The impact of weather forecast accuracy on the economic value of weather-sensitive industries

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The impact of weather forecast accuracy on the economic value of weather-sensitive industries *

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Abstract: This paper investigates the economic value of weather forecast accuracy in weather-sensitive industries. By analyzing statistical data from eight major industries across 31 provinces in China and meteorological data spanning from 2007 to 2021, we examine the sensitivity of industries to meteorological factors. The results reveal that improving weather forecast accuracy significantly enhances the output levels of all industries, with weather-sensitive industries experiencing a more pronounced impact. For every 1 % increase in weather forecast accuracy, the output of non-sensitive industries will increase by around 1.5%, and that of weather-sensitive industries will increase by 2-3%. Moreover, we construct composite forecast indices and perform robustness tests to validate the findings. Based on the empirical results, we put forward policy recommendations to enhance the economic value of weather forecasting, including improving forecast technology and accuracy, broadening information dissemination channels, and promoting synergistic cooperation between meteorological departments and industries. These measures can empower decision-making, reduce risks, and improve efficiency across various sectors, ultimately contributing to sustainable economic development.

Keywords: weather forecast accuracy, economic value evaluation

1. Introduction

Meteorology is a vital public service that plays a key role in national economic development, national defense, social progress, and the well-being of people's lives. Effective meteorological services can empower economic activities and livelihoods, leading to tangible economic benefits. The 14th Five-Year Plan for National Meteorological Development explicitly emphasizes the need to develop accurate meteorological forecast, advocating for the "Meteorology+" approach to enhance the

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quality and efficiency of meteorological services. The economic value derived from weather forecast in various sectors of the national economy is primarily realized through two main avenues. Firstly, categorized management departments within each industry utilize various weather forecast products to enable scientific resource allocation and rational planning. Secondly, enterprises and individuals in each industry benefit from weather forecast service products by strategically arranging production, consumption, circulation, storage, and transportation to mitigate risks and maximize economic value. The World Bank estimates that weather forecast generates global benefits of approximately $162 billion annually [1], while risk management studies conducted by Hallegatte (2012) suggest that global disaster management potential benefits amount to $66 billion [2]. However, the difficulty in measuring, identifying, revealing, and attributing these economic values has made the assessment of the benefits of industry weather services a challenging research topic recognized internationally.

The structure of industries affected by meteorological services reveals the significant economic value generated. Meteorological services contribute to the agricultural, forestry, animal husbandry, fishery, manufacturing, electricity, gas, construction, transportation, tourism, wholesale and retail, and insurance industries. Foreign scholars have adopted various research approaches to study the economic value of weather forecast and prediction in each industry. For instance, the Food and Agriculture Organization estimates that 5-10% of national agricultural product losses can be attributed to weather variability estimates that 5-10% of national agricultural product losses can be attributed to weather variability[3], and Rathore & Chattopadhyay (2016) show that the losses can be reduced by 10-30% through weather and climate forecast[4]. In the water supply sector, optimizing water system operations through weather forecast can lead to improved performance in 33% of water systems, resulting in approximately $5 billion in annual benefits (Anghileri et al., 2016)[5]. In the energy sector, Anghileri et al. (2016) conclude that energy production can be improved by 5%, and other aspects such as demand forecasting and production management can be enhanced by 1% through weather and climate impacts, particularly in hydro, wind, and solar energy. Hertzfeld et al.(2004) found that improvements in weather forecast can reduce electricity load forecasting errors by approximately 1-2%, potentially generating millions of dollars for utilities[6]. Teisberg (2005) suggests that 24-hour temperature forecasts could save U.S. generators $166 million annually[7]. In air transport, Anaman (2017) suggests that aircraft can save 30% of fuel on short flights based on weather forecasts[8]. Gerbet et al. (2016) estimate that full digitalization of non-residential buildings by 2025, coupled with better utilization of weather information, could result in global annual cost savings of $0.7 trillion to $1.2 trillion in engineering and construction[9]. Given the varied channels through which different industries are affected by weather changes and their varying sensitivities, understanding the sensitivity of each industry is crucial for a comprehensive assessment of the economic benefits of weather forecast.

Existing studies in China have examined the economic value of weather forecast for industries from different perspectives. They have analyzed the use of weather information in decision optimization and output increase. For example, Xiao (2000) estimated that accurate precipitation forecasts could increase the average wheat yield by 1.5%[10]. Zou et al. (2007) estimated that decisions on sowing based on weather forecasts could bring economic benefits of approximately 6 million RMB to farmers in Yiyang City and reduce losses by 36.2% [11]. Fu et al. (2002) compared input-output methods and estimated that the average annual meteorological input in Inner Mongolia Autonomous Region from 1992 to 1994 amounted to 130 million RMB[12]. Han and Pu (2010) pointed out that meteorological services are public goods, and assessment methods include voluntary payment, cost-saving, shadow price, and Delphi methods[13]. Using the cost-saving method, Yu et al. (2012) calculated the benefits of meteorological services in Jiangsu Province from a public service perspective, amounting to approximately 866 million yuan in 2010[14].

In summary, most existing studies on the economic value of weather forecast for industries have focused on individual industries, based on local surveys or statistics, aiming to enhance industry output through optimal decision-making or cost reduction. However, due to the complexity of factors influencing economic output, much of the literature remains based on qualitative descriptions or theoretical derivations, making it challenging to quantify the economic benefits of weather accuracy. Moreover, there is a lack of aggregate analysis of weather forecast accuracy at the national level and across major industries. This paper complements existing studies by considering the overall economic perspective and industry differences. Specifically, it estimates the relative weather sensitivity of major industries by Multiple Regression Analysis, using output value and weather forecast data for each industry in each province of China [15]. The paper also quantitatively assesses the impact of weather forecast accuracy on the output of sensitive industries using a difference-in-difference measure. Lastly, it comprehensively evaluates the impact of weather forecast accuracy on industry output from multiple dimensions, considering multiple indicators such as short-term and long-term variations in temperature and precipitation.

2. The Theoretical Analysis

The purpose of this study is to investigate the variations in weather sensitivity across different industries and examine the influence of weather forecast accuracy on weather-sensitive industries. The findings of this research will provide valuable insights for industry decision-making and policy formulation.

Firstly, due to the distinct characteristics and operational nature of industries, their adaptability and vulnerability to meteorological conditions differ. For instance, agriculture, forestry, animal husbandry, and fishery industries are highly reliant on weather and climate conditions, making them susceptible to changes in meteorological factors. On the other hand, manufacturing and service industries may experience minimal impact from meteorological changes. In this study, we will quantitatively estimate the weather sensitivity of various industries by analyzing output data and associated weather forecast information.

Hypothesis 1: Weather sensitivity varies **across industries.**

Secondly, this study explores the heterogeneous effects of weather forecast accuracy on different types of industries, taking into account the identified weather sensitivity. Accurate weather predictions provide sensitive industries with valuable insights to effectively allocate resources, reduce costs, mitigate risks, and improve productivity and economic efficiency. However, industries that are less sensitive to weather changes or are influenced by other factors may not experience significant impacts from the accuracy of weather forecasts. To test this hypothesis, we will quantitatively evaluate the relationship between weather forecast accuracy and the output of weather-sensitive industries. Additionally, we will conduct an in-depth analysis to determine the extent to which accuracy affects different industries.

Hypothesis 2: The impact of weather **forecast accuracy is more pronounced for weather-sensitive industries.**

By examining the weather sensitivity of various industries and the influence of weather forecast accuracy, this study aims to shed light on the intricate relationship between weather conditions and economic outcomes. The findings will provide valuable guidance for industry stakeholders in making informed decisions and formulating effective policies.

3. Empirical methodology

3.1. Empirical Model

The analysis in this paper consists of two main parts. Firstly, we calculate the sensitivity of industries' output to meteorological characteristics using the approach proposed by Multiple Regression Analysis to identify weather-sensitive industries. Secondly, we employ a difference-in-difference (DID) model to examine the impact of weather forecast accuracy on industries' output.

3.1.1 Define weather-sensitive industries

To calculate the sensitivity of each industry to meteorological characteristics and identify weather-sensitive industries, we construct the following model:

$$lnY_{ipt} = \alpha_0 + \boldsymbol{\beta} X_{pt} \times Industry_i + \alpha_1 lnK_{ipt} + \alpha_2 lnL_{ipt} + \delta_i + \varepsilon_{it} \quad (1)$$

where i represents the industry, p denotes the province, and t denotes the year. Y_{ipt} represents the total output of industry i in province p in year t, and X_{pt} represents the meteorological characteristics of province p in year t. The average annual temperature and annual precipitation of the region are used to measure temperature and precipitation, respectively. $Industry_i$ is a dummy variable that takes a value of 1 if the observation belongs to industry i, and 0 otherwise. The regression coefficient $\boldsymbol{\beta}$ of the interaction term between X_{pt} and each industry dummy variable represents the sensitivity of the output of industry i to the meteorological feature X_{pt}.The control variables K_{ipt} and L_{ipt} correspond to the fixed asset input and total employment of the industry in the province in that year, respectively; Y and K are adjusted according to the price index in 2021, and we take the natural logarithm of Y, K, and L in the regression model. α_0 is the constant term, α_1 and α_2 are the regression coefficients, and ε is the random error term. We also include industry fixed effects δ_i to control for the effects of industry factors.

3.1.2 Weather forecast accuracy and economic value

To investigate the relationship between weather forecast accuracy and economic output of each industry, this paper employs a difference-in-difference (DID) model:

$$lnY_{ipt} = \alpha_0 + \beta_1 Accuracy_{pt} + \beta_2 Sensitive_i \times Accuracy_{pt} + \alpha_1 lnK_{ipt} + \alpha_2 lnL_{ipt} + \delta_i + \mu_p + \varepsilon_{it} \quad (2)$$

$Accuracy_{pt}$ refers to the corresponding forecast accuracy indicator in year t in province p. $Sensitive_i$ is a dummy variable indicating whether the industry belongs to weather-sensitive industries, as defined by the calculations in model (1). The sensitive industry dummy takes a value of 1 for weather-sensitive industries and 0 otherwise. β_1 represents the percentage change in output for non-sensitive industries for each unit (1%) increase in forecast accuracy, while β_2 represents the additional percentage change in output faced by the sensitive industry compared to the non-sensitive industry for each unit (1%) increase in forecast accuracy. In other words, the total output of the sensitive industry changes by $\beta_1 + \beta_2$.

Consistent with model (1), Y_{ipt}, K_{ipt}, and L_{ipt} represent the total output, fixed asset input, and total employment of industry i in province p for year t, respectively. This model includes industry fixed effects δ_i and province fixed effects μ_p to control for industry-specific and province-specific characteristics.

3.2 Variable constructions

3.2.1 Explanatory variables

(1) Meteorological indicators: This study employs the annual average temperature and annual average precipitation of the provinces as measures of meteorological conditions.

(2) Meteorological forecasts: Four indicators are used to represent the forecast accuracy of meteorological forecasts, including the forecast accuracy of short-term rainfall, short-term

highest and lowest temperatures, monthly precipitation, and monthly average temperatures.

3.2.2 Dependent variable

In this paper, the value added of each industry in each province is used as a proxy for the economic efficiency of each industry. To account for inflation, deflated values are calculated using constant prices in 2021 as the base period. Descriptive statistics for specific variables are presented in Table 1.

Table 1. Descriptive statistics of the Variables

Variables	Variable definition	Samples	Mean	Standard Deviation	Minimum	Maximum
Y	Total output	3720	2178.851	3796.911	11.733	45142.902
K	Fixed assets investment	3720	1489.069	3208.595	0.000	32067.066
L	Total labor	3720	40.931	82.191	0.000	1055.371
Temp	Average temperature	2480	13.563	5.555	2.378	25.426
Rain	Logarithm of precipitation scaled by area	2480	-5.337	1.561	-9.310	-1.310
Sensitive	1 if the industry is weather-sensitive, and 0 otherwise.	3720	1	1	0	1
Accuracy_ Short-term temperature	Forecast accuracy for short-term temperature	3720	75.059	7.215	0.750	92.765
Accuracy_ Long-term temperature	Forecast accuracy for monthly average temperature	3720	76.731	9.494	43.700	99.000
Accuracy_ Short-term precipitation	Forecast accuracy for short-term precipitation	3720	83.597	6.363	52.000	92.880
Accuracy_ Long-term precipitation	Forecast accuracy for monthly average precipitation	3720	67.153	8.466	28.6	86.3

3.3 Data sources

This study conducts empirical analysis based on statistical data from the National Bureau of Statistics for the 8 major industries in 31 provinces across the country, as well as meteorological data spanning from 2007 to 2021. The meteorological data and meteorological forecast data are obtained from the National Meteorological Operations Intranet.

To ensure data quality and completeness, several treatments are applied to the initial data. First, individual missing values are processed using interpolation methods. Second, missing values in fixed asset investment are adjusted and calculated due to differences in statistical methods. The fixed asset investment data for each industry are only available up to 2017, and values for subsequent years are manually calculated based on investment value-added. Fixed asset investment data are further categorized into extractive industry, electricity, gas and water production, and manufacturing industry, and the subsector data are aggregated to calculate total fixed asset investment. Third, industry value added, fixed asset investment, and the number of employed population variables are logarithmized to mitigate the effect of magnitude. Ultimately, a total of 3720 annual observations are obtained. These data treatments ensure the completeness and consistency of the dataset, allowing for reliable empirical analysis and accurate results.

4. Empirical results

4.1 Estimation of industry weather sensitivity

To examine the sensitivity of each industry's output to meteorological conditions, this study utilizes a sample from the period 2008-2017 for estimation. The results of the regression analysis are presented in Table 2. The findings in column (1) reveal that agriculture, forestry, and fishery industries exhibit the highest sensitivity to changes in average temperature, with a 1-degree Celsius increase leading to an output change of 8.1%. Following closely are the wholesale and retail trade sector with a sensitivity of 2.2% and the real estate sector with a sensitivity of 1.8%. Furthermore, the results in column (2) demonstrate that for every 1% change in average precipitation per unit area, agriculture, forestry, and fishery industries display the greatest sensitivity, with an output change of 12.5%. Additionally, the finance sector and the wholesale and retail trade sector exhibit sensitivities of 8.4% and 8.3%, respectively. For instance, considering the year 2021, the value added by the agriculture, forestry, animal husbandry, and fishery sectors amounts to $8.68 trillion. The impact of temperature conditions on the output of these sectors alone can reach up to $700 billion, while the impact of precipitation can reach up to $1.06 trillion.

Table 2. Estimation of industry weather sensitivity

	Variables:	
	Temp	Rain
Industries:	(1)	(2)
Agricultural	0.081***	0.125***

	(0.007)	(0.026)
Retail	0.022***	0.083***
	(0.007)	(0.025)
Real estate	0.018***	0.054***
	(0.005)	(0.018)
Finance	0.016**	0.084***
	(0.007)	(0.025)
Industrial	0.009	0.028
	(0.007)	(0.025)
Construction	-0.007	-0.008
	(0.007)	(0.025)
Transportation	0.003	0.014
	(0.007)	(0.025)
Accommodation and catering	0.005	-0.047*
	(0.007)	(0.025)
Industry FE	Y	Y
N	2,480	2,480
R^2	0.884	0.867

Note: Standard errors are clustered by province and are reported below the regression coefficients. ***, **, and * indicate statistical significance at the 1%, 5%, and 10% levels, respectively.

Based on the comprehensive analysis, this study defines agriculture, forestry, animal husbandry, and fishery industries, along with wholesale and retail trade, real estate, and finance sectors as weather-sensitive industries. These industries demonstrate a higher susceptibility to meteorological conditions, indicating the need for effective weather forecast and adaptation strategies to mitigate potential economic impacts.

4.2 The impact of forecast accuracy on industry output

To assess the impact of forecast accuracy on the output of weather-sensitive and non-sensitive industries, this study employs the DID method. Table 3 presents the results estimated based on model (2). The dependent variable is industry output. *Accuracy* is defined as the percentage-based weather forecast accuracy of short-term temperature, monthly average temperature, short-term precipitation and monthly average precipitation in columns (1)-(4), respectively. *Sensitive* is a dummy variable indicating whether the industry is weather-sensitive based on the results from Section 4.1.

The results demonstrate that the coefficients of forecast accuracy are positive and statistically significant at the 1% level, indicating a positive relationship between weather forecast accuracy and industry output. On average, for every 1 % increase in weather forecast accuracy, the output of non-sensitive industries will increase by around 1.5%, and that of weather-sensitive industries will increase by 2-3%.

Table 3. The impact of forecast accuracy on industry output

Forecast accuracy of:	(1) Short-term temperature	(2) Monthly average temperature	(3) Short-term precipitation	(4) Monthly average precipitation
Accuracy	0.018***	0.014***	0.012***	0.014***
	(0.002)	(0.001)	(0.002)	(0.001)
Sensitive * Accuracy	0.014***	0.003*	-0.004*	0.004**
	(0.002)	(0.002)	(0.003)	(0.002)
Industry FE	Y	Y	Y	Y
Province FE	Y	Y	Y	Y
N	3,720	3,720	3,720	3,720
R^2	0.885	0.885	0.876	0.884

For instance, considering the case of short-term temperature forecasts, a 1% increase in forecast accuracy is associated with a 3.2% increase in the output of weather-sensitive industries and a 1.8% increase in the output of non-sensitive industries. To illustrate, take Beijing as an example. The range of short-term temperature forecast accuracy in Beijing from 2007 to 2021 is observed to be between 61.85% and 79.08%. Throughout the sample period, the average annual output of weather-sensitive industries in Beijing amounts to RMB 212.5 billion, while that of non-sensitive industries totals RMB 139.7 billion. Consequently, the contribution of forecast accuracy in Beijing to weather-sensitive and non-sensitive industries ranges from 433 million yuan to 1.172 billion yuan, respectively, as accuracy levels increase from the lowest to the highest.

These findings highlight the significant impact of forecast accuracy on both weather-sensitive and non-sensitive industries, with weather-sensitive industries demonstrating a greater sensitivity to accuracy improvements. Such insights emphasize the importance of enhancing forecast accuracy to optimize the economic output of various industries, especially those highly dependent on weather conditions.

4.3 Robustness test

4.3.1 Composite forecast accuracy indices

To ensure the robustness of the analysis results, this study constructs a composite index to measure forecast accuracy and examines its impact on industry output. Table 4 presents the results. The dependent variable is industry output, and variable *Index* is defined as follows: Columns (1) and (2) calculate the temperature and precipitation forecast indices, respectively, by assigning weights based on the importance of long- and short-term forecast accuracy. Given that long-term temperature and short-term precipitation have a greater influence on output, the temperature forecast index is defined as 39.6% * short-term temperature forecast accuracy + 60.4% * monthly average temperature forecast accuracy, while the precipitation forecast index is defined as 38.1% * short-term urban rainfall forecast accuracy + 61.9% * monthly precipitation forecast accuracy. Furthermore, column (3) employs a composite average index, which takes the equally weighted average of the four accuracy indicators presented in Table 3. The weight scores for this composite index are determined through an expert scoring method.

Table 4. The impact on industry output based on composite forecast accuracy

	(1)	(2)	(3)	(4)
Index of:	Temperature	Precipitation	Average value of 4 indicators	PCA
Index	0.023***	0.026***	0.039***	0.255***
	(0.002)	(0.002)	(0.002)	(0.018)
Sensitive * Index				
( )	0.010***	0.000	0.014***	0.053**
	(0.002)	(0.003)	(0.003)	(0.024)
Industry FE	Y	Y	Y	Y
Province FE	Y	Y	Y	Y
N	3,720	3,720	3,720	3,720
R^2	0.890	0.882	0.894	0.888

Recognizing that the four forecast accuracy measures may share common characteristics, such as forecasting techniques, column (4) applies principal component analysis (PCA) to determine weights and derive a new standardized measure of accuracy. The PCA regroups the four forecast accuracies into four sets of mutually uncorrelated factors, with the first three factors accounting for 81% of the information contained in the accuracies. Subsequently, column (4) employs the composite index constructed from these three factors as a measure of accuracy.

The estimation results using every composite index demonstrate that forecast accuracy has a positive impact on industry output, particularly for weather-sensitive industries. These regression results obtained through the composite indices align with the earlier regression findings, reaffirming the robustness of the baseline regression results.

4.3.2 Forecast accuracy intervals

To assess the impact of changes in forecast accuracy on output more effectively, the corresponding composite indices are grouped into four intervals ranging from 1 to 4. Interval 1 represents the lowest accuracy rate, while interval 4 signifies the highest accuracy rate. In Table 5, we calculate the output growth relative to interval 1 accuracy when the accuracy falls within intervals 2 to 4 with the DID method. Taking the results in column (3) as an example: Compared to interval 1 accuracy, when the accuracy rate falls within intervals 2 to 4, the output growth for non-sensitive industries amounts to 24.9%, 34.4%, and 47.6%, respectively. Similarly, for weather-sensitive industries, the corresponding output contributions are 24.9%, 45.4%, and 62.8%. These findings align with the core conclusion of this study, emphasizing that improvements in forecast accuracy contribute to the output of all industry types. Moreover, the impact of accuracy improvement is particularly significant for weather-sensitive industries.

Table 5. The impact on industry output based on forecast accuracy intervals

	(1)	(2)	(3)
Index of:	Temperature	Precipitation	Average value of 4 indicators
Interval[2]	0.239***	0.146***	0.249***
	(0.031)	(0.032)	(0.030)
Interval[3]	0.369***	0.136***	0.344***
	(0.031)	(0.032)	(0.030)
Interval[4]	0.402***	0.388***	0.476***
	(0.031)	(0.033)	(0.031)
Sensitive * Interval[2]	0.100**	0.013	0.055
	(0.042)	(0.044)	(0.042)
Sensitive * Interval[3]	0.120***	0.041	0.110***
	(0.042)	(0.044)	(0.042)

Sensitive * Interval[4]	0.179***	0.000	0.152***
	(0.042)	(0.044)	(0.042)
Industry FE	Y	Y	Y
Province FE	Y	Y	Y
N	3,720	3,720	3,720
R^2	0.891	0.883	0.893

4.3.3 Figures and fitness of the model

Figure 2 gives the fitting results of the model according to column (3) of Table 4 for the total output of weather-sensitive and non-sensitive industries, respectively. As can be seen from the figure, the regression model in this paper fits better for the sensitive industries in the sample interval, while the fit for the non-sensitive industries has a larger error. The explanation for this result is that sensitive industries are more influenced by meteorological conditions and even forecast accuracy, so the corresponding models will also fit better compared to non-sensitive industries.

To further validate the results, the calculated values were plugged into the model to assess the model's fit with actual industry GDP. Figure 1 illustrates the relationship between the corresponding accuracy intervals and the average value added of the industry. The accuracy rates within the sample were equally divided into 50 intervals, and the industry value added for each interval was averaged. The visual representation demonstrates that as the accuracy rate increases, the marginal impact on industry value added becomes more pronounced.

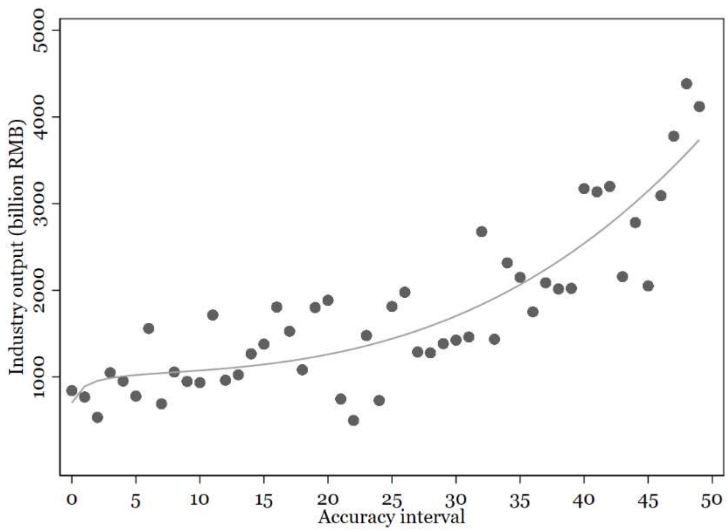
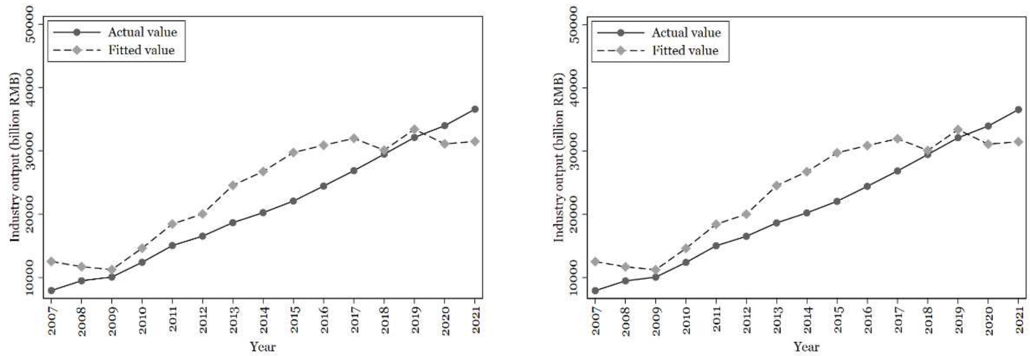


Figure 1. Accuracy and industry output

Figure 2 presents the model's fitting results based on the specifications in column (3) of Table 4 for the total output of weather-sensitive and non-sensitive industries separately. Observing the figure, it is evident that the regression model in this study provides a better fit for the sensitive industries within the sample interval, whereas there is a larger error for the non-sensitive industries. This outcome can be explained by the fact that sensitive industries are more susceptible to meteorological conditions and even forecast accuracy. Consequently, the corresponding models exhibit a superior fit compared to non-sensitive industries.



(a) Sensitive industries (b) Non-sensitive industries

Figure 2. Fitted results

5. **Conclusions and suggestions**

5.1 Research conclusions

Meteorological forecast plays a crucial role in shaping the output of various industries by influencing resource allocation and decision-making processes to mitigate potential harm. This study provides empirical evidence on the sensitivity of industries to meteorological factors, utilizing statistical data from 8 major industries across 31 provinces and meteorological data spanning from 2007 to 2021. Furthermore, it investigates the heterogeneous impact of meteorological forecasts on industries with different weather sensitivities using the difference-in-difference method. The findings indicate that improving weather forecast accuracy has a significant positive effect on the output of each industry, with weather-sensitive industries experiencing a more pronounced impact.

5.2 Policy suggestions

Based on the study's findings, the following policy recommendations are proposed to effectively enhance the economic value of weather forecast:

First, it is crucial to focus on improving the technology and accuracy of weather forecast by establishing a robust weather forecast system capable of addressing the impacts of climate change on various industries. This can be achieved through the expansion of meteorological observation stations, the implementation of advanced meteorological monitoring equipment, and the utilization of cutting-edge numerical models and data analysis techniques. Additionally, research efforts should be intensified in climate change monitoring and prediction, exploring new meteorological indicators and forecasting methods to enhance the precision and timeliness of weather forecasts. By providing governments, enterprises, and individuals with reliable and accurate weather forecast information, informed decision-making can be facilitated, risks can be minimized, and efficiency can be improved.

Second, it is essential to broaden the channels for distributing weather forecast information and strengthen the dissemination capabilities to ensure wide and timely access to weather-related information. Meteorological departments should enhance their collaboration with media outlets and employ multiple channels for releasing weather forecasts and alerts, such as television, radio, internet platforms, and mobile applications. Additionally, efforts should be made to interpret and popularize weather information, improving the public's comprehension and application of weather forecasts. Furthermore, active cooperation with social media platforms should be encouraged to disseminate weather forecast information through emerging social media channels, thereby reaching a broader range of audiences and regions.

Finally, it is crucial to strengthen synergistic cooperation between meteorological departments and various economic sectors to maximize the practical application of weather information in production processes. Establishing collaboration mechanisms between meteorological departments and industries to share weather data and information resources is essential. Industries should be encouraged to utilize weather forecast information for production planning and resource allocation to effectively address the challenges posed by weather changes. For instance, the agricultural sector can optimize crop planting time and irrigation plans based on weather forecasts, the manufacturing industry can enhance production scheduling and energy utilization through weather forecasts, and the tourism sector can develop strategies for managing passenger flow based on weather forecasts. By working collaboratively, industries can harness weather information more effectively to enhance production efficiency, reduce costs, tackle climate change risks, and achieve sustainable development.

By implementing these policy recommendations, governments, meteorological departments, and industries can leverage the power of accurate weather forecast to drive economic growth, enhance resilience, and foster sustainable development across various sectors of the economy.

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Data availability

The partial data that support the findings of this study are available from National data website (stats.gov.cn) , The partial meteorological data are available from the corresponding author on reasonable request.