Will Fighting Climate Change Affect Commercial Banks? A Carbon Tax Policy Simulation

Abstract: Policies implemented to address climate change, especially carbon tax policies, have profound impacts on risk management and credit losses in the financial system. Existing research suggests that climate risks may lead to high-carbon-emission companies facing asset stranding and credit downgrades; however, their specific effects on credit losses in the banking system have not been thoroughly elucidated. This study uses data from 21 listed Chinese commercial banks and 3,163 firms for 2020, applying climate stress-testing to construct 16 carbon tax scenarios. These scenarios simulate the effects of a carbon tax on firms' asset values and financial stability and estimate the potential transmission of these effects to credit losses in Chinese commercial banks. Our findings reveal that introducing a carbon tax significantly increases bank credit losses, with credit losses escalating exponentially as tax rates increase. State-owned commercial banks experience the highest losses, followed by joint-stock and city banks. The primary contributors to these credit losses are high-carbon industries such as electricity, manufacturing, and transportation. These findings underscore how carbon tax policies can decrease firms' asset values and thereby increase banks' credit risks, providing essential insights for policymakers designing climate policies.

Keywords: Climate transition risk; Carbon tax; Commercial banks; Credit losses; Carbon-intensive industries

1. Introduction

With global temperatures rising, shifts in precipitation patterns, and increasing occurrences of extreme weather events, climate change has already triggered significant climate risks, which are severely affecting the stability of the global economy (Chen et al., 2023; Kling et al., 2021) and exerting a direct impact on corporate financial health (Addoum et al., 2020; Hong et al., 2019; Huynh et al., 2020; Kling et al., 2021). According to the U.S. Environmental Protection

Agency (EPA)[1], climate risks are categorized into physical risks and transition risks. Physical risks refer to the potential physical losses to financial assets and collateral caused by natural disasters and extreme weather events (such as floods, hurricanes, droughts, and heat waves); transition risks arise from financial losses incurred by institutions as the economy shifts toward lower carbon emissions, due to factors like climate policies and technological innovation, including but not limited to carbon taxes and emissions trading systems (Carattini et al., 2023; Zhou et al., 2024). Physical risks increase operational costs and reduce production efficiency, limiting profit growth (Hong et al., 2019; Pankratz et al., 2023; Zhang et al., 2018). Conversely, climate transition risks can make the assets of high-emission enterprises obsolete or devalued, leading to asset stranding, which necessitates large impairment provisions and affects their balance sheets and financial stability (Matsumura et al., 2022).

As primary financial intermediaries, commercial banks hold large portfolios of loans to carbon-intensive enterprises. When these enterprises face asset-stranding risks, it may increase the banks' non-performing loan ratios, thereby affecting their financial stability. (Battiston et al., 2017). The asset value of carbon-intensive enterprises may decline due to policy changes and shifts in market demand, weakening their debt-servicing capacity and increasing the banks' default risk (Dietz et al., 2016). This also affects investor confidence, leading to declines in the stock prices of related enterprises, which further affects banks' investment returns and asset quality. Conversely, in response to these risks, banks may need to increase capital buffers and provisions, thereby affecting their profitability and capital adequacy (Alessi et al., 2024). As global efforts to combat climate change intensify, many countries and regions have introduced stringent environmental regulations and carbon emission limitations (Xu et al., 2023). These policies increase the operating costs for high-carbon-emission enterprises, prompting them to accelerate technological upgrades or transitions (Dang et al., 2023). Some enterprises may even be forced to close or downsize operations due to their inability to adapt to new policies. In this context, banks face significantly heightened credit risks as these enterprises become more financially vulnerable, increasing the probability of default.

In this study, we aim to explore how climate transition risks, by affecting enterprises' asset

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[1] https://www.epa.gov/climateleadership/climate-risks-and-opportunities-defined.

values and financial stability, indirectly affect the credit risk of commercial banks. Climate transition risks involve various policies and human-induced factors; this study focuses on one specific climate transition risk: the carbon tax implemented to combat climate change. Similarly, it is also a critical tool to achieve China's "dual carbon goals."[2] A carbon tax is a levy on carbon emissions, aimed at reducing greenhouse gas emissions by increasing the cost of emissions (the basic components of carbon tax policies can be found in **Appendix A, Table A.1**). Some studies have shown that the increased tax burden on high-carbon-emission enterprises may lead to a decline in their credit ratings, affecting their ability to secure financing in financial markets (Nguyen & Phan, 2020). Although the carbon tax burden for individual enterprises may be small relative to a bank's assets, the overall credit risk across the industry may accumulate as many firms simultaneously face financial pressures, ultimately having a systemic impact on the bank's loan portfolio. This risk is particularly pronounced for banks with significant loan exposures in carbon-intensive industries (Ding et al., 2023; Nguyen et al., 2023). This could further increase non-performing loans in banks and cause fluctuations in the financial system.

The existing literature has, to some extent, explored the relationship between climate transition risks and financial institutions. For example, Nguyen et al. (2023) suggest that climate transition risks faced by banks could lead to losses in their Common Equity Tier 1 (CET1) capital, ranging from 5% to 16%. Dafermos et al. (2018) found that climate change gradually decreases corporate liquidity and profitability, thereby increasing default rates and posing a potential threat to financial firms. Similarly, Lamperti et al. (2019) emphasized that climate change could compromise global banking system stability and heighten the frequency of banking crises. However, discussions on the specific impacts of a carbon tax as a climate transition risk on banks remain insufficiently explored. Although Reinders et al. (2023) observed that carbon taxes could result in a market value loss for Dutch banks, the scope of their study is limited to the developed country of the Netherlands and lacks a systematic analysis of the varying impacts on different types of banks. Thus, research on how carbon tax policies

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[2] In the Chinese context, the "dual carbon goals" refer to China's objectives to reach peak carbon emissions by 2030 and achieve carbon neutrality by 2060 (Zhang et al., 2024). These goals require China to significantly reduce greenhouse gas emissions over the coming decades. To achieve these goals, a range of policies and measures need to be adopted, including energy structure adjustments, green financial support, improvements in the emissions trading system, and the imposition of carbon taxes.

affect the financial system through credit channels, particularly in emerging markets like China, remains limited.

This study contributes to the literature in several ways. First, it provides empirical evidence on the impact of carbon tax policies on China's banking sector, highlighting the importance of understanding climate dynamics and managing climate risk, even for sectors such as banking that are not directly targeted by such a tax. Second, the study examines the sensitivity of different types of banks to carbon taxes, quantifying credit losses under various scenarios. This analysis provides concrete numerical support for subsequent research and reveals the distinct challenges faced by state-owned, joint-stock, and city banks in addressing climate risks. Finally, this study focuses on the credit losses caused by high-carbon sectors, such as energy, manufacturing, and transportation, underscoring the differing impacts of sector-specific characteristics on bank risk, which has not been sufficiently addressed in existing literature. Through this differentiated perspective, the study further enriches the theoretical framework on climate risk impacts within the banking system.

This study used climate stress testing to systematically analyze the potential impact of carbon tax policies on credit losses in Chinese commercial banks. Specifically, we examined 21 publicly listed Chinese commercial banks and 3,163 firms in 2020, establishing 16 scenarios based on several key features of carbon tax policy, including tax rates, urgency of implementation, and firms' ability to pass on tax costs. Under these scenarios, we used discounted cash flow models and the Kohn-Merchant-Vasicek (KMV) model to measure changes in asset values and default risk across industries and further estimate the transmission of these effects to banks' credit losses.

Our results show that in China, the introduction of a carbon tax significantly increases banks' credit losses, with losses multiplying as tax levels increase. This increase surpasses the impact of both the "urgency of carbon tax collection" and "the ability of carbon tax cost pass-through" on credit losses. State-owned banks incur significantly higher losses than joint-stock and city banks, with credit losses primarily stemming from high-carbon sectors such as electricity and manufacturing. These findings offer empirical insights for policymakers and financial institutions in designing risk management strategies to address climate transition risks.

The remainder of this paper is structured as follows: Section 2 reviews the relevant literature, Section 3 introduces the research methodology and data, Section 4 presents the empirical results, Section 5 discusses and analyzes the findings, and Section 6 concludes by summarizing the study's main insights and offering practical recommendations.

2. Literature Review

2.1 The effects of climate risks on financial institutions

As climate change intensifies, research on climate risk and financial institutions has focused on three aspects: the transmission mechanism of climate risk (Bolton & Kacperczyk, 2021; Zanin et al., 2024), qualitative analyses (Lemma et al., 2021), and quantitative analyses (Battiston et al., 2017; Reinders et al., 2023), aiming to reveal how climate change profoundly affects asset values and systemic risks of financial institutions through various pathways.

Climate risks are transmitted to financial institutions through two main channels: physical risks and transition risks. Physical risks involve the direct effects of extreme weather events or long-term climate changes on the economy and financial assets, such as asset losses and operational disruptions caused by natural disasters (Huang et al., 2018; Mallucci, 2022; Zanin et al., 2024). Transition risks are more complex and involve financial uncertainties arising from policy changes, technological innovations, or shifts in market preferences to mitigate climate change (Gan et al., 2024; Zhang et al., 2021). For example, as carbon prices rise, the operating costs of fossil fuel enterprises increase significantly, leading to a sharp decline in their asset values. McGlade & Ekins (2015) estimated that under a 2°C scenario, more than half of the world's coal and gas reserves could become stranded assets, potentially resulting in the evaporation of trillions of dollars in asset value. Bolton & Kacperczyk (2021) further pointed out that the bursting of this "carbon bubble" could lead to severe losses in investment portfolios and threaten overall financial system stability (Campiglio et al., 2018; Hansen, 2022).

In qualitative research, scholars have examined how carbon taxation influences financial institutions' behavior, governance structures, and strategic decisions. The profound uncertainty associated with climate risks can reduce corporate liquidity and profitability, leading to higher default rates (Dafermos et al., 2018). This indicates that financial institutions need to adopt more forward-looking strategies in risk management (Battiston et al., 2021). Campiglio et al. (2018) proposed incorporating climate risks into central bank policies to maintain financial stability, as climate change could lead to global banking system instability and increase the likelihood of banking crises (Lamperti et al., 2019). Additionally, Lemma et al. (2021) pointed out that corporate commitments to climate action can enhance their reputation, thereby reducing financing costs and increasing access to long-term debt.

In quantitative analyses, top-down approaches are commonly used to explore the links between climate change and macroeconomic variables (such as economic growth and income levels) and subsequently infer the potential risks to financial asset portfolios (Dunz et al., 2021; Freire-González & Puig-Ventosa, 2019). Specifically, Dunz et al. (2021) pointed out that under moderate climate change scenarios, the average GDP of Eurozone countries could decline by approximately 1.2% by 2030, directly affecting the quality of bank loans and capital adequacy ratios. Bottom-up approaches focus on individual financial institutions or markets, analyzing their balance sheets, risk management strategies, and market behaviors in detail to assess their financial condition and risk exposure to climate change and infer the potential risks faced by the entire financial system. Battiston et al. (2017) analyzed the balance sheets of European banks and found that loans related to the fossil fuel industry accounted for more than 20% of total loans. Additionally, climate stress testing, as a forward-looking analytical tool, has been widely used to assess the potential risks of climate change to the financial system (Xu et al., 2024; Zanin et al., 2024). For example, Nguyen et al. (2023) proposed that under a 2°C target scenario, banks could face CET1 capital losses of between 5% and 9%. The European Central Bank’s 2021 climate stress tests simulated various extreme climate scenarios, revealing an average decline of 3 percentage points in the capital adequacy ratios of Eurozone banks under the most severe scenarios. While these studies offer initial insights into the broad effects of climate risks on financial institutions, further analysis is needed on how policy-driven climate risks, such as carbon taxes, affect economic and financial development.

2.2 The effects of carbon tax policies on economic and financial development

As an essential climate policy tool, carbon taxes aim to promote the transition of enterprises and the economy to a low-carbon trajectory by increasing the cost of carbon emissions. Carbon taxes have been widely implemented globally (Marron & Toder, 2014). To date, 61 countries have established or plan to implement carbon pricing mechanisms, with 30 adopting carbon taxes. Research shows that with the implementation of carbon taxes, production costs for enterprises will significantly rise (Ernst et al., 2023), and capital investment will decrease (Jacob & Zerwer, 2024), particularly in energy-intensive industries. Muñoz (2021) pointed out that significant fluctuations in the asset values of carbon-intensive industries could cause substantial shocks to financial institutions' investment portfolios.

In China, research on carbon tax policies has primarily focused on their effects on technological investment, social welfare (Hua et al., 2024; Zhang et al., 2020), and appropriate tax rate levels (Lin & Jia, 2018). For instance, Hua et al. (2024) indicated that when a firm's production strategy is limited to either domestic or offshore regions, the social welfare provided by a carbon tax policy is lower than that of a carbon cap-and-trade policy. Lin and Jia (2018) found that carbon taxes exert minimal impact on economic growth and recommended that taxation be primarily applied to energy firms. Additionally, after balancing emission reduction effects and macroeconomic impacts, they suggested setting the carbon tax rate at around RMB 60 per ton. Nevertheless, these studies did not focus on the broader financial system or consider the potential credit losses that the banking sector might face under carbon tax policies.

Internationally, researchers have begun to explore how carbon tax policies affect the banking industry. For instance, Aiello & Angelico (2023) investigated the influence of carbon taxes on credit risk within the Italian banking sector, concluding that the effects of carbon taxes on banks are relatively mild when default rates are low. Although this study focused on the banking sector, its scenario design was relatively simple and did not calculate specific loss amounts for banks, limiting its ability to provide a comprehensive risk assessment. Reinders et al. (2023) analyzed the impact of carbon taxes on the banking industry using data from the Netherlands and found that increases in carbon taxes exponentially impact bank losses; however, it did not compare the differences between various types of banks.

2.3 Research gaps

While the existing literature has revealed the significant repercussions of carbon taxes on the economy, it remains insufficient in evaluating their effects on financial institutions, particularly various types of banks. Research on the Chinese market has primarily focused on the effects arising from carbon taxes on the macroeconomy or social welfare (Hua et al., 2024; Lin & Jia, 2018), lacking a deep exploration of financial institutions. Moreover, the scenario design in these studies is relatively simple, without comprehensively considering the urgency of tax implementation and the potential for carbon tax cost pass-through (Aiello & Angelico, 2023; Lin & Jia, 2018). Finally, existing studies rarely address the heterogeneous effects arising from carbon taxes on different types of banks (e.g., state-owned banks (SOBs), joint-stock banks (JSBs), city banks (CBs)) (Aiello & Angelico, 2023; Reinders et al., 2023). Therefore, through a more detailed scenario design, this study thoroughly explores the potential credit losses faced by three types of Chinese commercial banks under various carbon tax scenarios, filling gaps in the existing literature and providing a more empirically grounded risk assessment framework for policymakers.

3. Methodology and Data

This study aimed to assess the effects of carbon tax policies on the credit losses of Chinese commercial banks. To achieve this goal, we adopted the climate stress testing method, using multiple carbon tax scenarios to analyze how carbon tax policies influence enterprises' asset values and credit risks, which are then transmitted to the banking system. By leveraging the discounted cash flow (DCF) model and the KMV default prediction model, we quantified changes in asset and debt values for enterprises under these scenarios. We then assessed potential credit losses for banks under different carbon tax levels and implementation strategies, using loan portfolio data. This integrated approach allowed us to comprehensively analyze the ripple effects of carbon tax policies on carbon-intensive enterprises and their consequent effects on bank credit risks.

3.1 Climate stress testing method—carbon tax scenario design

Stress testing is a risk management and regulatory analysis tool designed to assess the potential effects of hypothetical, extreme but plausible adverse scenarios on financial systems or asset portfolios, thereby evaluating the negative effects on the asset quality, profitability, capital levels, and liquidity of financial institutions (Battiston et al., 2017; Xu et al., 2024). Stress testing can be viewed as a multi-step process that includes identifying specific risks, constructing scenarios, translating scenario outputs into analyses of financial institution balance sheets or income statements, conducting numerical analysis, considering any potential secondary effects, and summarizing and interpreting the results.

Climate stress testing specifically evaluates climate risks, applying stress testing methods for quantitative assessment to analyze the potential future risks that financial institutions or banks might face. Battiston et al. (2017) introduced the concept of “climate stress testing” to evaluate financial institutions’ risk exposure under different climate scenarios. Compared to traditional risk measurement models, climate stress testing is better suited to capture the deep uncertainty[3], fat-tailed distributions[4], and endogeneity characteristics[5] of climate risks (Zanin, 2024). Traditional risk measurement models struggle to capture these features, leading to insufficient accuracy and reliability in risk estimation, as they are usually based on historical data and assume that future risk distributions will be similar to past ones. However, the future path and effects of climate change cannot be simply inferred from historical data. Particularly in China, where the government has not yet explicitly proposed a carbon tax policy, relevant historical data are lacking.

Climate stress testing simulates potential future climate change pathways and their effects

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[3] The deep uncertainty of climate risks refers to the lack of clear predictions regarding the severity and pace of future climate change. This uncertainty arises not only from the complexity of natural sciences but also from changes in policies, technological advancements, and socio-economic behaviors (Yin & Gao, 2024). For example, the policy responses of different countries and regions, the pace of technological innovation, and public attitudes toward environmental protection all significantly affect the trajectory of climate change (Barnett, 2023).

[4] In risk management, a fat-tailed distribution implies that the probability of extreme events is higher than expected under a normal distribution, emphasizing tail risk, which is often underestimated by traditional risk measurement methods. This characteristic is particularly important in financial and climate risk analysis because it highlights the potential for extreme events. To identify possible extreme events in climate risk, methods that can capture fat-tailed distribution characteristics, such as stress testing, are necessary (Xu et al., 2024).

[5] Endogeneity of climate risks refers to the mutual influence between economic and climate systems. This bidirectional feedback makes the analysis of climate risks more complex (Battiston et al., 2017).

on the economy and financial system by constructing different scenarios. This approach does not rely on historical data but instead considers scientific forecasts and assumptions, factoring in different policy responses, technological advancements, and market behaviors, providing a more flexible and forward-looking analytical tool (Acharya et al., 2023). Moreover, this method is applicable to all banks within the same environment, meeting consistent regulatory requirements. As a result, it has been widely applied in measuring such risks (Battiston et al., 2017; Lin & Jia, 2018; Nguyen et al., 2023).

This study constructed 16 carbon tax scenarios based on three aspects: carbon tax rate, urgency of taxation, and whether enterprises have pass-through costs. These scenarios were used to explore changes in asset values and credit risks across industries under different carbon tax policies. Subsequently, this study analyzed the potential credit losses that commercial banks might face under these different carbon tax scenarios.

First, in setting the carbon tax rates, this study synthesized existing research findings (Lin & Jia, 2018) and China's carbon emission targets, simulating four different carbon tax scenarios: RMB 10/ton, RMB 50/ton, and RMB 100/ton to represent low, medium, and high carbon tax scenarios. An RMB 30/ton scenario was also simulated based on current policy practices and academic research recommendations. Specifically:

- A low-level carbon tax (e.g., RMB 10 per ton) was designed to examine the moderate effects of lower carbon taxes on the national economy and commercial banks (Lin & Jia, 2018). It can incentivize enterprises to make substantial emission reduction efforts to a certain extent, helping them gradually adapt to the carbon tax policy while simulating the cautious approach taken by the government to avoid causing excessive shocks to the economy.
- The RMB 30 per ton scenario was based on existing research that estimates the balance between China's economic adaptability and the benefits of emission reduction.
- The RMB 50 per ton rate was referenced from the current price levels in China's carbon market and aligns with current policy practices, helping to gradually increase the emission reduction efforts of enterprises.
- According to the International Energy Agency (IEA), achieving the Paris Agreement targets requires a higher carbon price. Therefore, the rate of RMB 100 per ton was used to

simulate stronger emission reduction incentives. This rate can significantly increase carbon emission costs, encouraging enterprises to make large-scale investments in low-carbon technologies and implement deep emission reduction measures. Although higher rates (e.g., RMB 200 or RMB 300) might further enhance emission reduction, considering China's current economic structure and the capacity of enterprises to bear the cost, RMB 100 is deemed a relatively high yet acceptable level (Lin & Jia, 2018).

Second, in terms of the carbon tax collection method, we distinguished between "emergency" implementation and "linear increase" scenarios.

- "Emergency" refers to the immediate collection of a carbon tax at the target rate once the government decides to implement the policy. For example, if the target rate is RMB 10, the government would immediately begin collecting the carbon tax at this rate. Similarly, if the target rates are RMB 30, RMB 50, or RMB 100, the corresponding rates would be directly implemented. This scenario simulates aggressive measures by the government to achieve rapid emission reduction targets. However, such abrupt changes might trigger stranded asset risks, rapid asset devaluation, and corresponding product price increases, significantly impacting the livelihoods of low-income residents.
- The "linear increase" scenario refers to a gradual increase in the carbon tax rate until it reaches the preset target. For example, if the target rate is RMB 10 per ton, the government would start with a lower rate and gradually increase it to RMB 10. If the target rate is RMB 100 per ton, the carbon tax rate would gradually increase to RMB 100, and so on. This scenario simulates a gradual implementation strategy by the government, considering economic and corporate adaptability, and provides a transition period for carbon-intensive industries, reducing the risk of severe shocks.

Although more complex scenarios exist, such as carbon tax rates increasing exponentially or with volatility to reach the target rate, these scenarios require more advanced model complexity and numerous assumptions, making them difficult to simulate effectively. Moreover, they overlap with the idea of a linear increase to the target rate. Our study focuses on evaluating the implications of carbon taxes on commercial bank credit losses rather than creating new modeling methods. The "emergency" and "linear increase" scenarios are sufficient to simulate the actual policy implementation while effectively conveying the core insights of our research.

Although more complex scenario settings are important, they go beyond the scope of this study, and we suggest future research explore this further.

Next, we further subdivided the scenarios according to whether enterprises choose to raise product prices to pass through the carbon tax costs, resulting in "0% pass-through" and "50% pass-through" scenarios.

- "0% pass-through" represents a situation in which enterprises fully absorb the carbon tax costs, increasing production costs without raising product prices. This simulates the scenario where enterprises maintain market share under competitive pressure.
- "50% pass-through" simulates a scenario in which enterprises pass on half of the carbon tax costs to consumers by raising product prices while absorbing the other half themselves. This compromise strategy avoids the profit pressure from fully absorbing the costs and prevents a significant market demand decline from fully passing on the costs.

Based on the application scope of the stress testing method and the goals of this study, our primary focus is on extreme but plausible scenarios. In highly competitive market environments, enterprises may choose not to pass through carbon tax costs to avoid losing market share due to price increases (Reinders et al., 2023). In this case, enterprises fully absorb the costs (0% pass-through) to maintain market competitiveness. In existing literature, passing on 50% of carbon tax costs to consumers is a relatively common practice (Reinders et al., 2023; Sun et al., 2022). In this case, the cost of price adjustments for enterprises is relatively low, allowing them to maintain profitability while considering consumer price sensitivity, making this approach widely applicable in practice. Therefore, choosing 0% and 50% as extreme and intermediate cases is reasonable, which simplifies the model while covering the basic pass-through scenarios (Marron & Toder, 2014).

Additionally, for all scenarios, we proposed two assumptions: First, carbon tax shocks are unexpected. This assumption was based on the sudden nature of policy implementation and the lag in the response of enterprises and financial institutions. In practice, policymakers usually do not fully disclose specific details of carbon tax policies in advance, and market participants typically adjust only after the policy is officially announced and implemented, especially in financial markets. Second, the introduction of the carbon tax policy does not affect market expectations of subsequent climate policies. Changing expectations could alter the future market value of assets in various industries, thereby affecting the market value fluctuations of debt.

This study aimed to simulate the specific implications resulting from carbon taxes on commercial bank's credit risk, providing an assessment of potential future risks rather than predicting market evolution. To this end, we employed the climate stress testing method. This method aimed to simulate the most adverse impact that the financial system might face under extreme but plausible scenarios. To simplify the model and maintain the operability of the study, we assumed that the carbon tax policy was isolated, without considering its cascading effects on future market expectations. This assumption clarifies the analysis process and avoids potential ambiguities in conclusions due to the introduction of multiple uncertainty factors. The specific scenario settings are shown in **Table 1**:

Insert Table 1 about here

3.2 Discounted cash flow model—measuring changes in asset value

Under carbon tax policies, both enterprises and consumers typically take measures to offset increased costs and potential value losses. Cost pass-through is a common response mechanism, whereby enterprises may choose to raise product prices, passing on part of the carbon tax costs to consumers (Fabra & Reguant, 2013). Based on the scenario settings in Section 3.1, a 50% pass-through ratio was selected to simulate a basic pass-through scenario. Of course, the pass-through of carbon tax costs may further propagate through various feedback mechanisms and nonlinear effects, affecting the broader economy. For instance, some products are necessities, and despite price increases, demand elasticity is low, so market share remains relatively stable. However, for most goods, price increases may lead consumers to reduce their demand for high-carbon products. A substitution effect may also occur, where consumers switch to low-carbon or carbon-free alternatives, such as electric vehicles and renewable energy, thereby altering market demand structures. As a result, price increases for these products may shrink the market, potentially leading to market exits or reduced production.

Furthermore, some enterprises might respond to carbon tax pressures by upgrading their technologies. Technological upgrades may include the development of energy-saving technologies and the substitution of inputs, such as replacing brown power with green power. This strategy not only reduces the enterprise's CO_2 emissions but may also reduce its reliance on carbon taxes in the long term.

However, due to factors such as competitive pressure, free trade policies, difficulties in transitioning, or the fact that profits remain within a manageable range, some enterprises may choose not to take any action. For instance, in some highly competitive industries, enterprises might opt not to pass through costs to avoid losing market share due to price increases (Reinders et al., 2023). In extreme cases, these enterprises may exit the market due to their inability to cope with high costs. To simulate such a situation, we used a 0% pass-through ratio (as referenced in Section 3.1). Based on this analysis, six potential scenarios were considered in this study (see **Table 2**).

Insert Table 2 about here

To estimate the effects of the carbon tax on the asset value of various industries, we applied the DCF model, as shown in **Equation (1)**:

$$NPV_{tax,k} = \sum_{t=0}^{T} \left[EM_{k,t}CP_t(1-\lambda_{k,t})\right]/[(1+r_k)^t] \tag{1}$$

Where $NPV_{tax,k}$ represents the net present value of asset value losses due to the carbon tax for each industry. $EM_{k,t}$is the CO_2 emissions of industry k in year t, and CP_t is the carbon tax rate in year t. Thus, $EM_{k,t} * CP_t$ represents the carbon tax amount that needs to be paid in year t (i.e., CO_2 emissions × carbon tax price per ton). Since future cash flows related to the carbon tax need to be discounted to their net present value, r_k is the discount rate applicable to industry k. Based on the possible cost pass-through ratio, the losses due to the carbon tax were adjusted using the adjustment factor $\lambda_{k,t}$, with values set at 0% and 50% according to the scenarios in **Table 2** and the approach by Reinders et al. (2023).

Additionally, we calculated the carbon tax effects coefficient for each industry under the carbon tax scenario, as shown in **Equation (2)**:

$$\varepsilon_k = NPV_{tax,k}/TAV_k \tag{2}$$

Where ε_k is the carbon tax effects coefficient, representing the degree of effects the carbon tax has on the total asset value of the industry. TAV_k is the total asset value of each industry.

3.3 KMV model-based estimation of market value losses in bank loans

3.3.1 Estimating enterprise asset values and their volatility

First, this study drew on some of the principles of the KMV model to derive enterprise asset values and their volatility. The KMV model mainly uses stock market data rather than historical book data, which more accurately reflects the current credit status of listed enterprises, making it widely used (Zhang & Li, 2018).

The model assumes that credit risk in loans is determined by the market value of the debtor's assets, given their liabilities. However, since the market value of an enterprise's assets is not actively traded, it cannot be directly observed. The model employs a reverse approach: It indirectly infers the enterprise's asset value V_t and its volatility σ_v using known equity value E, equity volatility σ_E, the remaining time to debt maturity $T-t$, risk-free interest rate r, and total liabilities D. The core idea of the KMV model is to treat the equity value of an enterprise as a call option on the value of the enterprise's assets, with the strike price being the enterprise's liabilities. If, at debt maturity, the company's asset value exceeds its liabilities, shareholders will exercise the call option and fulfill the debt; otherwise, the company defaults. Therefore, equity value E can be expressed using the Black-Scholes Option Pricing Model[6], as shown in **Equation (3)**:

$$\begin{cases} E = V_t \cdot N(d_1) - D \cdot \exp\left[-r(T-t)\right] \cdot N(d_2) \\ d_1 = [\ln(V_t/D) + (r + \sigma_v^2/2)(T-t)]/\left[\sigma_v \sqrt{T-t}\right] \\ d_2 = [\ln(V_t/D) + (r - \sigma_v^2/2)(T-t)]/\left[\sigma_v \sqrt{T-t}\right] \end{cases} \tag{3}$$

Where $N(\cdot)$ is the cumulative function of the standard normal distribution. For a more detailed explanation and derivation, please refer to Black & Scholes (1973) and Merton (1973). The equity volatility σ_E and asset value volatility σ_v follow a geometric Brownian motion and can thus be converted using **Equation (4)**:

$$\sigma_E = V_t/[E \cdot N(d_1) \cdot \sigma_v] \tag{4}$$

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[6] The Black-Scholes Option Pricing Model is a renowned financial model. Its introduction not only provided an effective tool for option pricing but also laid the foundation for the entire field of financial engineering, with related research being awarded the Nobel Prize in Economics in 1997. Despite some idealized assumptions, the model remains a cornerstone of modern financial theory and is widely used in practical applications for option pricing and risk management. For detailed principles and assumptions of the model, please refer to Black & Scholes (1973) and Merton (1973).

By simultaneously solving Equations (3) and (4), the enterprise's asset value V_t and asset volatility σ_v can be obtained.

3.3.2 Estimating debt loss coefficients for enterprises and industries

Next, using the calculated asset value V_t of each company and the carbon tax impact coefficient ε_k, we derived the market value of a company's assets V_t^* after the external economic shock from carbon taxation at time t. The calculation follows **Equation (5):**

$$V_t^* = (1 - \varepsilon_k)V_t \tag{5}$$

According to the asset-liability relationship, at time t, the enterprise's asset value V_t is related to its equity E_t (equity value) and debt D as expressed in **Equation (6)**:

$$D = V_t - E_t \tag{6}$$

By substituting values, we obtained the post-shock debt market value D^*. The debt value ratio η_D and the debt value loss coefficient δ_D can then be calculated using **Equation (7)**:

$$\begin{cases} \eta_D = D^*/D \\ \delta_D = 1 - \eta_D \end{cases} \tag{7}$$

3.3.3 Estimating market value losses in bank loans

The arithmetic means of the loss coefficients δ_D for individual companies were used as the debt value loss coefficient $\delta_{D,k}$ for the industry. $\delta_{D,k}$ is multiplied by the commercial bank's loan exposure $exposure_{D,K}$ in each industry to calculate the market value loss $TMVL$ that different carbon tax implementation scenarios may cause to Chinese commercial banks, as shown in **Equation (8)**:

$$TMVL = \sum_{k=1}^{n} \delta_{D,K} \cdot exposure_{D,K} \tag{8}$$

3.4 Data and sample

This study selected six specific industries based on the classification of energy consumption industries by the National Bureau of Statistics and the loan data of banks in various industries: (1) Construction (CON), (2) Mining (MIN), (3) Transportation, warehousing, and postal services (TWP), (4) Manufacturing (MAN), (5) Electricity, heat, gas, and water supply (EHGW), (6) Wholesale and retail trade (WR). These industries have relatively high carbon emissions (see Appendix **Table A.3**) and can be considered carbon-intensive industries that would face significant effects under a carbon tax shock. Given the availability of data, this study assumed that all enterprises within each industry are subject to the same initial effects[7]. The carbon tax effects coefficients ε_k for each industry were then calculated based on CO_2 emissions, discount rates, adjustment factors, and total industry asset value (data processing details are provided in **Table 3**).

Next, based on the industry classification of the China Securities Regulatory Commission (CSRC), A-share listed companies with non-zero and positive long-term debt were selected as the study's subjects. Companies with zero market capitalization were excluded, resulting in a final sample of 3,163 companies (see Appendix **Table A.4**). Missing data were interpolated linearly. By calculating these companies' equity values, stock volatilities, debt levels, and other indicators (data processing details are provided in **Table 3**), the loss coefficients for each company were derived and the arithmetic mean of the company loss coefficients was used as the loss coefficient for each industry.

Insert Table 3 about here

Finally, regarding the selection and processing of the bank sample, a total of 45 commercial banks had completed their listings by the end of 2020. After screening, banks that did not disclose loan information for the selected industries in their annual reports were excluded, resulting in a final sample of 21 commercial banks (see **Table A.2**). Missing data were substituted with loan amounts from 2019. Since commercial banks generally follow stable industry policies and risk control strategies in their loan allocation, using data from the previous year is a common and reasonable substitution method. These 21 banks collectively hold 72% of the total assets of China's banking industry. Their loan exposure across various industries is shown in **Fig. 1**.

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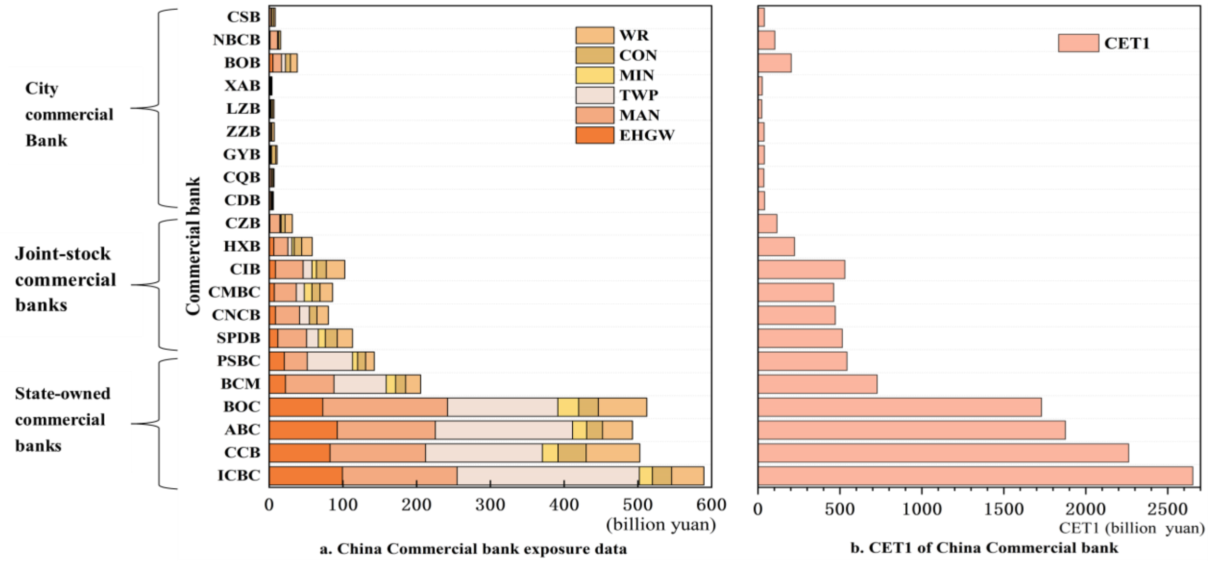
[7] The assumption that all companies in the industry are subject to the same initial effects is based on the practical difficulties of data acquisition. In actual operations, it is very challenging to obtain specific carbon emission data for each company, so the unified assumption simplifies the analysis process, and this simplification is acceptable when studying the effects of industry-level policies. In addition, when facing policy shocks, companies usually show similar response patterns, such as rising costs and falling profits. Therefore, unified treatment can accurately reflect the effects on the industry as a whole to a certain extent.



a. China Commercial bank exposure data

b. CET1 of China Commercial bank

Fig. 1 Loan exposure data and distribution of commercial banks by industry

Notes: Fig. 1a illustrates the loan exposure distribution of 21 commercial banks across six major industries, while **Fig. 1b** presents the CET1 levels of these banks. 2) Abbreviations such as CSB, NBCB, BOB, …, CCB and ICBS represent the 21 banks, with full names and abbreviations in **Table A.2.** 3) Industry abbreviations are as follows: EHGW (electricity, heat, gas, and water supply), MAN (manufacturing), TWP (transportation), MIN (mining), CON (construction), and WR (wholesale and retail). 4) CET1 indicates Common Equity Tier 1, reflecting banks' capital adequacy and resilience.

4. Empirical Results

4.1 The effects of carbon taxes on various sectors of the national economy

Tables 4 and **5** detail the effects of carbon tax imposition on the production costs of various sectors of the national economy under different hypothetical scenarios, yielding the carbon tax loss coefficients for each industry. Specifically, these tables illustrate the level of financial pressure or asset value loss that different industries experience when the tax measures are implemented. The scenarios cover a range of carbon tax levels, from emergency collection to linear increases, as well as various cost pass-through situations.

Insert Table 4 about here

Insert Table 5 about here

The data in **Tables 4** and **5** indicate that the EHGW sector is most economically impacted by the imposition of carbon taxes, with loss coefficients higher than those of other industries across all scenarios. MAN follows, while TWP and MIN experience relatively smaller losses. CON and WR have the smallest loss coefficients, indicating that these industries are relatively less affected by carbon taxes. Particularly in the extremely adverse scenario of a carbon tax of RMB 100 implemented in 2020, with enterprises not passing the increased production costs on to consumers, the carbon tax effects coefficient for the EHGW sector is approximately 253 times that of the smallest sector, WR, and twice that of MAN.

Secondly, as the carbon tax level increases, the asset value loss coefficients for all industries significantly rise. For example, when the carbon tax increases from RMB 10 to RMB 100, the loss coefficient for the EHGW sector increases more than tenfold, from 0.00566 to 0.05663. A similar trend can be observed in other industries, indicating that an increase in the carbon tax level significantly raises the economic burden on industries.

Finally, at the same carbon tax level, different collection methods and cost pass-through ratios significantly affect industry losses. For example, with a carbon tax of RMB 50 per ton (0% pass-through), the loss coefficient for the EHGW industry is 0.02831 under the “emergency” collection method, while this value decreases to 0.00457 under the “linear increase” method, indicating that “linear increase” can effectively mitigate economic losses for the industry. Similarly, when the cost pass-through ratio increases from 0% to 50%, the loss coefficients across all industries decrease significantly, highlighting the important role of cost pass-through in alleviating the burden of the carbon tax. For instance, with a carbon tax of RMB 50 per ton, the loss coefficient for the EHGW industry at a 50% cost pass-through ratio is only half of that at 0%. These results suggest that the gradual introduction of the carbon tax, along with a reasonable cost pass-through mechanism, can significantly reduce the economic effects of the carbon tax on high-emission industries.

This study further evaluated the implications of carbon taxes on the debt value. **Tables 6** and **7** show the debt value loss coefficients for each industry under different carbon tax scenarios, which more directly affect the debt repayment ability of enterprises, thereby significantly influencing banks’ credit risks.

Insert Table 6 about here

Insert Table 7 about here

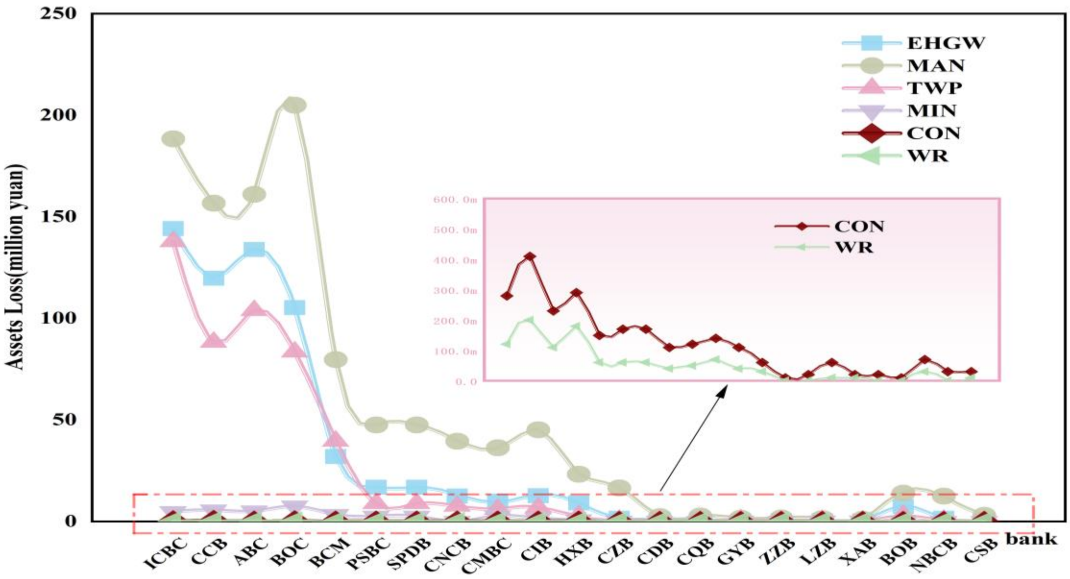
The implications of carbon taxes on sector debt values in **Tables 6** and **7** are similar to the asset value effects results presented in **Tables 4** and **5**. (1) The EHGW sector exhibits the highest debt value loss coefficients across all carbon tax levels, indicating its high sensitivity to the carbon tax. MAN and TWP follow, while CON and WR have relatively low loss coefficients. (2) As the carbon tax rate escalates, the coefficients indicating debt value losses across industries also show marked increases. For example, at a carbon tax rate of RMB 100, the loss coefficient for the EHGW sector reaches 0.02242, more than ten times that of the RMB 10 per ton carbon tax scenario. Other industries show similar trends, underscoring the heightened compressive impact of elevated carbon taxes on the debt value of firms. (3) At the same carbon tax level, using RMB 50 per ton as an example, the debt value loss coefficient for the EHGW industry under the "emergency" collection method is 0.01050, whereas this value drops to 0.00144 under the "linear increase" method, indicating that "linear increase" can significantly mitigate the debt value loss for the industry. Similarly, when the cost pass-through ratio is raised from 0% to 50%, the debt value loss coefficients for all industries significantly decrease.

Overall, the carbon tax not only reduces the market value of enterprise assets but also weakens their debt repayment ability, which implies that the carbon tax increases banks' credit risks.

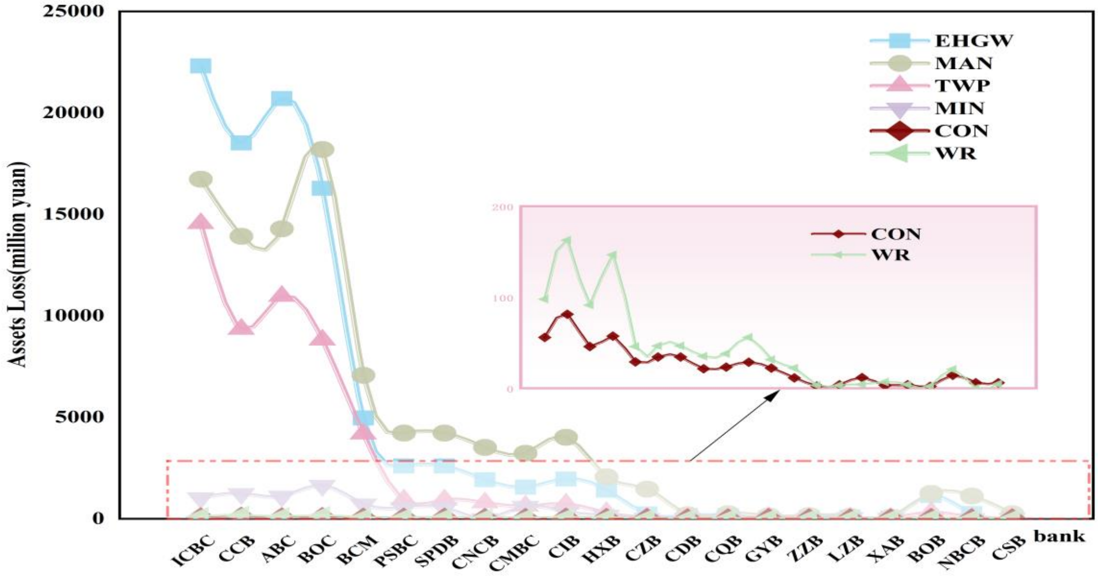
4.2 The effects of the carbon tax on bank credit losses

4.2.1 21 Commercial banks

Appendix **Tables A.5** through **A.20** report the absolute credit losses for banks that may result from the debt value losses of various industries under 16 different carbon tax scenarios. To observe these effects more clearly, this study compared the differences in credit losses across 21 commercial banks between the scenario with the smallest effects (carbon tax gradually increasing linearly to RMB 10 per ton, with enterprises passing 50% of the carbon tax costs—**Table A.8**) and the most extreme scenario (carbon tax of RMB 100 per ton starting in 2020, with enterprises not passing the carbon tax costs to consumers—**Table A.17**). These differences can be more intuitively observed in **Fig. 2**.



a. Credit loss of 21 banks when carbon tax of 10 yuan/ton is imposed under Scenario IV (million yuan)



b. Credit loss of 21 banks when carbon tax of 100 yuan/ton is imposed under Scenario I (million yuan)

Fig. 2 Credit loss levels for 21 commercial banks under minimum and maximum effects scenarios (million yuan)

Notes: 1) **Fig. 2a** shows the absolute credit losses of 21 banks by sector under the scenario with the lowest impact (10 yuan/ton, linear increase, 50% pass-through). Conversely, **Fig. 2b** reports the highest-impact scenario (100 yuan/ton, emergency, 0% pass-through) for comparison. 2) Abbreviations such as ICBC, CCB, ABC, …, CSBC, and CSB represent the 21 banks, with full names listed in **Table A.2**. 3) Industry abbreviations are: EHGW (electricity, heat, gas, and water supply), MAN (manufacturing), TWP (transportation), MIN (mining), CON (construction), and WR (wholesale and retail).

First, it can be observed that the bank credit losses shown in **Fig. 2b** are much higher than those in **Fig. 2a**. The losses multiply under the extreme scenario, indicating the significant effects of high carbon taxes and the lack of cost pass-through on banks. Whether under minimal or maximum effects, the EHGW, MAN, and TWP industries have the greatest impact on bank credit losses, far exceeding other industries. Particularly in extreme scenarios, the high losses in these industries are especially prominent. For example, the loss for ICBC from the EHGW industry increases from RMB 144.22 million in **Table A.8** to RMB 22,309.56 million in **Table A.17**, demonstrating the immense pressure that carbon tax policies impose on the energy and manufacturing sectors.

Second, China's four major commercial banks (ICBC, CCB, ABC, BOC) are much more affected by the carbon tax than smaller banks. However, in extreme scenarios, smaller banks such as CQB, GYB, and XAB also experience significant increases in losses. In the worst-case scenario, the credit loss for China's largest commercial bank, ICBC, will account for 21.33% of the total loss value, while the combined credit loss for the four major SOBs could reach 74.15% of the total loss value.

To address these losses, banks can diversify their investment portfolios to reduce dependence on carbon-intensive industries, thereby mitigating risks. Additionally, banks should enhance risk management, particularly in assessing carbon emission risks, to identify and address potential credit risks in advance. Furthermore, SOBs can mitigate their reliance on traditional carbon-intensive industries by innovating in green finance, such as channeling investments into green bonds and sustainable development ventures that facilitate the shift toward a low-carbon economy. Finally, banks can negotiate cost pass-throughs, working with enterprises to pass some carbon tax costs to consumers or other parts of the supply chain, reducing direct losses to banks.

Fig. 3 depicts the total credit loss changes for 21 banks under different carbon tax scenarios.

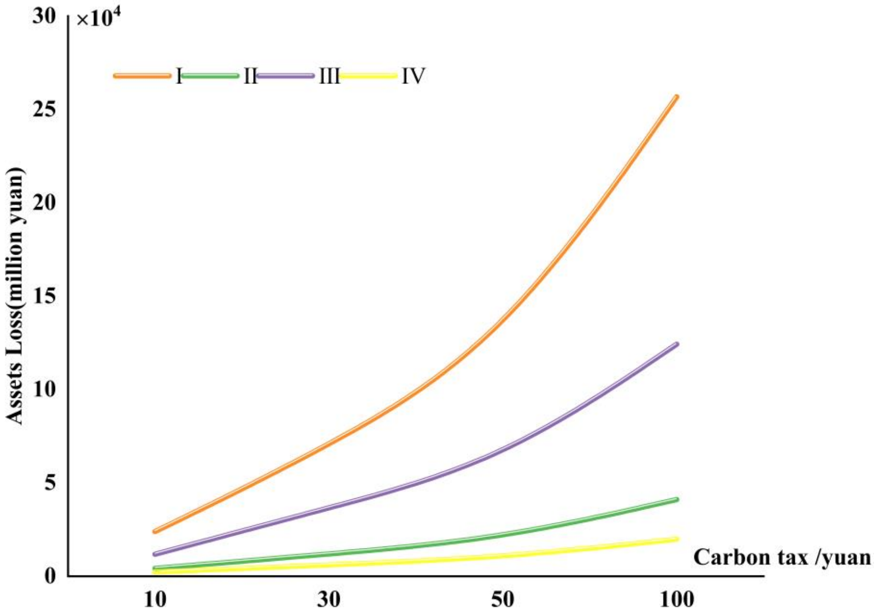


Fig. 3 Absolute credit loss levels of 21 Chinese commercial banks under different carbon tax scenarios

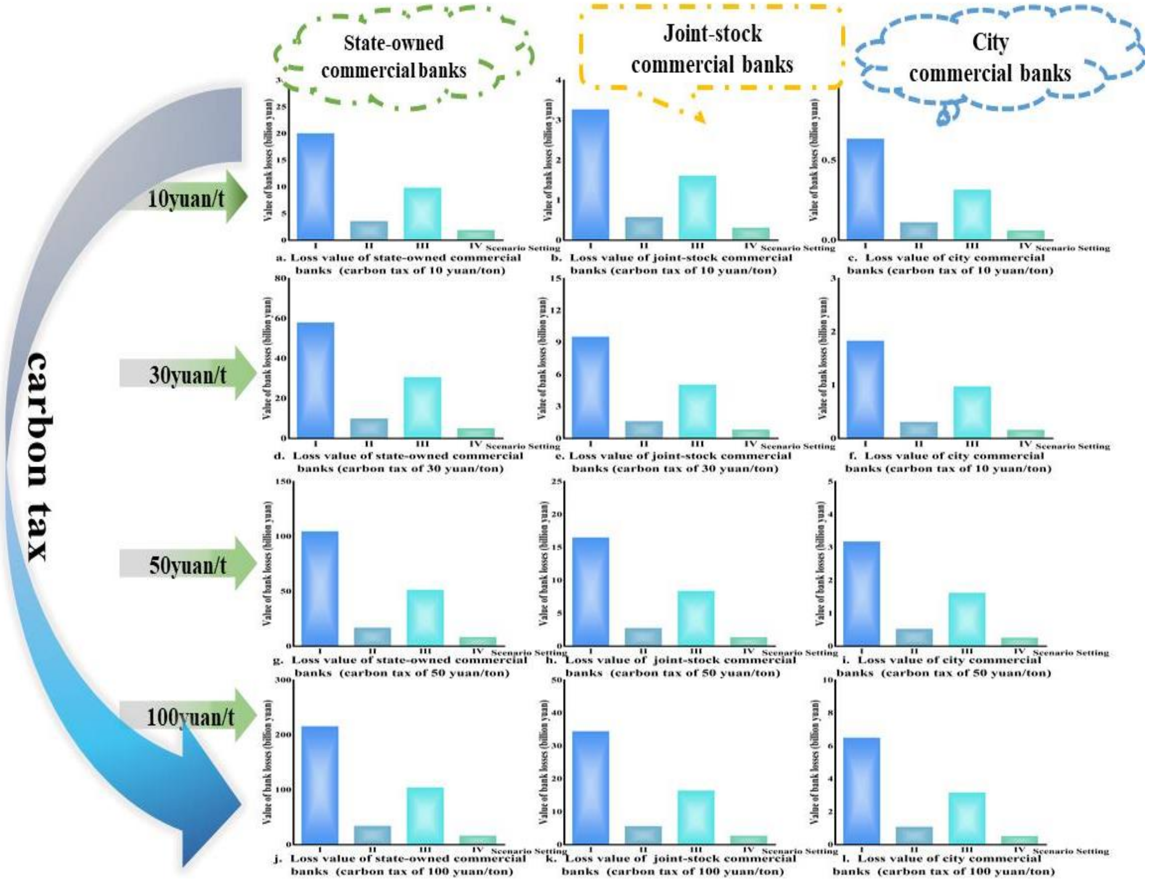
Notes: 1) This figure shows changes in absolute credit losses for banks as the carbon tax rate increases, along with credit loss differences across scenarios I, II, III, and IV. 2) Scenario definitions: I (emergency, 0% pass-through), II (linear increase, 0% pass-through), III (emergency, 50% pass-through), IV (linear increase, 50% pass-through).

Since the 21 listed banks selected in this paper collectively hold 72% of the total assets within China's banking sector, it is evident that as the carbon tax escalates, the total credit losses for Chinese commercial banks exhibit almost exponential growth. Based on the market share of these banks, it is estimated that the total market value loss of the entire Chinese banking system could range from RMB 3.1 billion to RMB 356.7 billion when a carbon tax of RMB 10 to RMB 100 per ton is imposed.

This growth indicates the potential for systemic risk, especially concerning loans to enterprises in high carbon-emission-intensive industries, which could lead to greater instability in the financial system. This trend highlights the need for policy adjustments. Policymakers may need to consider a more gradual implementation of the carbon tax to avoid sudden shocks to the market from high carbon taxes. It is also essential to explore ways to better support enterprises in their low-carbon transition, including adjusting loan portfolios, increasing loans to low-carbon industries, and developing new financial products and services to help enterprises cope with the increased costs brought about by the carbon tax. Finally, strengthening green financial incentives, such as through tax incentives, subsidies, and support for green bonds, along with purchasing carbon credits, can help offset the financial burdens of the carbon tax and stabilize the economic and financial pressures it creates.

4.2.2 Effects of the carbon tax on three types of commercial banks

This research includes an analysis of 21 banks: 6 SOBs, 6 JSBs, and 9 CBs. Based on the data in Appendix **Tables A.5** to **A.20**, we conducted a summary analysis of the loss situations for these three types of banks under 16 scenarios. The results are depicted in **Fig. 4**. (For detailed values after summary, see Appendix **Tables A.21-A.32.**)



a. Loss value of state-owned commercial banks (carbon tax of 10 yuan/ton)
b. Loss value of joint-stock commercial banks (carbon tax of 10 yuan/ton)
c. Loss value of city commercial banks (carbon tax of 10 yuan/ton)
d. Loss value of state-owned commercial banks (carbon tax of 30 yuan/ton)
e. Loss value of joint-stock commercial banks (carbon tax of 30 yuan/ton)
f. Loss value of city commercial banks (carbon tax of 10 yuan/ton)
g. Loss value of state-owned commercial banks (carbon tax of 50 yuan/ton)
h. Loss value of joint-stock commercial banks (carbon tax of 50 yuan/ton)
i. Loss value of city commercial banks (carbon tax of 50 yuan/ton)
j. Loss value of state-owned commercial banks (carbon tax of 100 yuan/ton)
k. Loss value of joint-stock commercial banks (carbon tax of 100 yuan/ton)
l. Loss value of city commercial banks (carbon tax of 100 yuan/ton)

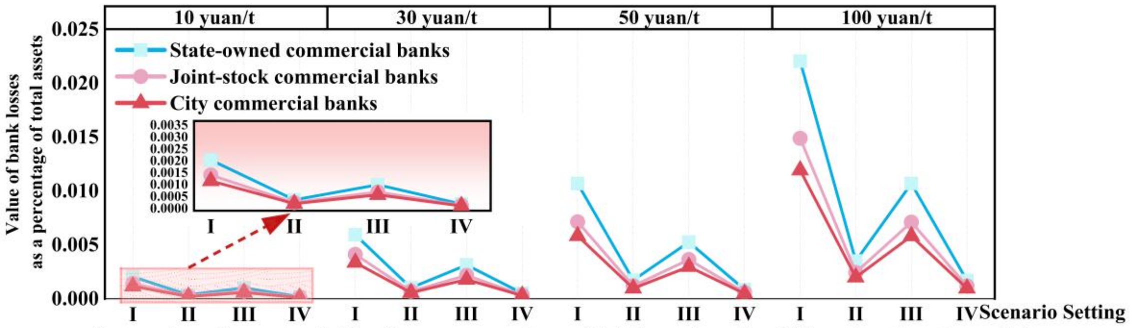
Fig. 4 Total credit losses for three types of banks under 16 carbon tax scenarios

Notes: 1) This figure compares credit losses across 16 scenarios for three types of commercial banks: state-owned, joint-stock, and city banks. 2) Scenario definitions: I (emergency, 0% pass-through), II (linear increase, 0% pass-through), III (emergency, 50% pass-through), IV (linear increase, 50% pass-through).

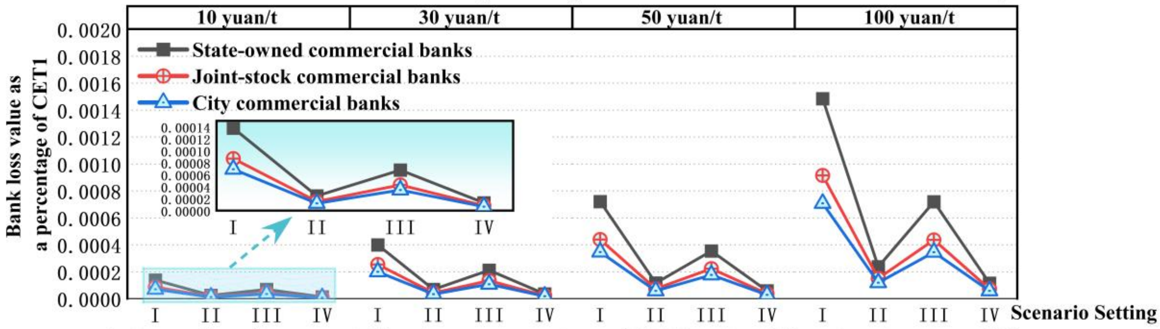
Under all circumstances, SOBs experience the highest losses, followed by JSBs, with CBs experiencing the smallest losses. This pattern is especially pronounced when carbon tax levels are high and companies are unable to pass the costs onto consumers. For example, in the extreme scenario (carbon tax scenario I of RMB 100 per ton), the total loan value loss for SOBs is 6.37 times that of JSBs and 33.74 times that of CBs.

SOBs typically hold large loan portfolios in carbon-intensive industries, particularly in the EHGW and MAN sectors, which are high-carbon-emission sectors. As a result, these banks face greater risks under carbon tax policies. In contrast, due to their smaller scale of operations and loan concentration in local, low-carbon industries, CBs experience relatively lower losses under carbon tax policies. Additionally, SOBs and JSBs generally have greater risk exposures and more complex business structures. They also require higher capital buffers to cope with potential losses due to their higher-risk loan portfolios. CBs, on the other hand, have smaller risk exposures due to their limited scale and business scope, and, therefore, require lower capital, making their risks more manageable. By optimizing loan portfolios and enhancing risk management, particularly in managing exposure to carbon-intensive industries, these banks can minimize potential credit losses under future carbon tax policies.

This study also examined the relative loss situations of different types of banks by calculating the total credit losses as a proportion of their total assets and CET1, as shown in **Fig. 5**.



a. Loss value of commercial banks as a percentage of total assets under different carbon tax policies



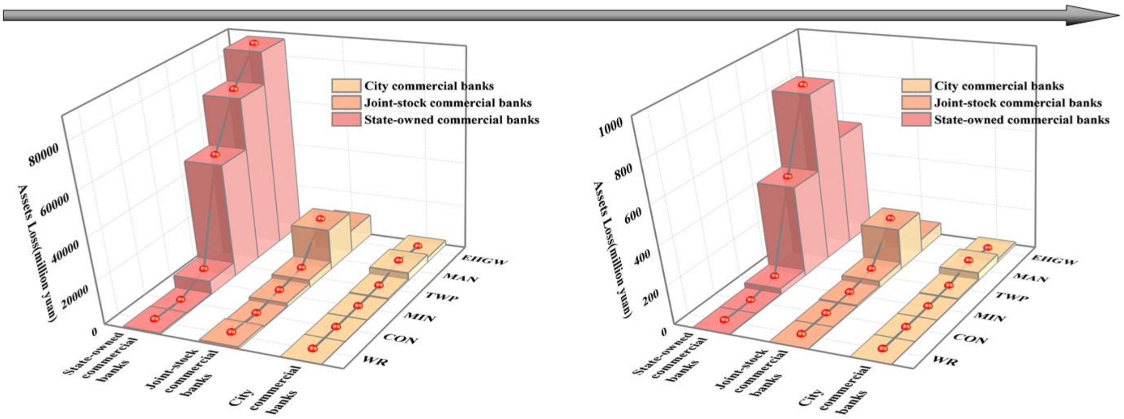
b. Loss value of commercial banks as a percentage of CET1 under different carbon tax policies

Fig. 5 Relative credit loss levels for three types of banks

Notes: 1) **Figure 5a** shows credit losses relative to total assets of three types of commercial banks (state-owned, joint-stock, and city banks) under 16 scenarios. **Figure 5b** shows credit losses relative to CET1 of these banks under these scenarios. 2) Scenario definitions: I (emergency, 0% pass-through), II (linear increase, 0% pass-through), III (emergency, 50% pass-through), IV (linear increase, 50% pass-through).

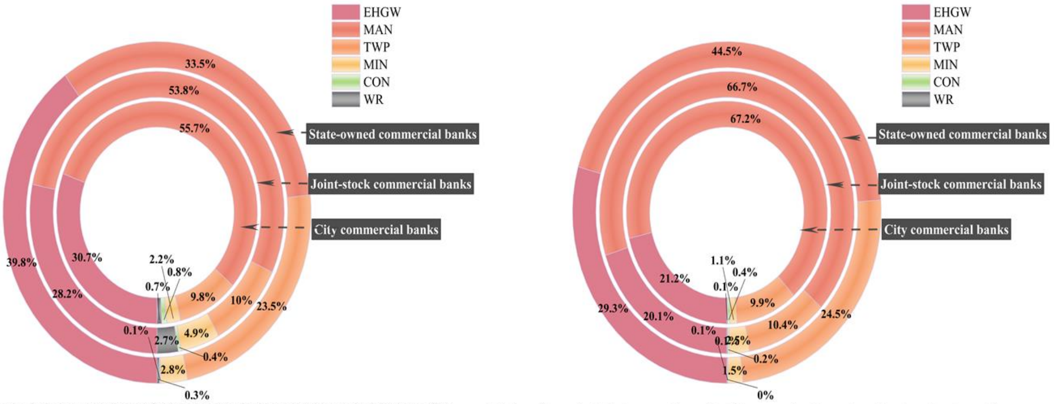
The results indicate that the relative losses among the different types of banks have narrowed significantly, though the overall trend remains that SOBs have slightly higher losses as a proportion of their CET1 and total assets compared to JSBs, with CBs experiencing the lowest relative losses. For instance, in the most extreme scenario (carbon tax scenario I at RMB 100 per ton), the loss ratio for the six SOBs is 2.21%, while this value is 1.49% for JSBs and 1.19% for CBs. This suggests that although SOBs have stronger scale and capital strength, they still bear greater credit loss pressures in the face of carbon tax policies. This also reflects the fact that SOBs have larger loan exposures to high-carbon-emission industries, making them more susceptible to risks after the implementation of carbon tax policies.

Finally, this study explored the distribution of losses among various industries for the three types of banks, focusing on the comparison between the most extreme scenario (carbon tax scenario I at RMB 100 per ton) and the most moderate scenario (carbon tax scenario IV at RMB 10 per ton). The results are shown in **Fig. 6**. (For detailed values, see Appendix **Tables A.21–A.32**.)



a. Losses of different types of banks under the most severe carbon tax policies

b. Losses of different types of banks under the most moderate carbon tax policy



c. Value of losses by industry as a share of total losses under the most severe carbon tax policy

d. Value of losses by industry as a share of total losses under the most moderate carbon tax policy

Fig. 6 Effects on three types of banks under the most extreme and most moderate scenarios—industry-based comparison

Notes: 1) **Fig. 6a** shows the loss values caused by each industry to three types of banks (state-owned, joint-stock, and city banks) under the highest impact scenario (100 yuan/ton, emergency, 0% pass-through), while **Fig. 6b** presents these values under the lowest impact scenario (10 yuan/ton, linear increase, 50% pass-through). **Fig. 6c** illustrates each sector's contribution ratio to the total losses of these banks under the highest impact scenario, with **Fig. 6d** showing this ratio under the lowest impact scenario. 2) Industry abbreviations are: EHGW (electricity, heat, gas, and water supply), MAN (manufacturing), TWP (transportation), MIN (mining), CON (construction), and WR (wholesale and retail).

Fig. 6 illustrates the industry structure of credit losses for the three types of banks under the most extreme (immediate implementation of a RMB 100 per ton carbon tax without passing the tax burden to consumers) and the least impactful scenarios (gradual implementation of a RMB 10 per ton carbon tax with 50% of the cost passed to consumers).

The credit losses of these three types of banks are primarily concentrated in the EHGW, MAN, and TWP industries. These three industries account for 96.81%, 91.97%, and 96.23% of the total loan losses for each type of bank, respectively. For SOBs, losses in the EHGW, MAN, and TWP industries are relatively balanced. However, for JSBs and CBs, loan losses are mainly concentrated in the MAN sector, accounting for 53.78% and 55.74% of their losses, respectively. In the least impactful scenario, MAN is the largest contributor to credit losses across all three types of banks. As the carbon tax effects intensify, the losses for SOBs tend to balance out, with the EHGW sector's share of losses increasing to 39.82%, making it the largest loss-contributing industry. Meanwhile, for JSBs and CBs, losses remain predominantly concentrated in MAN.

This loss distribution pattern is primarily attributed to a combination of industry characteristics, loan structures, and the carbon tax transmission mechanism. The EHGW industry, as a high-carbon-emission sector, is directly impacted by carbon tax policies, resulting in a significant increase in the proportion of loan losses for SOBs in this industry. Additionally, MAN, due to its capital-intensive nature and broad credit demand, constitutes an essential part of the loan portfolios for JSBs and CBs, making it the dominant source of losses for these two types of banks.

5. Discussion and Analysis

Through 16 different carbon tax scenarios, this study explored the potential influence exerted by carbon taxes over Chinese commercial banks. The findings reveal that carbon tax policies significantly affect bank credit losses, with bank credit losses growing exponentially as carbon tax levels increase. This finding corroborates previous research (Reinders et al., 2023). Carbon taxes increase the operating costs of high-carbon-emission enterprises, leading to reduced profitability and weakened debt repayment capabilities, which, in turn, increases non-performing loans in banks. Moreover, the sudden introduction of carbon tax policies, combined with limited avenues for cost pass-through mechanisms, make it difficult for enterprises to mitigate financial pressures in the short term through price increases or technological upgrades, thereby exacerbating bank credit losses. Existing studies support this conclusion, noting that the implementation of climate-related policies, including carbon taxation, significantly worsens the financial distress of enterprises, which, in turn, amplifies its effects on the financial sector (Dietz et al., 2016; Yu et al., 2021).

Further analysis shows that across all carbon tax scenarios, SOBs experience the highest losses, followed by JSBs, with CBs incurring the smallest losses. This is because SOBs have a higher proportion of loans in carbon-intensive industries, making them more sensitive to the financial deterioration of these sectors. The distribution of loan portfolios, risk management capabilities, and capital buffer levels are key influencing factors. SOBs dominate policy loans and large infrastructure projects, which are usually associated with high-carbon-emission industries, resulting in greater losses. Furthermore, the relatively complex business structure and wide-ranging risk exposures of SOBs increase the difficulty of coping with the effects of climate policies. In contrast, CBs, whose businesses are concentrated in local industries and have more focused loan portfolios, primarily in low-carbon or carbon-neutral sectors, demonstrate greater resilience in facing carbon tax effects. JSBs, with their flexible business models and strong market adaptability, are better positioned to mitigate the adverse effects of carbon tax policies through loan portfolio adjustments and enhanced risk management.

It is particularly noteworthy that the credit losses of different types of banks are mainly concentrated in three major industries: EHGW, MAN, and TWP. First, the EHGW industry, as a key sector with high carbon emissions, is directly impacted by carbon taxes. The imposition of these taxes greatly increases the operational costs for such industries, diminishing their profitability and significantly raising their risk profile within bank loan portfolios. Similar conclusions have been reflected in existing research; for example, Aiello & Angelico (2023) point out that the stranded asset risks of carbon-intensive industries can transfer to the financial system via bank credit, increasing systemic financial risk. Second, MAN, as a critical pillar of China’s economy, faces substantial financial pressure under carbon tax policies due to its high energy consumption and carbon emission characteristics, making it one of the primary sources of bank losses. The literature also highlights the high sensitivity of the manufacturing sector to carbon tax policies (Ahmadi et al., 2022), particularly under scenarios of high tax levels or rapid policy implementation, where the financial deterioration in this sector is particularly pronounced. Finally, the TWP industry, which relies heavily on fuel consumption, faces direct cost increases due to carbon tax implementation, thereby affecting its profitability and debt repayment ability.

In summary, this study, through detailed scenario analysis, reveals the differentiated effects of carbon tax policies on various types of banks and provides empirical insights for policymakers and bank managers to address climate risks. As global initiatives to combat climate change gain momentum, financial institutions must optimize their loan portfolios, reduce reliance on carbon-intensive industries, and continuously refine their risk management strategies to navigate the increasingly complex environmental risks and policy challenges.

6. Conclusions, Policy Recommendations, and Limitations

7.1 Conclusions

This paper quantitatively examined the effects of a carbon tax as a climate transition risk on the Chinese commercial banking system during the low-carbon transition, using data on bank loans to enterprises in various industries. It assessed the credit risks and financial pressures that commercial banks may face in responding to the implementation of carbon tax policies. The research results indicate that: First, the implementation of carbon taxes will significantly increase bank credit losses, and as the carbon tax level increases and cost pass-through decreases, losses for various banks multiply. The credit loss values of Chinese commercial banks exhibit almost exponential growth as the carbon price rises. Second, in all scenarios, SOBs experience the highest losses, followed by JSBs, with CBs experiencing the smallest losses. Finally, the losses for various banks are primarily concentrated in the EHGW, MAN, and TWP industries, with the EHGW sector and manufacturing contributing the most to credit losses for banks under extreme scenarios.

7.2 Policy recommendations

Optimize carbon tax rate design. Given the significant impact of carbon tax rates on banks' credit losses, policymakers should adopt a gradual increase mechanism for setting these rates. This approach allows for flexibility in response to economic conditions and helps to mitigate sudden financial shocks in the banking sector. Policymakers must closely monitor the financial health of both the banking industry and high-carbon sectors, such as electricity and manufacturing, to identify potential vulnerabilities. Regular assessments can inform timely adjustments to the carbon tax rate, ensuring that it remains effective without destabilizing the credit market. Additionally, implementing a phased approach allows businesses time to adapt to new costs, thereby reducing the risk of sudden defaults that could adversely affect banks. Transparent communication regarding future tax rate adjustments will further bolster confidence among financial institutions, enabling them to plan effectively for the anticipated impacts.

Differentiated capital requirements for the banking sector. The research indicates that state-owned banks face the highest credit losses in the context of carbon tax implementation. Therefore, it is essential to establish differentiated capital adequacy requirements tailored to various types of banks. By doing so, regulators can enhance the overall stability of the banking system under carbon tax policies. For state-owned banks, which have substantial loan portfolios and relatively robust credit assessment systems, it is advisable to increase capital requirements and risk buffers. This adjustment will fortify their capacity to absorb shocks associated with carbon taxation. Furthermore, regulators should assist these banks in developing effective climate-related risk management frameworks, including integrating climate risk factors into their loan pricing models and establishing reasonable loan term limits. Financial institutions should also utilize credit and other financial support tools to facilitate the transition of high-carbon sectors toward low-carbon alternatives.

Strengthen credit regulation for high-risk industries. Considering the high concentration of credit exposure in high-carbon emission sectors such as EHGW, MAN, and TWP, financial regulators must enforce stricter risk management and capital buffer requirements for banks' lending to these industries. Enhanced regulatory oversight will compel banks to implement robust risk assessment frameworks that consider the unique vulnerabilities associated with these sectors. Establishing an industry-risk early-warning system can aid banks in promptly identifying and adjusting their credit allocations to high-risk industries. This system would facilitate continuous monitoring of market conditions and emerging risks, allowing banks to proactively manage their exposure. By ensuring that banks maintain sufficient capital reserves against potential losses in these sectors, regulators can safeguard the stability of the financial system while promoting more prudent lending practices.

7.3 Limitations and future research avenues

This study has several limitations. First, it assumes a uniform carbon tax impact across all industries, overlooking variations in companies' responses to technological upgrades, carbon management, and price adjustments. Future research should consider industry-specific elasticities and transmission mechanisms within supply chains for a more accurate analysis.

Second, while this study constructs 16 different carbon tax scenarios to assess their impact on bank credit losses, these scenarios may not account for all potential external economic conditions and policy changes, such as global market volatility, regulatory adjustments, and technological innovations. Future studies could enhance scenario settings by incorporating more complex economic variables and policy contexts to improve model adaptability and predictive capability.

Finally, this research primarily focuses on the short-term impacts of carbon tax implementation, lacking an in-depth analysis of its long-term effects. Carbon tax policies may induce structural changes in industries and adjustments in corporate investment behaviors, which might not fully materialize in the short term. Future research should employ dynamic models to analyze the long-term implications of carbon tax policies on the banking system and the economy, as well as explore how financial institutions adapt their risk management strategies and lending behaviors over time in response to these policies.

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Table List

Table 1

Carbon tax scenario settings

Preset carbon tax rate	Urgency of carbon tax collection	Carbon tax cost pass-through	Scenario
10 yuan/ton	Emergency	0%	I
	Linear increase	0%	II
	Emergency	50%	III
	Linear increase	50%	IV
30 yuan/ton	Emergency	0%	I
	Linear increase	0%	II
	Emergency	50%	III
	Linear increase	50%	IV
50 yuan/ton	Emergency	0%	I
	Linear increase	0%	II
	Emergency	50%	III
	Linear increase	50%	IV
100 yuan/ton	Emergency	0%	I
	Linear increase	0%	II
	Emergency	50%	III
	Linear increase	50%	IV

Notes: 1) This table details the setup of the 16 carbon tax scenarios based on carbon tax rates, urgency of collection, and cost pass-through levels. 2) In the “Urgency of carbon tax collection” category, “Emergency” refers to the immediate collection of the carbon tax at the target rate once the government decides to implement the policy; the “linear increase” scenario refers to gradually increasing the carbon tax rate until it reaches the preset target. 3) In the “Carbon tax cost pass-through” category, “0%” represents a situation where enterprises fully absorb the carbon tax costs, increasing production costs without raising product prices; “50%” simulates a scenario where enterprises pass on half of the carbon tax costs by raising product prices while absorbing the other half themselves.

Table 2

Potential responses to carbon tax policies and their effects

Action taken	Type of action	Potential outcome	Change in CO_2 emissions	Cost pass-through ratio
Yes	Cost pass-through	Product is a necessity, market share remains stable	No significant change	50%
		Price increase, demand reduction, market share declines	Decrease	50%
		Severe, exit from the market	0	50%
	Technological upgrade	——	Decrease	0% or 50%
No		High tax burden, reduced profits	No significant change	0%
		Severe, exit from the market	0	0%

Note: This table presents potential measures that firms might adopt under carbon tax policies and simulates the corresponding cost pass-through ratios, providing assumptions and theoretical references for setting the adjustment factor $\lambda_{k,t}$ in Equation (1).

Table 3

Data processing and parameter settings

	Variable and Parameter	Symbol	Processing Method/Value Setting	Data Source
Calculating Carbon Tax Effects Coefficient	CO_2 Emissions	$EM_{k,t}$	The annual growth rate of CO_2 emissions from 2010 to 2020 was used to estimate the future trend of CO_2 emissions in each industry for the next ten years.	Wind Database
	Discount Rate	r_k	Future cash flows related to carbon taxes (0–T) were discounted to their net present value at a rate of 6%.	——
	Adjustment Factor	$\lambda_{k,t}$	The values of the adjustment factors were set to 0% and 50% based on the scenarios in **Table 2** and the approach by Reinders et al. (2023).	——
	Total Industry Asset Value	TAV_k	The total operating surplus for 2020 was used as a proxy for each industry's current profitability, and the discount rate was set at 6%. The total asset value for each industry was calculated using the perpetual annuity method.	Wind Database
Calculating Bank Market Value Losses Based on KMV Model	Equity Value	E	The total market capitalization of stocks was estimated based on the CSRC algorithm as of the end of 2020.	Wind Database
	Equity Volatility	σ_e	The stock volatility of companies was calculated as the annualized standard deviation of daily returns in 2020.	Wind Database
	Risk-Free Rate	r	A risk-free rate of 2% was set based on the studies by Battiston et al. (2017) and Reinders et al. (2023).	——
	Total Debt	D	Total liabilities were derived from the consolidated balance sheets in the 2020 annual reports of listed companies.	Wind Database
	Loan Exposure of Banks in Each Industry	$exposur$	The loan exposure of 9 CBs, 6 SOBs, and 6 JSBs to each industry was measured based on 2020 data.	Wind Database, Annual Reports of Banks

Notes: 1) This table summarizes the key variables and parameters used to estimate the impact of carbon tax policies on banks' credit losses, including detailed explanations of each variable's treatment and data sources. 2) The selection of a 6% discount rate and a 2% risk-free rate is based on the relatively stable economic environment over the past period. The yield on 10-year government bonds has generally remained between 2.5% and 3.5%, with lower rates in some years, so the 2% rate is set as a cautiously conservative estimate. The 6% discount rate considers the cost of capital and the return required by investors for future uncertainties, which is a common valuation benchmark in the Chinese market. Additionally, the fixed rate simplifies model calculations, improving model stability and interpretability. While a floating rate might better reflect economic fluctuations, it increases model complexity and prediction difficulty. In cases of limited data, a fixed rate is a more practical choice.

Table 4

Carbon tax loss coefficients by sector under carbon tax rates of 10 and 30 yuan/ton CO2

Scenario		I	II	III	IV
	Urgency of carbon tax collection	Emergency	Linear increase	Emergency	Linear increase
Sector	Carbon tax cost pass-through	0%	0%	50%	50%
EHGW	10 yuan/ton CO2	0.005662765	0.000913100	0.002831382	0.000456550
MAN		0.002951877	0.000511458	0.001475938	0.000255729
TWP		0.001722970	0.000288789	0.000861485	0.000144394
MIN		0.001602052	0.000256716	0.000801026	0.000128358
CON		0.000062081	0.000010624	0.000031040	0.000005312
WR		0.000020031	0.000002222	0.000008654	0.000000265
EHGW	30 yuan/ton CO2	0.016988294	0.002739301	0.008494147	0.001369650
MAN		0.008855630	0.001534374	0.004427815	0.000767187
TWP		0.005168911	0.000866366	0.002584455	0.000433183
MIN		0.004806157	0.000770149	0.002403078	0.000385074
CON		0.000186243	0.000031872	0.000093121	0.000015936
WR		0.000065612	0.000010119	0.000031440	0.000005875

Notes: 1) This table presents the carbon tax loss coefficients (or asset value loss coefficients) by sector under carbon tax rates of 10 and 30 yuan per ton CO_2, reflecting the potential impact of carbon tax policies on asset values across sectors. 2) For each tax rate, Scenarios I and II represent loss coefficients with a 0% cost pass-through under emergency and linear tax increase models, respectively, while Scenarios III and IV correspond to a 50% cost pass-through. 3) Industry abbreviations are: EHGW (electricity, heat, gas, and water supply), MAN (manufacturing), TWP (transportation), MIN (mining), CON (construction), and WR (wholesale and retail).

Table 5

Carbon tax loss coefficients by sector under carbon tax rates of 50 and 100 yuan/ton CO2

Scenario		I	II	III	IV
	Urgency of carbon tax collection	Emergency	Linear increase	Emergency	Linear increase
Sector	Carbon tax cost pass-through	0%	0%	50%	50%
EHGW	50 yuan/ton CO2	0.028313823	0.004565502	0.014156911	0.002282751
MAN		0.014759384	0.002557289	0.007379692	0.001278645
TWP		0.008614851	0.001443943	0.004307426	0.000721971
MIN		0.008010261	0.001283581	0.004005131	0.000641791
CON		0.000310405	0.000053120	0.000155202	0.000026560
WR		0.000111227	0.000019638	0.000052552	0.000008135
EHGW	100 yuan/ton CO2	0.056627646	0.009131003	0.028313823	0.004565502
MAN		0.029518768	0.005114579	0.014759384	0.002557289
TWP		0.017229702	0.002887885	0.008614851	0.001443943
MIN		0.016020522	0.002567162	0.008010261	0.001283581
CON		0.000620810	0.000106241	0.000310405	0.000053120
WR		0.000223536	0.000033846	0.000111227	0.000019638

Notes: 1) This table presents the carbon tax loss coefficients (or asset value loss coefficients) by sector under carbon tax rates of 50 and 100 yuan per ton CO_2, reflecting the potential impact of carbon tax policies on asset values across sectors. 2) For each tax rate, Scenarios I and II represent loss coefficients with a 0% cost pass-through under emergency and linear tax increase models, respectively, while Scenarios III and IV correspond to a 50% cost pass-through. 3) Industry abbreviations are: EHGW (electricity, heat, gas, and water supply), MAN (manufacturing), TWP (transportation), MIN (mining), CON (construction), and WR (wholesale and retail).

Table 6

Debt value loss coefficients by sector under carbon tax rates of 10 and 30 yuan/ton CO2

Scenario		I	II	III	IV
	Urgency of carbon tax collection	Emergency	Linear increase	Emergency	Linear increase
Sector	Carbon tax cost pass-through	0%	0%	50%	50%
EHGW	10 yuan/ton CO2	0.00180448	0.00028769	0.00089297	0.00014491
MAN		0.00111811	0.00021132	0.00054430	0.00012115
TWP		0.00056393	0.00011187	0.00027502	0.00005582
MIN		0.00057074	0.00007335	0.00027854	0.00002680
CON		0.00007210	0.00000313	0.00005918	0.00000108
WR		0.00002002	0.00000224	0.00000864	0.00000027
EHGW	30 yuan/ton CO2	0.00471167	0.00086403	0.00268752	0.00043053
MAN		0.00338593	0.00056548	0.00177277	0.00030058
TWP		0.00174623	0.00029481	0.00084786	0.00014729
MIN		0.00172754	0.00025956	0.00083824	0.00011987
CON		0.00010346	0.00001004	0.00007942	0.00000396
WR		0.00006560	0.00001010	0.00003143	0.00000590

Notes: 1) This table shows the debt value loss coefficients by sector under carbon tax rates of 10 and 30 yuan per ton CO_2, reflecting the potential impact of carbon tax policies on debt values across sectors. 2) For each tax rate, Scenarios I and II represent loss coefficients with a 0% cost pass-through under emergency and linear tax increase models, respectively, while Scenarios III and IV correspond to a 50% cost pass-through. 3) Industry abbreviations are: EHGW (electricity, heat, gas, and water supply), MAN (manufacturing), TWP (Transportation), MIN (mining), CON (construction), and WR (wholesale and retail).

Table 7

Debt value loss coefficients by sector under carbon tax rates of 50 and 100 yuan/ton CO2

Scenario / Sector		I	II	III	IV
	Urgency of carbon tax collection	Emergency	Linear increase	Emergency	Linear increase
	Carbon tax cost pass-through	0%	0%	50%	50%
EHGW	50 yuan/ton CO2	0.01050061	0.00144229	0.00448644	0.00071964
MAN		0.00535440	0.00097439	0.00295168	0.00048307
TWP		0.00290973	0.00049137	0.00146418	0.00024564
MIN		0.00287796	0.00044586	0.00140078	0.00021301
CON		0.00013449	0.00001672	0.00009603	0.00000859
WR		0.00011121	0.00001964	0.00005254	0.00000811
EHGW	60 yuan/ton CO2	0.02241644	0.00288883	0.01050061	0.00144229
MAN		0.01075746	0.00203394	0.00535440	0.00097439
TWP		0.00589750	0.00098329	0.00290973	0.00045978
MIN		0.00579838	0.00091191	0.00287796	0.00044586
CON		0.00021387	0.00003191	0.00013449	0.00001672
WR		0.00022352	0.00003383	0.00005943	0.00001964

Notes: 1) This table shows the debt value loss coefficients by sector under carbon tax rates of 50 and 100 yuan per ton CO_2, reflecting the potential impact of carbon tax policies on debt values across sectors. 2) For each tax rate, Scenarios I and II represent loss coefficients with a 0% cost pass-through under emergency and linear tax increase models, respectively, while Scenarios III and IV correspond to a 50% cost pass-through. 3) Industry abbreviations are: EHGW (electricity, heat, gas, and water supply), MAN (manufacturing), TWP (transportation), MIN (mining), CON (construction), and WR (wholesale and retail).