How does vertical fiscal imbalance affect CO2 emissions? the role of capital mismatch

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How does vertical fiscal imbalance affect CO₂ emissions? the role of capital mismatch

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Abstract: The issue of climate warming caused by greenhouse gases is an important practical issue. This research aims to explore the impact of vertical fiscal imbalance (VFI) on CO₂ emissions from the perspective of theoretical analysis and empirical research. This study uses panel data from 30 provinces in China from 2004 to 2018 to test this issue. Results show that VFI has a significant positive impact on CO₂ emissions and that capital misallocation exacerbates the positive impact of VFI on CO₂ emissions. These research results also have significant temporal heterogeneity. In the sample results after 2008, the results are more significant. These conclusions provide an economic and political reference for local governments to achieve CO₂ neutrality and CO₂ peaking policy goals and to promote in-depth reform of the fiscal system.

Keywords: Vertical fiscal imbalance · Capital mismatch · CO₂ emissions

1 Introduction

In recent years, global warming caused by the greenhouse effect is an important issue of general concern worldwide. Global warming will lead to a worsening of the human living environment, violating the concept of sustainable development having a potentially catastrophic impact on the future (Stern, 2008). Carbon dioxide (CO₂) is the most important greenhouse gas. The Fifth Assessment Report of the United Nations Intergovernmental Panel on Climate Change pointed out that in 2011, the global atmospheric CO₂ equivalent concentration had reached 430 ppm. If not controlled, the CO₂ equivalent concentration will exceed 450 ppm by 2030 and will exceed 750 ppm by the end of this century. How to effectively curb CO₂ emissions has become a major issue of concern in the international community. For China, solving this practical problem is an important guarantee for achieving high-quality economic development in the future. In 2007, China's total CO₂ emissions were 6.792 billion tons, surpassing the total CO₂ emissions of the United States at 5.795 billion tons during the same period, becoming the world's highest emitter of CO₂. The long-term development model of "pollution first, governance later" has brought China's rapid economic growth while also consuming energy and paying high environmental costs. This model goes against the strategic goal of high-quality economic development advocated by China at this stage. To solve this urgent practical problem, China has provided relevant targets. According to the Paris Agreement, with 2005 as the base period, China's CO₂ emissions per unit of GDP needs to be reduced by 60%–65% within 25 years. In September 2020, the Chinese government proposed at the 75th United Nations General Assembly that China's CO₂ emissions will peak by 2030 and strive to achieve CO₂ neutrality by 2060. Against this realistic background, this provides a good opportunity for us to study China's CO₂ emissions.

The achievement of targets such as controlling CO₂ emissions and advancing CO₂ emission reductions in depth also depends on the relationship between governments because the issue of CO₂ emissions is an environmental issue and has negative externalities to the outside world. Just as achieving the goal of CO₂ neutrality requires the cooperation of many countries around the world, China's solution to the problem of high CO₂ emissions also requires the coordination of the central government and the full cooperation of local governments. However, given the reform of the tax sharing fiscal system in 1994, from a vertical point of view, China's intergovernmental fiscal relationship has been in an unbalanced state (Liu and Zhang, 2021). This specific governance structure with a prominent vertical fiscal imbalance (VFI) provides an interesting context to analyze the relationship between VFI and CO₂ emissions. Here, this study considers whether and how VFI affects CO₂ emissions. Despite the growing literature that explores how VFI affects China's CO₂ emissions by environmental regulation and industrial transformation (Huang and Zhou, 2020), not much is known on how VFI affects CO₂ emissions by capital mismatch. Varying degrees of capital mismatches occur among regions, industries, and companies in China (Dollar and Wei, 2007; Hsieh and Klenow, 2009; Brandt et al., 2013). Song and Wu (2015) use the generalized ARP approach and empirically find that capital misallocation causes a 20% loss in China's production efficiency. This loss severely restricts the sustainable development of China's economy (Huang, 2010). The misallocation of capital leads to excessive capital inflow into inefficient enterprises (Guariglia and Poncet, 2006; Bian et al., 2019), promoting the development of extensive industries, thereby aggravating environmental pollution. Therefore, this study aims to investigate how VFI affects CO₂ emissions by capital mismatch.

On the basis of these problems, the contribution of this paper is mainly in the following three aspects. First, the existing literature has not yet explored the effect of VFI on CO₂ emissions from the perspective of capital mismatch. This study first attempts to explore this effect from the perspective of theoretical and empirical analysis, enriching the relevant research. Second, this study puts forward specific policy recommendations. These findings have certain reference significance for local governments to achieve CO₂ neutrality, CO₂ peaking policy goals, and fiscal system reforms.

The remainder of the paper is structured as follows. Section 2 discusses the background of literature and the development of hypothesis. Section 3 introduces the analysis strategy and data explanation. Section 4 immediately follows with the empirical results. Section 5 summarizes policy arguments.

2 Literature review and hypotheses development

2.1 Literature review

Existing research has launched many discussions on the economic consequences of VFI. Eyraud and Lusinyan (2013) use data from 28 OECD countries to quantify VFI, explore the relationship between VFI and the financing structure of local governments, and find that reducing VFI can help increase the overall fiscal balance of local governments. Jia et al. (2014) study the impact of VFI on local government expenditure policies based on China's 1997–2006 county-level panel data and find that the decentralization of expenditures increased government expenditures, but focused on production and constructive expenditures. Jia et al. (2020) use China's 1995–2014 county-level panel data to study the impact of VFI on taxation policies and find that VFI suppressed the taxation efforts of local governments. Liu and Zhang (2021) use China's 1998–2018 provincial panel data to study the impact of VFI on government science and technology expenditures. They find that VFI has significantly suppressed local government spending on science and technology, and they found heterogeneity in time and space. Lin and Zhou (2021) use China's 1995–2017 provincial panel data to study the impact of VFI on the upgrading of industrial structure. They find that VFI is not conducive to the rationalization of the industrial structure, and significant differences occur between different regions.

At present, studies on VFI and environmental pollution are limited. The most recent research is Huang and Zhou (2020) and Li et al. (2021). Huang and Zhou (2020) used China's provincial panel data from 1999 to 2016 to empirically analyze the impact of VFI on environmental pollution and explore the path of its impact. The study found that VFI will significantly aggravate environmental pollution, mainly by influencing environmental regulation and industrial transformation and other intermediary pathways to promote CO₂ emissions, leading to the deterioration of environmental quality. Li et al. (2021) used Pakistan's provincial panel data from 2000 to 2018 to empirically analyze the impact of VFI on CO₂ emissions. They found that VFI promotes CO₂ emissions through intermediary paths such as environmental supervision and industrial structure. This result is similar to the conclusion of Huang and Zhou (2020). In general, their research has reached relevant conclusions through empirical studies on samples from China and Pakistan. They found that VFI has a positive effect on CO₂ emissions and will deteriorate environmental quality. At the same time, they all believe that environmental supervision and industrial structure are important intermediary paths. However, they did not consider the influence of other mechanisms, such as the moderating effect of capital mismatches.

In summary, the above literature provides empirical evidence for the study of economic consequences such as VFI and capital mismatch. However, they did not consider the impact of VFI on CO₂ emissions from the perspective of capital misallocation. This situation provides an opportunity for the development of this article.

2.2 Hypothesis development

Central governments in many countries around the world have decentralized fiscal power and delegated more expenditure responsibilities and revenue functions to lower-level local governments (Eyraud and Lusinyan, 2013). However, the balance between decentralized expenditure responsibility and income power is tilted, and expenditure responsibility is often greater than income, which directly leads to VFI. In recent decades, China has implemented various fiscal system reforms, such as the highly centralized fiscal management system (before 1978), the fiscal contracting system (1979–1993), and the tax sharing system (1994–present). The reform of the fiscal system has had a profound impact on China's economic transformation and development (Qian and Roland, 1998). Different from the previous two fiscal system reforms, the tax sharing system helps the central government achieve tax revenue

concentration while delegating more expenditure responsibilities to local governments. In China, the fiscal imbalance between the central and local governments has gradually appeared. Generally, the central government bears the expenditure responsibility for national public goods and services, and the local government bears the expenditure responsibility for local public goods and services (Yang, 2016). However, in reality, VFI causes local governments to favor productive expenditures such as infrastructure construction (Jia et al., 2014) and reducing the provision of public goods and services (Qian and Weingast, 1997), such as reducing investment in environmental governance. The environment is a public product with extremely strong negative externalities, requiring the government to invest a large amount of subsidy funds to intervene (Fairchild, 2008). Reducing investment in environmental governance and allowing development will inevitably deteriorate environmental quality.

First, under the political promotion championship, the promotion of local government officials is assessed based on GDP (Li and Zhou, 2005). After the central government takes over part of the financial power, the local government can use fewer factor resources and bear greater financial expenditure pressure, causing the local government to have investment short-sighted behavior (Ehdaie, 1994). For example, in productive investment and innovative investment, local government officials tend to choose productive investment. The reason for this choice is because productive investment has the characteristics of short investment cycle, quick results, and low risk. Innovative investment has a long investment cycle, slow results, high risk, and high uncertainty (Holmstrom, 1989). Based on the hypothesis of “political-economic man,” for local government officials, their choice of productive investment conforms to the maximization of economic benefits and political benefits. Therefore, the final result of the VFI is to promote an extensive economic growth model, aggravate regional environmental pollution, and increase CO₂ emissions. Second, due to limited resources, the government puts more resources into productive expenditures, inevitably reducing expenditures on other public product projects. The expenditure originally invested in the environment will also be transferred and occupied (Fairchild, 2008), which is not optimistic for overall environmental governance. Third, due to the previous vertical information gap between the central and local governments, supervision requires a huge cost (Oates, 1972). Chinese-style decentralization allows local governments and their officials to control the local economy, master various element resources, and have more autonomous decision-making power (Qian and Roland, 1998; Jin et al., 2005). This directly leads to the “absence of supervision” by the central government over local governments and their officials, and it is prone to deviations in policy objectives between the central and local governments.

Controlling CO₂ emissions requires local governments to invest in environmental governance and other public product and service projects to maximize resource allocation and promote the development of a low-carbon economy. The rational behavior of local governments under the VFI will increase the level of CO₂ emissions, also violating the strategic decision of the central government. From a theoretical or practical point of view, VFI is not conducive to the central and local governments in reaching a consensus on achieving CO₂ neutrality and CO₂ peaking policy goals. Thus, we put forward the following hypothesis:

Hypothesis 1 *Ceteris paribus*, the higher the VFI level, the higher the regional CO₂ emissions.

The phenomenon of capital mismatch is widespread in China (Brandt et al., 2013). Given that the establishment of my country’s capital market is relatively short, the allocation of capital resources is largely subject to local government intervention. Wu (2018) used the data of the Chinese industrial enterprise database to establish a structural model and found that policy distortions and financial frictions are the causes of capital mismatches, and capital mismatches cause the loss of production efficiency. In terms of green and sustainable development, capital misallocation may exacerbate the economic consequences of VFIs on CO₂ emissions. First, capital misallocation distorts the price of capital factors. The direct result of the distortion of capital factor prices is the inefficient capital allocation (Dollar and Wei, 2007; Hsieh and Klenow, 2009; Song and Wu, 2015). The reason may be that capital

elements cannot comply with changes in the basic supply–demand relationship under intervention and cannot supply capital to the sectors that need it most. At the same time, distortions in the price of capital factors will also induce companies to enter industries with overcapacity, leading to a waste of resources. Even if a higher economic output is ensured, it will eventually lead to deterioration of environmental quality. Second, capital misallocation supports extensive industrial development. Under capital misallocation, too much capital flows into the extensive industries with quick short-term results and low resource efficiency, restricting the upgrading of the industrial structure. The price of short-term GDP rise is waste of resources and environmental pollution, greatly restricting the high-quality development of the local economy (Huang, 2010). Alam (2020) used European company data from 2005 to 2014 to examine the periodicity of capital mismatch and its sources of funding and found that the degree of capital mismatch is higher during economic downturns than during economic prosperity. A possible reason is that capital misallocation distorts capital factor prices, inducing companies to enter industries with overcapacity or invest in extensive growth projects. Such results will also affect the quality of the environment. Third, capital mismatches allow zombie companies to survive, and market competition makes achieving “survival of the fittest” difficult. A large amount of capital is misallocated to low-efficiency enterprises, resulting in a large amount of low-efficiency output. At the same time, due to the lack of long-term capital for development and innovation, and the mismatch and distortion of short-term capital, innovative companies cannot easily maintain R&D and innovation activities. More importantly, this process is not conducive to reducing energy consumption per unit of output, and it is also not conducive to pollution treatment equipment and clean technology innovation. It will inevitably increase environmental pollution and hinder the development of a low-carbon economy (Bian et al., 2019). Finally, to attract the inflow of social capital, local governments often use some policy measures to enhance their competitiveness (Deng et al., 2019), such as relaxing environmental regulations (Qian and Xu, 2010). Such measures will aggravate environmental pollution and lead to an increase in CO₂ emissions. In general, capital misallocation will exacerbate the positive effect of VFI on CO₂ emissions. Thus, we put forward the following hypothesis:

Hypothesis 2 *Ceteris paribus*, capital misallocation has exacerbated the impact of VFI on regional CO₂ emissions.

The outbreak of the financial crisis in 2008 had a recessionary impact on the global economy, causing huge expenditure losses (Schularick and Taylor, 2012), which have exceeded the impact of previous crises (Claessens et al., 2011). Before the financial crisis, local governments had begun to intervene deeply in the financial system to deal with problems such as the shortage of financial resources. At the same time, administrative control directly intervenes in the allocation of funds to support the development of industries with short-term results. After the 2008 financial crisis, China’s economic development was affected and the growth rate slowed down. Financial resources have also become scarcer, leading to fierce competition for capital. To revive the economy and ensure the GDP performance of local officials during their tenure, local governments will increase their intervention in the allocation of funds in the financial system, intensifying the degree of capital misallocation, and a large amount of funds flowed into low-efficiency enterprises (Liu et al., 2018; Cong et al., 2019; Chen et al., 2020). At the same time, local governments have increased production expenditure input (Bonomo et al., 2015), supported the rapid recovery of extensive industries, and achieved short-term economic recovery (Liu and Zhang, 2021). However, these practices are not friendly to environmental governance and will lead to a sharp rise in CO₂ emissions. Thus, we put forward the following hypothesis:

Hypothesis 3 *Ceteris paribus*, after the financial crisis, the moderating effect of capital allocation has become more significant.

3 Empirical strategy, variables, and data

3.1 Econometric model specification

To test Hypothesis 1, we have established a benchmark regression model to verify the impact of VFI on CO₂ emissions, as shown in Eq. (1):

$$\ln(\text{CO}_2)_{i,t} = \alpha_0 + \alpha_1 \text{VFI}_{i,t} + \alpha_2 \text{Control}_{i,t} + \tau_i + \mu_t + \varepsilon_{i,t}, \quad (1)$$

where i and t represent province and year, respectively. CO₂ represents per capita CO₂ emissions, VFI means vertical fiscal imbalance, and Control shows a series of control variables. α_0 , α_1 , and α_2 are the unknown regression coefficients. τ and μ represent the province fixed effect (province FE) and the year fixed effect (year FE), respectively. ε is the error term.

To test Hypothesis 2, we further examine the impact of capital misallocation. Based on the original model, we add a moderating variable that characterizes capital mismatch and its interaction term with VFI. Following Eq.(1), we construct Eq. (2).

$$\ln(\text{CO}_2)_{i,t} = \alpha_0 + \alpha_1 \text{VFI}_{i,t} + \alpha_2 \text{Kims}_{i,t} + \alpha_3 \text{VFI}_{i,t} \times \text{Kims}_{i,t} + \alpha_4 \text{Control}_{i,t} + \tau_i + \mu_t + \varepsilon_{i,t}, \quad (2)$$

Kims means the capital misallocation index. Other variables are explained in the same way as above.

3.2 Variable definitions

3.2.1 Measuring CO₂ emissions

For the measurement of CO₂ emissions, we mainly measure the per capita CO₂ emissions by taking the natural logarithm ($\ln(\text{CO}_2)$).

3.2.2 Measuring VFI

Based on the characteristic facts of China's fiscal decentralization, following Eyraud and Lusinyan (2013), we calculate the coefficient of VFI by constructing an index system:

$$\text{VFI} = 1 - \frac{\text{FRD}}{\text{FED}} (1 - \text{LFG}), \quad (3)$$

where FED and FRD denote fiscal spending decentralization and fiscal revenue decentralization, respectively. According to the measurement method of fiscal decentralization by Liu et al. (2019) and Liu and Li (2019), FED (FRD) is equal to local per capita fiscal budget expenditure (revenue)/local per capita fiscal budget expenditure (revenue) and central per capita fiscal budget expenditure (revenue). LFG is the local fiscal self-sufficiency rate, which is measured by the difference between local fiscal budget expenditure and local fiscal budget revenue/local fiscal budget expenditure. When the degree of asymmetry between FED and FRD is higher, the degree of VFI is greater.

3.2.3 Measuring the moderator variable

Referring to the practice of Hsieh and Klenow (2009) and Chen and Hu (2011), we calculate the capital mismatch index for each province. The calculation formula is shown in Eq. (4).

$$\text{Kmis}_i = \frac{1}{\gamma_{K_i}} - 1, \quad (4)$$

where γ_K is the absolute distortion coefficient of capital prices, and his calculation method is shown in Eq. (5).

$$\gamma_{K_i} = \left(\frac{K_i}{K} \right) / \left(\frac{s_i \beta_{K_i}}{\beta_K} \right), \quad (5)$$

where $\frac{K_i}{K}$ represents the proportion of the capital of the region i in the total capital. $S_i = \frac{P_i y_i}{Y}$ represents the share of the output y_i of region i in the output Y of the entire economy. The output variable Y is represented by GDP. $\frac{s_i \beta_{K_i}}{\beta_K}$ represents the theoretical proportion of capital used by region i when capital is effectively allocated. The amount of capital input (K_i) is expressed by the fixed capital stock of each province, calculated using the perpetual inventory method, and the formula is as follows:

$$K_{i,t} = I_{i,t} / P_{i,t} + (1 - \delta) K_{i,t-1}, \quad (6)$$

where $K_{i,t}$ is the current stock of fixed capital, $I_{i,t}$ is the total amount of nominal fixed assets formed in the current period, $P_{i,t}$ is the fixed asset investment price index, δ is the depreciation rate, and $K_{i,t-1}$ is the stock of fixed capital in the previous period.

Finally, we calculate the capital mismatch index according to Eq. (4) and take the absolute value. When the value of the index is larger, the degree of capital mismatch is more serious.

3.2.4 Measuring control variables

Based on previous studies, we further consider the influencing factors of CO₂ emissions, including various control variables. First, we control the impact of regional economic development on regional CO₂ emissions, and use (the log of) GDP per capita (lnGDPPC) as a control variable. Second, we control the impact of government decisions on CO₂ emissions, and use trade opening (Open) and (the log of) the amount of fixed asset investment in the whole society (lnInvest) as control variables. Third, we control the impact of natural resources on CO₂ emissions, using (the log of) total forestry investment (lnForestry) and (the log of) water resources per capita (lnWater) as control variables.

3.3 Data sources

Considering the availability of data, the study uses data from 30 provinces (except for Hong Kong, Macau, Taiwan, and Tibet) from 2004 to 2018 to test the hypothesis. On this basis, we have a total of 450 observations. Panel data come from the Statistical Yearbook of China, Finance Yearbook of China, and WIND database. Table 1 displays the descriptive analysis of each empirical variable. The results show that VFI is more serious, and CO₂ emissions (ln(CO₂)) are also relatively high. These findings provide a solid foundation for our follow-up research on the relationship between VFI and CO₂ emissions. We also use the variance inflation factor test (VIF) to test whether a multicollinearity problem exists between variables. The test results show that the maximum VIF is 6.560, meaning that the data used in this study do not have a high degree of multicollinearity.

Table 1 Descriptive statistics of each variable

Var	Obs	Mean	Std. Dev.	Min	Median	Max
ln(CO ₂)	450	-2.757	0.645	-4.695	-2.779	-0.837
VFI	450	0.685	0.235	0.009	0.779	0.978
Kmis	450	0.234	0.179	0.001	0.200	1.471
lnGDPPC	450	10.298	0.675	8.353	10.369	11.925
Open	450	0.045	0.055	0.003	0.020	0.259
lnInvest	450	8.856	1.080	5.667	8.951	10.981
lnForestry	450	12.853	1.343	8.186	12.949	16.213
lnWater	450	7.028	1.242	4.288	7.379	9.691

4 Empirical results

We first empirically studied the influence of VFI on CO₂ emissions according to Eq. (1). Then, we analyze the influence mechanism of capital mismatch between VFI and CO₂ emissions according to Eq. (2). Next, we test the robustness of the basic regression results, such as alternative VFI measurement methods, adding control variables, potential endogenous testing, and eliminating periodic interference. Finally, we further consider the heterogeneous impact of financial crisis events and technological innovation.

4.1 Baseline regression results

Table 2 shows the baseline regression results. Column [1] is the regression result considering only VFI and some control variables, and column [2] is the regression result after adding all the control variables. The explained variables in columns [1] and [2] are CO₂ emissions (ln(CO₂)). Compared with column [1], the control variables in

column [2] are more comprehensive and the goodness of fit is higher. Therefore, we believe that the results of column [2] can explain the phenomenon better. We also add the capital mismatch variable and its interaction term with VFI (VFI×Kims) in column [3] to observe the adjustment mechanism of capital mismatch. The results of the F test reveal that in the above three models, the overall regression results are significant.

Table 2 Baseline regression results

	[1] ln(CO ₂)	[2] ln(CO ₂)	[3] ln(CO ₂)
VFI	0.406** (2.03)	0.602*** (3.05)	0.688*** (3.47)
Kims			0.510*** (3.98)
VFI×Kims			0.861*** (3.21)
lnGDPPC	0.658*** (6.43)	0.223* (1.68)	0.281** (2.14)
Open	2.188*** (2.85)	2.236** (3.00)	2.298*** (3.06)
lnInvest		0.259** (4.80)	0.204*** (3.62)
lnForestry		-0.059 (-3.13)	-0.056*** (-3.06)
lnWater		0.059 (1.43)	0.068* (1.66)
Province FE	Yes	Yes	Yes
Year FE	Yes	Yes	Yes
Constant	-9.867*** (-10.26)	-7.612*** (-6.99)	-7.993*** (-7.37)
R ²	0.666	0.689	0.701
F test	47.33	44.30	42.40
Observations	450	450	450

Notes: *, **, and *** denote significance level at 10%, 5%, and 1%, respectively; t statistics in parentheses.

According to the estimation results (columns [1] and [2]), we find that the regression coefficient of VFI is significantly positive, meaning that VFI has a significant positive effect on CO₂ emissions. Thus, Hypothesis 1 is supported. This result shows that VFI has significantly promoted the growth of CO₂ emissions. On the one hand, the imbalance in fiscal revenue and expenditure has led local governments to favor productive investment and promote the growth of extensive industries. On the other hand, when fiscal expenditure responsibility is greater than income, as a “political-economic man,” local governments tend to reduce the provision of public products and services such as environmental governance, hindering environmental governance and increasing CO₂ emissions.

According to the estimation results in column [3], we find that VFI and CO₂ emissions are still significantly positive, further supporting Hypothesis 1. The coefficient of the interaction term of capital mismatch, VFI and capital mismatch is significantly positive, that is, the higher the degree of capital mismatch, the more significant the positive impact of VFI on CO₂ emissions. This finding means that capital mismatches have a positive moderating effect. Thus,

Hypothesis 1 is supported. This result shows that capital misallocation has exacerbated the impact of VFI on regional CO₂ emissions, possibly because capital mismatches distort the price of capital factors and support extensive industries, thereby exacerbating the impact of VFIs on CO₂ emissions.

Next, we briefly describe the results presented by the control variables. GDP per capita (lnGDPPC) has a significant positive effect on CO₂ emissions, meaning that the higher the level of regional economic development, the greater the degree of CO₂ emissions. A possible reason for this result is that the previous regional economic development mainly relied on the contribution of the secondary industry. The development of industrial enterprises is often accompanied by high energy consumption, leading to an increase in CO₂ emissions. The regression coefficients of the trade opening variable (Open) and the fixed asset investment variable of the whole society (lnInvest) are significantly positive. A possible reason for this result is that the opening of trade and the increase in social investment will further stimulate social demand and bring about the rapid development of the real economy, leading to increased CO₂ emissions. The regression coefficient of the forestry investment variable (lnForestry) is negative, and the regression coefficient of per capita water resources (lnWater) is positive. This finding shows that natural resources will have a certain impact on CO₂ emissions.

4.2 Robustness checks

In this part, we use several methods to test whether the baseline regression results are robust. We carry out the robustness test on the basis of columns [3] in Table 2. First, we change the way of measuring VFI. In the calculation of VFI, we replaced the local fiscal gap rate with the national fiscal revenue and expenditure gap rate. The calculation method of the national fiscal revenue and expenditure gap rate is the ratio of the national budget gap (national public budget expenditure minus national public budget revenue) in the national public budget expenditure. According to the estimation results in column [1] of Table 3, we still find that the regression coefficients of VFI are significantly positive, and the regression coefficients of capital mismatch and interaction terms remain significantly positive. This finding shows that the use of the new VFI indicator does not change the original result. In addition, the performance of the control variables remains consistent.

Second, to eliminate the endogenous interference, we re-regress the key variables after a period of lag. According to the estimated results in columns [2] in Table 3, we still find that the regression coefficients of key variables after a lag of one period are consistent with the basic results.

Table 3 Robustness test results

	[1] ln(CO ₂)	[3] ln(CO ₂)	[4] ln(CO ₂)
VFI	0.764*** (3.08)	0.520*** (2.73)	1.287** (2.59)
Kims	0.419*** (3.33)	0.550*** (4.28)	0.625*** (2.73)
VFI×Kims	0.949** (2.57)	0.835*** (3.19)	0.958** (2.00)
lnGDPPC	0.281** (2.14)	0.161 (1.19)	0.076 (0.32)
Open	2.246*** (2.99)	2.638*** (3.56)	2.589* (1.83)
lnInvest	0.220*** (3.89)	0.202*** (3.72)	0.289*** (2.67)

lnForestry	-0.056*** (-3.01)	-0.051*** (-2.75)	-0.075** (-2.06)
lnWater	0.061 (1.48)	0.046 (1.13)	0.256** (2.15)
Province FE	Yes	Yes	Yes
Year FE	Yes	Yes	Yes
Constant	-8.007*** (-7.28)	-6.500*** (-5.00)	-8.166*** (-4.04)
R ²	0.696	0.649	0.752
F test	41.41	32.48	27.28
Observations	450	450	150

Notes: *, **, and *** denote significance level at 10%, 5%, and 1%, respectively; t statistics in parentheses.

Finally, to eliminate business cycle effects (Baskaran, 2010), we take the average of all variables with a period of three years and retest. Therefore, the panel data become smooth data instead of annual data. Our research object was reduced to 150 observations. According to the estimated results in columns [3] in Table 3, the results shown by the smoothed data remain consistent with the previous ones.

After the robustness tests, we found that the results have not changed. We believe that our conclusion is reliable. VFI has a significant positive relationship with CO₂ emissions, and capital mismatch has a positive regulatory effect.

4.3 Heterogeneity analysis

In this part, based on Eq. (2), we further capture the heterogeneity in time. Table 4 shows the test results of the heterogeneity analysis. The F test shows that the following model results are generally significant.

We explored the impact of time heterogeneity before and after the financial crisis. Column [1] reports the estimation results of the samples before the financial crisis (2004–2008), and column [2] introduces the estimation results of the samples after the financial crisis (2009–2018). According to the estimation results, we find that a significant difference between the results of columns [1] and [2]. The regression coefficient of VFI in the results before the financial crisis was positive but not significant, and the regression coefficient of VFI in the results after the financial crisis was significantly positive. This finding supports Hypothesis 1 and also shows that the impact of VFI on CO₂ emissions is temporally heterogeneous. Therefore, to promote local economic development as soon as possible after the financial crisis, local governments are more inclined to invest in industrial enterprises that yield quick results. To some extent, this practice has contributed to the increase in CO₂ emissions. Further observing the regression coefficients of capital mismatch and interaction terms, we find that the results in column [1] are not significant, while in the results of column [2], the regression coefficients of capital mismatch and interaction terms are both significantly positive. This finding is consistent with the previous results, showing that after the financial crisis, the adjustment effect of capital mismatch is more significant. Therefore, the more serious the capital misallocation is, the positive relationship between VFI and CO₂ emissions is more significant. This supports Hypotheses 2 and 3 and also shows that the adjustment effect of capital mismatch is heterogeneous in time. In areas with serious capital mismatches to encourage economic recovery, local governments will pay more attention to investing in industrial enterprises with faster short-term performance improvement. Such policies are often accompanied by high energy consumption, which will promote the increase of CO₂ emissions (Liu and Zhang, 2021).

Table 4 Heterogeneity test results

	[1] 2004-2008 ln(CO ₂)	[2] 2009-2018 ln(CO ₂)
VFI	0.251 (0.87)	0.652** (2.21)
Kims	-0.699* (-1.88)	0.468*** (3.10)
VFI×Kims	-0.513 (-0.47)	0.720** (2.29)
lnGDPPC	0.689 (1.61)	0.049 (0.30)
Open	-4.270* (-1.95)	2.119*** (2.77)
lnInvest	0.012 (0.06)	0.091 (1.61)
lnForestry	-0.092* (-1.95)	-0.030 (-1.48)
lnWater	0.066 (0.85)	-0.006 (-0.17)
Province FE	Yes	Yes
Year FE	Yes	Yes
Constant	-9.120** (-2.27)	-4.175*** (-2.61)
R ²	0.595	0.356
F test	13.24	8.216
Observations	150	300

Notes: *, **, and *** denote significance level at 10%, 5%, and 1%, respectively; t statistics in parentheses.

5 Conclusions

Since the signing of the Kyoto Protocol, the issue of climate warming has received widespread attention. How to effectively control CO₂ emissions has become the key to achieving sustainable development. For China, to effectively control CO₂ emissions, changing the extensive economic growth model is necessary. However, since the tax-sharing system reform in 1994, fiscal revenue has been concentrated and expenditure responsibilities have been decentralized, increasing the gap in local government revenue and expenditure. VFI changed the decision-making behavior of local governments but promoted extensive industrial growth, violating the Sustainable Development Goals and led to an increase in CO₂ emissions. These two realistic backgrounds provide a good opportunity for this article to study the impact of VFI on CO₂ emissions. This article explores the impact of VFI on CO₂ emissions from the perspective of capital mismatch, and further considers the impact of time heterogeneity, enriching related research. In this paper, using the panel data of 30 provinces in China from 2004 to 2018, we obtain the following findings. (1) VFI has had a significant positive impact on CO₂ emissions. (2) Capital misallocation exacerbates the positive impact of VFI on CO₂ emissions. The more serious the capital misallocation, VFI has a more significant positive impact on CO₂ emissions. (3) These research results have significant heterogeneous differences in time. In the sample results after 2008, the results are more significant.

Based on empirical research conclusions, this paper puts forward the following policy recommendations. First, social planners should appropriately balance the fiscal revenue and expenditure gap between the central and local governments, expand local fiscal revenue sources, and reduce the positive impact of VFI on carbon emissions. Second, social planners reasonably consider the impact of capital mismatch with local low-carbon economic development, formulate relevant policy guidelines, design and effectively implement relevant supervision and control systems, and guide local governments to maximize the efficiency of capital allocation. Finally, social planners continue to correct the capital mismatch problem caused by VFI. In this process, we must guide resources to flow into green development, further reduce CO₂ emissions, and promote the improvement of environmental quality.

This study provides a new perspective and empirical evidence for the research on the relationship between VFI and environmental pollution, but some limitations remain. First, this article only focuses on the impact of VFI on carbon emissions and does not consider the impact of VFI on carbon emissions intensity. Second, this article only analyzes related issues at the provincial level. Owing to the difficulty in obtaining some data, this paper fails to consider the impact of prefecture-level cities or county levels. Finally, due to the difficulty of obtaining corporate carbon emissions data, this article fails to consider the impact of VFI on corporate carbon emissions from a micro-enterprise perspective, which needs to be expanded in subsequent research.

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