu and Song [38], who validated the promotion effect of local FD and decreasing effect of neighbors' FD. Moreover, Khezri et al. [6] supported the positive spillover effects on the neighboring countries, but a negative effect on the local CEs. This was possibly because under different contexts, different underlying channels from FD to CEs stand the dominant and substantial position and appear to different results. Generally, the spillover effect of FD indicates that policymakers should consider the possible reactions of neighboring cities and countries while implementing effective strategies.

Table 8

Results of the spatial spillover effect

	Wcont		*Wdist*		*Wpgdp*	
	(1)	(2)	(3)	(4)	(5)	(6)
CCB×Post	0.1457***	0.1619***	0.1433***	0.1554***	0.1414***	0.1552***
	(0.0512)	(0.0517)	(0.0509)	(0.0514)	(0.0508)	(0.0513)
W_i×*CCB×Post*	0.0342***	0.0269**	0.6648***	0.1538	1.5424***	0.4379
	(0.0121)	(0.0119)	(0.1994)	(0.1967)	(0.5478)	(0.5639)

CVs	No	Yes	No	Yes	No	Yes
City/Year FE	Yes/Yes	Yes/Yes	Yes/Yes	Yes/Yes	Yes/Yes	Yes/Yes
Province-specific time trends	Yes	Yes	Yes	Yes	Yes	Yes
Obs.	4560	4310	4560	4310	4560	4310
R-squared	0.9482	0.9540	0.9483	0.9540	0.9482	0.9540

6. Conclusions

To understand the mixed effects of FD on CEs, we proposed a two-sector model to theoretically analyze the scale, structural, and technological channels from FD to CEs; subsequently, we empirically tested the comprehensive nexus between FD and CEs in China using a city-level database by considering CCB construction as a quasi-natural experiment and using the DID method. The key findings are as follows: First, constructing CCBs showed a positive effect on the CEs of cities mainly because of the increase in electricity consumption (scale effect) and reindustrialization (structure effect) caused by establishing CCBs despite the technological effect stimulating patent creation. Second, heterogeneity existed and a positive effect of CCB construction was more evident in the western, resource-based, high FIR, and non-key environmentally regulated cities. Finally, CCB construction showed a positive spatial spillover effect on the neighbors' CEs.

Based on the results of this study, we provide suggestions for policymakers from the perspectives of CCB construction, asset management optimization, and strategic interactions. First, against the background of carbon neutrality, CCBs should be established not only for economic growth but also to reduce CEs. The establishment of CCBs as a driver of CEs should be more deliberative during the transformation of economic development. Second, the asset and liability management of existing CCBs should be optimized for promoting green development. As an inseparable part of FD, the banking system should have a green asset structure transformation to provide financial support for further sustainable development. Moreover, local governments should push banking capital into green sector by enhancing environmental regulations. Lastly, considering the spillover effect of CCBs on neighbors' CEs, local governments should implement financial policies based on the forecast of neighbors' reaction to achieve a "win-win" situation for both.

Glossary

CCB: city commercial bank
DID: difference-in-difference
IV: instrument variable
CE: carbon emissions
FD: financial development
FDI: foreign direct investment
SME: small and medium-sized enterprises
PSM: propensity score matching
GDP: gross domestic product

R&D: research and development
FIR: financial interrelation ratio
PopD: population density
FisD: fiscal decentralization
PGDP: per capita income
SecIS: industrialization

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