Economic Analysis and Policy

Research on the Impact of Natural Disasters on China's Agricultural Economic Development in the context of Climate Change

--Manuscript Draft--

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Article Type:	Research Paper
Section/Category:	1. Analyses of Topical Policy Issues
Keywords:	Natural disasters, Agricultural economy, CGE model, Economic losses from disasters
Abstract:	Abstract: Agriculture is an industry that is highly exposed to various natural meteorological risks. In the context of climate change, frequent occurrence of natural disasters inevitably affects agricultural production. This paper analyzes the spatial and temporal distribution characteristics of climate change and drought and flood disasters in China in recent years. It utilizes a fixed-effects model to regressively analyze the negative effects of natural disasters on agricultural production and employs a CGE model to simulate the impact of increased agricultural output due to reduced agricultural disaster-affected areas on macro economy in China. The research indicates that temperature fluctuations in different regions of China range from -1°C to 1°C. Abnormal precipitation events are more frequent in South China, East China, and Central China, while annual precipitation is less in amount but shows more stability in northern and northwestern regions. Drought disasters occur frequently throughout China and have longer durations, whereas flood disasters mainly occur in the middle and lower reaches of the Yangtze River, the Yellow River, the Haihe River, and the Huaihe River. The regression analysis reveals that a 1% increase in agricultural disaster-affected areas leads to a decrease of 0.02% in the total output value of agriculture, forestry, animal husbandry, and fishery, as well as a decrease of 0.027% in total grain production. In the past decade, compared to the previous decade, the reduction in annual average disaster-affected areas in China has avoided 3% of agricultural production losses, resulting in positive effects on all macroeconomic indicators. Additionally, this paper proposes specific policy recommendations and discusses the methods.

Response to Editor and Reviewers

Dear Editor and Reviewers,

We sincerely appreciate the opportunity to revise our manuscript and the valuable feedback provided by all of you. The constructive comments and thoughtful suggestions have greatly contributed to improving the quality of our work, and we are truly grateful for your input. In response to your comments, we have carefully revised the manuscript, addressing each of your specific and informative points. Below, we have included your comments (in italics) along with our corresponding responses. While our responses may be concise, please note that we have made changes throughout the entire revised paper.

Response to Editor

Editor's comments:

1.Please strengthen the discussion on policy relevance of your findings.

Response:

Thank you for your valuable feedback and suggested modification regarding the policy relevance of our findings. We appreciate your efforts in helping us enhance the impact and significance of our research. Based on your recommendations, we have carefully considered the policy implications of our study and have made the necessary revisions to strengthen the discussion on this aspect. In our revised manuscript, we have expanded the section discussing the policy relevance of our findings to provide a more comprehensive analysis. We now highlight the practical implications of our research and how it can inform and shape policy decisions in the relevant field.

2.Highlight how does your paper contribute to the international literature.

Response:

Thank you for your feedback and suggestion to highlight the contribution of our paper to the international literature. We have taken your advice into consideration and made the necessary revisions to emphasize the unique contribution of our study in the newly added literature review section. In the revised manuscript, we have incorporated a comprehensive literature review that contextualizes our research within the existing international literature. This review serves as a foundation for discussing the novelty and significance of our study.

3.Cite relevant papers from the journal.

Response:

Thank you for your suggestion. We have incorporated a literature review section in the revised manuscript and included relevant citations from this journal to support our research. These citations establish a connection with the scholarly discourse of this journal and provide readers with broader background and references.

By citing relevant papers from this journal in the literature review section, we have strengthened the alignment between our paper and the content published in this journal, highlighting the uniqueness and innovation of our study. We appreciate your valuable feedback and guidance throughout the review process again.

Response to Reviewer #1

This study examined the impact of meteorological disasters on China's agricultural economic development in the context of climate change. This is an interesting study with good originality and presents some valuable data, however, I have following comments/ suggestions that should be addressed before the consideration of this paper:

1--The abstract part is not presented very well; the authors should make it better with main purpose of the study, main methods are applied, key findings, and policy implication.

Response:

Thank you for providing valuable feedback on the abstract of our manuscript. We have taken your suggestions into consideration and made significant revisions to improve the presentation of the abstract. The revised abstract now clearly highlights the study's background, objectives, methodology, key findings, and policy implications. Please find the updated abstract in the revised manuscript.

2--In the introduction, Pg# 1 Like 22-26, (Agriculture is an indispensable industry in the modern industrial system. Both in developed and developing countries, the basic position of agriculture needs to be strengthened in the modern industrial system, and modern agriculture also needs to play a leading role in the primary industry. However, agriculture production that is severely constrained by meteorological disasters has a high degree of vulnerability), this statement is interesting but it is lack of citation, please support it with suggested references:

https://doi.org/10.1016/j.ecolmodel.2023.110381

Read this study, it is also related to your research work and it will be useful.

Response:

Thank you for your valuable feedback on the introduction of our manuscript. We appreciate your suggestion to support the statement with relevant citations. We have carefully reviewed the suggested reference, and found it to be highly relevant to our research work. In the revised version of the introduction, we have incorporated the suggested reference to provide support for the statement regarding the vulnerability of agriculture production constrained by meteorological disasters. By citing this study, we enhance the scientific basis of our argument and strengthen the validity of our research. We appreciate your recommendation as it has also greatly contributed to the analysis section of our paper

--The presentation of the introduction section could be improved, and the authors should clearly mention major contribution of the study at the end.
Why this paper is lack of literature review? I suggest to authors must overview of previous studies which have been done globally/ Asian context. Some suggested studies:
https://doi.org/10.1016/j.ecoinf.2022.101778
https://doi.org/10.3390/ijerph191912341
https://doi.org/10.1007/s11356-021-17579-z
https://doi.org/10.1080/09640568.2021.1980378
https://doi.org/10.1016/j.ecoinf.2022.101960
https://doi.org/10.1016/j.ecoinf.2023.102038
https://doi.org/10.1108/IJCCSM-10-2020-0111

Response:

Thank you for your valuable feedback. We appreciate your suggestions for improving the introduction section and incorporating a literature review into our paper. We agree that providing an overview of previous studies conducted globally or within the Asian context would strengthen the background and contextualization of our research.

We have thoroughly reviewed the suggested studies with their corresponding DOIs you mentioned. In the revised version of our manuscript, we have included a comprehensive literature review section that encompasses these suggested studies along with other relevant works. By incorporating these studies, we provide readers with a broader understanding of the existing knowledge on the subject and highlight the novelty and contribution of our research.

Furthermore, we have improved the presentation of the introduction section to ensure clarity and coherence. At the end of the introduction, we now explicitly state the major contribution of our study, summarizing its unique aspects and significance.

We greatly appreciate your valuable suggestions, which have significantly enhanced the quality and content of our paper. Thank you for your guidance and for bringing these relevant studies to our attention.

-- *Recheck all equations again carefully with the variables explanations.*

<u>Response:</u>

Thank you for your feedback. We have carefully rechecked all the equations in the methods section and made the necessary revisions to ensure their accuracy and clarity.

-- *Study limitations and future research paths should be included in the Conclusion and policy recommendations.*

<u>Response:</u>

We greatly appreciate the reviewer's valuable feedback on our manuscript. We have carefully considered the suggestion to include study limitations and future research paths in the Conclusion and policy recommendations section. In light of this suggestion, we have made some revisions to address these aspects.

We acknowledge the limitations of our study, such as the focus on specific agricultural areas affected by natural disasters, and we emphasize the importance of future research to explore broader geographic scopes and additional factors influencing agricultural output. We also discuss potential directions for future investigations, including quantitative analysis using proxy variables in a CGE model to evaluate the effectiveness of mitigation strategies.

By incorporating these updates, we hope that addressing the study limitations and providing guidance for future research not only adds academic rigor to our work but also facilitates further advancements in the field. We sincerely appreciate the reviewer's insightful comments, which have contributed to the overall improvement of our manuscript.

<u>Response to Reviewer #2</u>

Based on the data on drought and flood-affected areas and disaster areas in China from 1950 to 2018, as well as temperature and precipitation data from various regions from 2000 to 2020, this manuscript analyzed the spatiotemporal distribution characteristics of drought and flood disasters caused by climate change in China in the past 70 years. Then used CGE model to quantitatively analyze the direct impact of meteorological disasters on agriculture and the indirect impact on macroeconomic and other industries. There is good theoretical guidance and practical significance for the healthy development of agriculture in the context of climate change. However, it is recommended to further improve in the following aspects:

1. The article lacks a literature review section and lacks a systematic review and analysis of current research on the impact of meteorological disasters on agricultural development, resulting in insufficient innovation and marginal contribution value of this study. It is recommended that the author systematically review existing research from the perspectives of meteorological disaster types, feature distribution, evaluation *methods of meteorological disasters on agriculture, and different ways of introducing meteorological disasters into CGE models to highlight research value.*

Response:

We appreciate the reviewer's insightful comment and suggestions regarding the need for a literature review section in our article. Based on this feedback, we have carefully revised the manuscript to include a comprehensive literature review that systematically examines current research on the impact of meteorological disasters on agricultural development.

In the revised manuscript, the literature review section provides a systematic review and analysis of existing studies from various perspectives. Firstly, we examine the different types of meteorological disasters and their distribution patterns, highlighting the diverse challenges they pose to agricultural systems. Secondly, we discuss the evaluation methods used to assess the impact of meteorological disasters on agriculture, considering both quantitative and qualitative approaches employed in previous research. Thirdly, we explore the different ways meteorological disasters have been incorporated into Computable General Equilibrium (CGE) models, emphasizing the evolving methods used to simulate and quantify the economic consequences.

By incorporating these elements into the literature review section, we aim to demonstrate the research value of our study and its contribution to the existing knowledge. The systematic review and analysis of current research provide a solid foundation for our study's innovation and highlight the unique aspects and contributions of our research.

Thank you again for your valuable feedback, which has significantly improved the quality and relevance of our manuscript. We sincerely appreciate your guidance and support throughout the review process.

2. In the method introduction section:
(1) Under the impact of the COVID-19, China's economy was seriously affected in 2020, the author should conduct a rational analysis on the use of the 2020 input-output table.

Response:

Thank you for your valuable feedback. Considering the impact of COVID-19 on China's economy in 2020 and the challenges associated with interpreting the results derived from the 2020 input-output table, we have made significant revisions to address this concern. Specifically, we have replaced the 2020 input-output table, which consists of 149 sectors, with the 2017 input-output table containing 42 sectors. We further aggregated the 42 sectors into 18 sectors for easier analysis. By utilizing the merged 18-sector input-output table from 2017, we have constructed a Social Accounting Matrix (SAM) for China to conduct a revised CGE analysis.

These adjustments ensure that our analysis takes into account the specific circumstances of the COVID-19 pandemic and provides a more rational and reliable assessment of the economic impacts. We appreciate your feedback, which has led to the enhancement and refinement of our research methodology.

Thank you again for your valuable input, and we sincerely appreciate your guidance throughout the review process.

(2) The author could explain the reasons for merging 149 departments into 15 departments to enhance the reference value of the research results.

Response:

Thank you for your suggestion. We understand the importance of explaining the rationale behind merging the 149 departments into 15 departments to enhance the reference value of our research results. Considering your previous suggestion, we have replaced the 2020 input-output table, which consists of 149 sectors, with the 2017 input-output table containing 42 sectors. We further aggregated the 42 sectors into 18 sectors for easier analysis. In the revised manuscript, we have provided a detailed explanation for this approach.

The decision to merge the 42 departments into 18 departments was driven by the need for greater simplicity and interpretability of the analysis. By reducing the number of sectors, we aimed to capture the key economic activities and interdependencies while avoiding excessive complexity that may hinder understanding and practical application. Furthermore, the merger of departments was based on economic similarities, functional relationships, and sectoral interactions. We considered factors such as input-output relationships, production processes, and the degree of interdependence among sectors. This consolidation enables a more comprehensive analysis of the intersectoral relationships and economic dynamics within the chosen departments.

We believe that this approach enhances the reference value of our research results by providing a clearer and more manageable framework for analysis. It allows for a more coherent interpretation and facilitates policy implications and decision-making processes. Thank you again for your valuable feedback, which has helped us provide a more detailed explanation of the rationale behind merging the departments.

(3) Due to the fact that the selection of elastic parameters often affects the simulation results to a large extent, the author could provide specific values and references for key parameters such as substitution elasticity between primary factors, export demand elasticity, price substitution elasticity between domestic and imported products in different industries, and expenditure elasticity of residents towards different commodities, which can demonstrate the rationality of the model construction.

Response:

Thank you for your insightful feedback. We agree that providing specific values and references for key parameters in our model construction will enhance the rationality and transparency of our research. In response to your suggestion, we have made the necessary revisions to address this concern.

In the revised manuscript, we have included specific values (see the supplementary tables) and referenced studies for key parameters such as the substitution elasticity between primary factors, export demand elasticity, price substitution elasticity between domestic and imported products in different industries, and expenditure elasticity of residents towards different commodities. These values and references are derived from established literature and empirical studies in the field. We appreciate your valuable feedback, which has contributed to the improvement and refinement of our manuscript. Thank you for your guidance throughout the review process.

3. In section 3.2, the author only reported temperature anomalies in China from 2006 to 2007 and 2011 to 2012, with little introduction to other years, especially after 2012. From Figure 4, we can see that the cold temperatures in various regions have been decreasing since 2012, and the temperature in China was generally in a state of positive anomalies since 2014. It is recommended that the author supplement this.

Response:

Thank you for pointing out the need for additional information regarding temperature anomalies in China after 2012. We appreciate your suggestion, and based on your feedback, we have made the necessary revisions to address this concern.

In the revised manuscript, we have supplemented the information regarding temperature anomalies in China after 2012. As shown in Figure 1, we observe that the cold temperatures in various regions have been decreasing since 2012, and the temperature in China has generally exhibited a state of positive anomalies since 2014. This suggests a significant shift towards warmer temperatures in the country. To address this, we have included a discussion in Section 3.2 that highlights the change in temperature patterns after 2012. We emphasize that China's climate has entered an unusual warm-wet pattern since 2012, with a notable rise in the country's average temperature. Specifically, we note that the northwest, north, and northeast regions have experienced a considerable increase in temperatures.

We sincerely appreciate your valuable feedback, which has led to the improvement and refinement of our manuscript. Thank you again for your guidance throughout the review process.

4. In section 3.3, the analysis of CGE simulation results is not in-depth enough, the author could further revise and improve, such as:
(1) According to Table 1, under the η_agr^dis=4.77% scenario, both household income and consumption decreased by 0.28% compared to the baseline scenario, while the author reported a decrease of 2.732% and 1.59% in household income and consumption, respectively. Such a large difference is confusing.

Response:

Thank you for pointing out this oversight and error. We sincerely apologize for this mistake. We have made the necessary corrections and significant revisions to the analysis of the CGE simulation results in response to your suggestion.

In the revised manuscript, we have provided a more in-depth analysis of the simulation results. For example, we have included a table that demonstrates the impact of agricultural output growth on various macroeconomic indicators, such as GDP, total investment, total consumption, household income, household consumption, enterprise income, government revenue, and trade volume. These results show the effects of a 3% change in agricultural output on the macroeconomy.

Furthermore, we have discussed the implications of the simulation results in more detail. We highlight the importance of reducing disaster-affected areas and increasing agricultural output in mitigating losses and promoting economic growth. We explain how the increase in agricultural output leads to growth in household income, consumption, and savings, as well as increased business income, government revenue, and expenditure. We also emphasize the positive impact on trade, with increased import and export volumes. These findings align with previous research on the relationship between agricultural output, disaster mitigation, and macroeconomic indicators.

To explore future uncertainties and potential impacts, we have introduced additional scenarios with higher agricultural output growth rates (6% and 9%). We project the corresponding effects on GDP, household income, household consumption, business income, government revenue, and expenditure. These scenarios demonstrate the potential benefits of further mitigating the effects of natural disasters on agricultural production.

We sincerely appreciate your valuable feedback, which has led to the improvement and refinement of our manuscript. Thank you again for your guidance throughout the review process.

(2) In the results of the macroeconomic impact, the author only briefly reported the impact of natural disasters on macroeconomic indicators such as GDP and household income, and pointed out that government consumption decreased more than household consumption, but did not explain the mechanism and path in detail. It is recommended that the author improve it.

Response:

Thank you for your valuable feedback. We appreciate your suggestion to provide a more detailed explanation of the mechanism and path behind the impact of natural disasters on macroeconomic indicators, particularly with regards to government consumption and household consumption. Based on your recommendation, we have made the necessary revisions to enhance the result analysis in the manuscript.

In the revised manuscript, we have expanded the analysis of the macroeconomic impact to provide a more comprehensive understanding of the mechanisms at play. Specifically, we have elaborated on the factors influencing government consumption and household consumption in the context of natural disasters. Thank you again for your suggestions.

(3) In the impact and analysis of industry output, the author also only reported the magnitude of output changes in different industries. However, why did the mining and manufacturing industries increase output while other industries decrease output? And the decline in different industries varies significantly? The author could conduct an in-depth analysis of how agricultural output damage affects other industries through complex correlation mechanisms between industries, categorize and summarize the reasons.

Response:

Thank you for your insightful comments and suggestions regarding a more in-depth analysis of the impact of agricultural output on different industries. We greatly appreciate your feedback, and we have addressed this issue in the revised manuscript.

In the revised version, we have conducted a comprehensive analysis of the relationship between agricultural output and other industries. We acknowledge that the impact on industry output may vary, and understanding the mechanisms and factors behind these variations is crucial. We have categorized and summarized the effects of agricultural output on different industry outputs, considering factors such as inter-industry relationships, supply chain effects, and changes in consumer demand. By exploring these complex interconnections among industries, we have revealed the specific reasons for variations in output changes across different sectors.

We hope that this expanded analysis provides a more nuanced understanding of how agricultural output damage affects various industries and addresses the concerns you raised. We sincerely appreciate your valuable feedback, as it has significantly contributed to the improvement and refinement of our manuscript. Thank you again for your guidance throughout the review process.

(4) In the comparative analysis of η_agr^dis=10% 、 η_agr^dis=15% and η_agr^dis=4.77% scenario, it is also recommended that the author identify macro indicators and industries with significant changes and improve the mechanism analysis.

Response:

Thank you for your suggestion. In the revised manuscript, we have conducted a comprehensive analysis of the macroeconomic indicators and industries under these scenarios. We have identified the sectors with significant changes in output and examined the underlying mechanisms driving these changes. For example, the agricultural, forestry, animal husbandry products, and services sector show significant increases in both intermediate inputs and total output as agricultural output damage increases. This is due to the interdependencies between the agricultural sector and related industries, such as the use of agricultural products as inputs in food processing and the demand for services related to agricultural activities.

Additionally, we have analyzed the effects on other sectors and macro indicators, including the petroleum, coke, nuclear fuel processing, and chemical products industry, as well as sectors like food and tobacco, machinery, transportation equipment, electronics, and other equipment, among others. We have examined how changes in agricultural output damage propagate through the interconnections among industries and impact the overall economy. We appreciate your valuable feedback and will ensure that these improvements are reflected in the revised version.

(5) It is recommended that the author present macro indicators and industry output results in the form of graphs to enhance the readability of the article.

Response:

Thank you for your suggestion. We have incorporated a graph into the revised manuscript to enhance readability. The graph presents the industry output results in a visual format, making it easier for readers to understand and interpret the data. We believe that this addition will greatly improve the readability of the article and enhance the overall presentation of the analysis. Thank you again for your valuable input.

5. The policy suggestions put forward in this paper are perfect, but not targeted. For example, "improve the pest control plan", "the government timely and effectively disclose casualty rescue information when responding to natural disasters, and maintain the order of disaster areas", these suggestions cannot be derived from the research results of this paper. The author should put forward more targeted policy suggestions based on the research results.

Response:

Thank you for your feedback. We apologize for the lack of specificity in the previous policy suggestions. Based on the research results, we have revised and provided more targeted policy recommendations. These revised policy suggestions are directly derived from the research results and aim to address the specific impacts of climate change and natural disasters on agriculture and the overall economy. We appreciate your valuable input and have taken it into consideration in improving the targeted nature of our policy recommendations.

Response to Reviewer #3

This paper investigated the impact of meteorological disasters on China's agricultural economic development in the context of climate change, which is a new attempt for the application of CGE model. However, in this paper, the method of incorporating *meteorological disaster losses into CGE model is too simple to reflect the advantages of CGE model. My specific comments are as blow:*

1) The literature review in the introduction should be enhanced. For example, we can't find any paper using CGE model to simulate the economic impact of some kind of disaster or some important event in this section.

Response:

Thank you for your suggestion. We acknowledge that the literature review in the introduction could be further enhanced to provide a more comprehensive overview of previous studies that have used Computable General Equilibrium (CGE) models to simulate the economic impact of various disasters or significant events.

In response to your recommendation, we have revised the literature review section to incorporate recent relevant studies that have employed CGE models for similar purposes. The updated literature review highlights the contributions of these studies in understanding the economic consequences of disasters and significant events, and we have emphasized the novelty of our research in the context of the CGE modeling approach.

We appreciate your valuable feedback again, and we have taken it into consideration to improve the quality and academic rigor of our paper.

2) In section 3.1 and 3.2, the author spend a lot of space to discribe "the occurrences of droughts and floods in China from 1950 to 2018" and "Variations of temperature and precipitation in China from 2000 to 2020", but in section 3.3 the authors only use the data to analyze the impact of the decrease in agricultural production caused by natural catastrophes on macroeconomics. section 3.1 and section 3.2 can't be taken as results of this paper and should be moved to the appendix.

Response:

We appreciate the reviewer's feedback and suggestion regarding the organization of our paper. After carefully considering the reviewer's comments, we have made adjustments to the research content and logical structure of our paper.

In the revised paper, in sections 3.1 and 3.2, we analyzed the spatial and temporal distribution characteristics of temperature, precipitation, droughts, and floods in China based on the available data from 1950 to 2018 and 2000 to 2020, respectively. These analyses provided important background information to understand the climate change and natural disaster patterns in China.

In section 3.3, we utilized the data on the occurrence of natural disasters and their impact on agricultural production to examine the macroeconomic consequences. Specifically, we employed a fixed-effect model to regress the decrease in agricultural production caused by natural disasters and assess its negative effects on the overall economy.

Considering the interconnections between these sections and the logical flow of our research, we believe it is appropriate to include sections 3.1 and 3.2 in the Results section in the revised paper. These sections provide essential contextual information and serve as the foundation for the subsequent analysis of the economic impact of natural disasters on agriculture.

With the revised research content, methods, and logical structure, we believe our modifications address the reviewer's concerns and enhance the overall coherence of the paper. We hope that the you find these revisions suitable.

3) In this paper, the authors only use 4.77% to represent the disaster damage parameter of natural disasters on agricultural production in 2020 and put this parameter into the CGE model to get all simualtion results, it a very simple treatment method and make the results only have limited persuasiveness. The authors should read related papers to find how to simulate the disaster damage more accuately in the CGE model.

Response:

We appreciate the reviewer's comment and acknowledge the importance of accurately simulating the impact of natural disasters on agricultural production in the CGE model. In the revised version, we have made improvements to address this concern.

To better represent the disaster damage parameter, we have incorporated a more robust approach. Firstly, we utilized a fixed-effect regression model to estimate the coefficient capturing the influence of changes in the affected area on agricultural production. This coefficient represents the quantitative relationship between the percentage change in the affected area of crops and the corresponding change in agricultural output.

Based on the estimated coefficient, we then derived the absolute change in agricultural production using a formula. By incorporating this parameter into the CGE model, we aim to enhance the persuasiveness and accuracy of our simulation results. We believe that the use of the coefficient derived from the regression analysis provides a more reliable representation of the impact of natural disasters on agricultural production, thereby improving the credibility of our findings.

In summary, we have taken the reviewer's suggestion into account and modified our approach to simulate the disaster damage more accurately in the CGE model. By utilizing the coefficient derived from the fixed-effect regression model, we aim to provide more persuasive results regarding the impact of natural disasters on agricultural production. We believe that these adjustments significantly enhance the robustness and validity of our study.

Response to Reviewer #4

This study focused on an important and interesting topic.

1. However, there lacks literature review. Thus, it is not clear what the innovation of this study is.

Response:

We appreciate the reviewer's comment regarding the literature review in our paper. In the revised version, we have made significant improvements to enhance the clarity and highlight the innovation of our study.

We have conducted a comprehensive literature review to provide a solid foundation for our research. The literature review now includes a wide range of studies that investigate the economic impact of natural disasters and climate change on agricultural production. We have identified and discussed the existing research on the topic, highlighting the gaps and limitations in the literature.

The innovation of our study lies in the combination of two key elements: the analysis of the spatial and temporal distribution characteristics of climate change and natural disasters in China, and the application of a CGE model to simulate the economic impact of these events on the agricultural sector and the broader economy. While previous studies have examined either the climatic aspects or the economic implications, our study integrates both dimensions to provide a comprehensive analysis of the issue. The revised version of our paper includes an improved literature review that clearly identifies the gaps in existing research and highlights the innovation of our study. We hope that the you find these revisions suitable.

The description of the Material and Methods is not clear enough. For example:

(1) Is land input considered in the production of the agricultural sector? If considered, it should be clearly stated; if not considered, the reason should be explained.

Response:

Thank you very much for your valuable feedback. In our study, land input is not considered in the production of the agricultural sector. We acknowledge that this decision may have certain implications and limitations on our research findings. However, incorporating land input in CGE models is a complex and challenging task, involving quantitative assessment of land resources and simulating changes in land use, among other aspects. Due to data limitations and the complexity of the model, we chose not to consider land input in this study to maintain model operability and result interpretability.

Although we did not consider land input, our research still provides important insights into the impacts of natural disasters and climate change on agricultural output and the overall economy. Our model considers other factors of production such as labor and capital, as well as the interplay between different economic sectors, enabling us to capture the effects of natural disasters on agriculture and other industries.

We have explicitly stated the reason for not considering land input in the agricultural sector and provided a proper discussion of this limitation in the paper. We will also consider exploring ways to more comprehensively incorporate the effects of land input on agricultural output in future research. Thank you again for your guidance and suggestions, and we will make the necessary revisions in the revised version.

(2) The expenditure behavior of both residents and government should be described.

Response:

Thank you for your comment. We agree that describing the expenditure behavior of both residents and the government is important for a comprehensive analysis. In our revised version, we have included a section that specifically discusses the expenditure behavior of residents and the government. Furthermore, we have provided additional descriptions in the construction of the CGE model. We have included the first-order conditions equation for function optimization and the price equation. We have also provided a comprehensive description of income and expenditure behavior of economic agents. We hope that these modifications will make the content more understandable for readers.

(3) For Eq(14) and Eq(15), isn't that agriculture output endogenous in the model? Then how can it be adjusted and still satisfied with the production function thereby maintain the balance of the whole model?

Response:

Thank you for your comments. In our model, agriculture output is indeed endogenous. The adjustments made in equations (14) and (15) (revised as equations (30) and (31)) do not directly alter the production function. The purpose is to incorporate the impact of natural disasters on agricultural sector output by introducing the parameter of disaster effect. This parameter represents the quantitative relationship between changes in disaster-affected crop area and changes in agricultural output. It is derived from a fixed-effects regression model that captures the effect of changes in disaster-affected area on agricultural production.

As $QA_a = \alpha_a^t \left[\delta_a^t QD_a^{\rho_a^t} + (1-\delta_a^t) QE_a^{\rho_a^t} \right]^{1/\rho_a^t}, \rho_a^t > 1$ and $QQ_c = \alpha_a^q \left[\delta_a^q QD^{\rho_c^q} + (1-\delta_c^q) QM^{\rho_c^q} \right]^{1/\rho_a^q}$ interact with each other through QD, and $QQ_c = \sum_a QINT_{ca} + \sum_h QH_{ch} + \overline{QINC_c} + QG_c, c \in C$ is affected by the total investment of the economy (EINV), which represents capital formation and consists of investments from various sectors, it is assumed that investment is exogenously determined, as shown in equation (23)

$EINV = \sum_c PQ_c \cdot \overline{QINV_c}, c \in C$. Therefore, the parameter of disaster effect indirectly influences the macroeconomy through its impact on QA, which is ultimately adjusted by the exogenous variable of agricultural capital formation. By embedding this parameter into the model, we can simulate the exogenous shocks of natural disasters such as rainfall and floods on agricultural sector output. Thank you again for your feedback.

(4) The second paragraph of section 3.3 should be move to the method section, and to describe these figures correspond to which parameters in which equation, one by one accordingly.

Response:

Thank you for your valuable suggestion. We agree that the second paragraph of section 3.3, which describes the figures corresponding to specific parameters in equations, should be moved to the method section for better clarity and organization. In the revised version, we have restructured the paper to include a dedicated section that explicitly explains the relationship between the figures and the parameters in the equations. This will provide a clear and detailed description. We appreciate your suggestion and hope this modification will improve the overall quality of the paper.

(5) Line 83: "using the latest input-output table of 149 sectors in China in 2020". Isn't the latest survey-based input-output table in China the one for the year 2017? Is the 2020 table actually just an extension table? The extension tables are based on partial-survey, so the number of sectors is generally significantly less than that of the survey-based tables. How was the detailed sector division version used in this study obtained (the link provided is not accessible)? Will there be a significant impact on calculation accuracy due to too many assumptions during the table preparation process?

Response:

Thank you for your valuable feedback. Firstly, the 2020 input-output table is indeed available and is not an extension table. We apologize for the inaccessibility of the link provided. Here is an alternative accessible link that explains how the 2020 input-output table was obtained: https://data.stats.gov.cn/ifnormal.htm?u=/files/html/quickSearch/trcc/trcc01.html&h=740&from=groupmessage&isappinstalled=0.

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Excel下载

2020年全国投入产出表
(按当年生产者价格计算) （Data are calculated at producers' prices in 2020)
单位：万元

投入 产出	部门名称	农产品	林产品	畜牧产品	渔产品	农、林、牧、渔服务产品
部门名称	代码	01001	02002	03003	04004	05005
农产品	01001	81659022	0	28912192	1003088	624035
林产品	02002	143	3546732	0	0	28520
畜牧产品	03003	149	0	22735172	0	188811
渔产品	04004	0	0	0	3757309	70012
农、林、牧、渔服务产品	05005	14857171	6999667	773802	4114588	566093
煤炭开采和洗选产品	06006	346797	35737	71954	48685	9849
石油和天然气开采产品	07007	0	0	0	0	
黑色金属矿采选产品	08008	0	0	0	0	
有色金属矿采选产品	09009	0	0	0	0	
非金属矿采选产品	10010	627	727	485	190	27
开采辅助活动和其他采矿产品	11011	0	0	0	0	
谷物磨制品	13012	930384	0	6416877	1406424	104976
饲料加工品	13013	896645	0	69552790	21755974	456745
植物油加工品	13014	4683	0	174680	236861	9
糖及糖制品	13015	0	0	0	0	
屠宰及肉类加工品	13016	0	0	14526	125	
水产加工品	13017	0	0	0	152044	
蔬菜、水果、坚果和其他农副食品加工品	13018	0	0	0	0	
方便食品	14019	0	0	0	0	
乳制品	14020	0	0	0	0	
调味品、发酵制品	14021	0	0	0	0	
其他食品	14022	0	0	0	0	
酒精和酒	15023	13692	9034	3447	6625	19674
饮料	15024	22008	126799	12275	21885	20520

Secondly, in response to the concerns raised by Reviewer 2, we have made revisions to the manuscript. Considering that the 2020 data may be influenced by the COVID-19 pandemic and may not reflect the typical economic conditions, we have switched to using the 2017 input-output table with 42 sectors to construct the Social Accounting Matrix (SAM) and conducted the CGE model analysis accordingly.
Lastly, it is true that excessive assumptions can impact calculation accuracy. However, they can still provide a baseline reference. It is important to note that there is no perfect model, but rather appropriate models that can capture the key dynamics and relationships within the analyzed system. We appreciate your understanding and assure you that we have addressed the concerns raised, ensuring the reliability and validity of our results within the chosen data and methodological framework.

Lack of explanation for the results from the CGE model. For example:
(1) Line 337, "the decline in government consumption is higher than that of household consumption", why?

<u>Response:</u>

Thank you for your feedback. In the analysis conducted using the revised 2017 data, the results indicate that the increase in government consumption is lower than the increase in household consumption. The following explanation provides insights into this result.

With the improvement of the level of economic development, there has been an increased focus on strengthening the agricultural infrastructure in China. This includes initiatives such as the expansion of rural electricity facilities, the enhancement of water resources infrastructure, the use of rural machinery, and the adoption of improved agricultural cultivation techniques.

As a result of these efforts, the average disaster-affected area of crops decreased significantly by 49.5% from 2011 to 2021, compared to the period of 2000 to 2010. This reduction in disaster-affected areas has led to an annual avoidance of nearly 3% of agricultural production losses. Given this context, when there is a 3% increase in agricultural output, it has ripple effects on the macroeconomy. It can be observed from the CGE model that the growth in agricultural output positively influences several macroeconomic factors such as GDP, total investment, total consumption, household income, and government revenue. However, the impact on government consumption is relatively lower compared to household consumption. This can be attributed to various factors such as different spending priorities, budget allocations, and policy considerations between the government and households. The detailed explanations and numerical values in the table in the revised paper provide a clearer understanding of the results from the CGE model and highlight the differential effects on government and household consumption.

(2) "The output of the textile and products industry reduced by 3.12%, the output of the agricultural sector fell by 1.67%," Why is the loss of the textile and products industry greater than that in agriculture? It should be explained in more detail. For example, the input share of agricultural products in food and tobacco should be greater than that in general manufacturing, but the total output of manufacture of food and tobacco decreased only by 0.93%.

Response:

Thank you for your feedback. In the previous analysis using the 2020 data, which might have been affected by the COVID-19 pandemic, the results showed certain errors. With the revised analysis using the 2017 data, under the impact of increased agricultural output, the industry that is most affected by the increase in agricultural production is the agriculture, forestry, animal husbandry, fishing products, and services sector. The growth in agricultural output will drive an additional increase of 0.667% and 1.121% in intermediate inputs and total output for this industry. The petroleum, coke, nuclear fuel processing, and chemical products industry rank second, with an increase of 0.53% in intermediate inputs and 1.037% in total output. This is due to the significant use of chemical fertilizers, pesticides, and other agricultural inputs in the agricultural production process, which leads to increased demand for intermediate inputs and final products in this industry, thereby increasing its intermediate inputs and total output.

Furthermore, the five industry sectors that are significantly affected by the increase in agricultural output are: food and tobacco, machinery and equipment, transportation equipment, electronics, electrical, and other equipment, other services, transportation, warehousing and postal services, and wholesale and retail. These sectors will experience output growth of 0.73%, 0.31%, 0.304%, 0.288%, and 0.267%, respectively.

The reasons for these differences can be explained by the following mechanisms: Firstly, the agriculture, forestry, animal husbandry, fishing products, and services sector is directly linked to agriculture, making it more sensitive to changes in agricultural output, and its output growth is primarily driven by changes in agricultural output. Secondly, the petroleum, coke, nuclear fuel processing, and chemical products industry has a supply chain relationship with agriculture. The growth in agricultural output stimulates the demand for intermediate inputs and final products in this industry, leading to increased output. As for other industries, their relatively smaller impact from the increase in agricultural output may be due to their lower association with agriculture or their position in the supply chain. Additionally, changes in consumer demand also affect the output of industries that are more susceptible to agricultural influences.

This paper needs to include more analysis. For example:
(1) "It is challenging for this paper to determine how a decrease in grain production due to natural disasters affects the volume of imports and exports". Actually, this can be done. When you fixed FSAV, it's just that the overall trade balance has been fixed, not the trade balance of agricultural products. So, this analysis should be added to the paper.

Response:

Thank you for your valuable feedback. We appreciate your suggestion to include more analysis regarding the impact of a decrease in grain production on the volume of imports and exports. In the revised analysis, we have indeed incorporated this aspect. The simulation results demonstrate that the reduction in disaster-affected areas leads to a significant avoidance of agricultural production losses. This, in turn, has implications for various macroeconomic indicators, including imports and exports.

Based on the simulation results, it is evident that the increase in agricultural output has a positive effect on imports and exports. Specifically, the total volume of imports shows a growth rate of 0.779%, and the overall export volume increases by 0.591%. These findings validate the research conclusions of Gassterbner, as avoiding or mitigating losses caused by natural disasters and ensuring stable growth in agricultural output contribute to an increase in both imports and exports.

Furthermore, the increase in agricultural output has a ripple effect on other macroeconomic indicators. It leads to growth in household income, consumption, and savings, as well as an increase in business income and savings. Additionally, government revenue and expenditure also experience growth. The total investment and total consumption show positive growth, with the import volume of various commodities exhibiting the fastest growth rate.

Although the contribution of increased agricultural output to GDP is relatively limited, it is significant given the scale of China's economy and the absolute growth value. Therefore, the analysis considers the impact on imports and exports comprehensively and provides valuable insights into the relationship between grain production and trade dynamics. Thank you again for your valuable input, and we have incorporated the additional analysis into the revised version of the paper.

(2) "In the future, it may be possible to experiment with other approaches to parameter calculation that are better in accordance with the features of the real economy." Sensitivity analysis in this regard should have been done in this study, which is also a common practice in other CGE related studies.

Response:

Thank you very much for your valuable feedback. Indeed, conducting sensitivity analysis on parameter calculation methods is a common practice in CGE modeling and related research. It helps us assess the sensitivity of model results to changes in parameters and provides a more comprehensive interpretation and understanding of the results. In this revision, we have performed sensitivity analysis by altering the elasticity coefficients in the CGE model and found that the impact on the results was minimal. Therefore, the elasticity coefficients have passed the sensitivity analysis. Once again, we appreciate your support and valuable input in our research.

(3) Section 3.4.2 "discusses possible mitigation policies". However, this section is only a qualitative discussion and can be included in any other articles on agriculture. Therefore, it is recommended to remove it. The CGE model itself can simulate many mitigation policies. It is recommended that the authors refer to existing relevant literature and perform additional quantitative analysis to replace the current section.

Response:

Thank you very much for your suggestion. We apologize for any confusion caused. In response to your comment, we have carefully considered the inclusion of the section on possible mitigation policies (Section 3.4.2). While we understand that the section may contain qualitative discussions that could be included in other agriculture-related articles, we would like to provide some clarifications.

Firstly, our study aims to analyze and predict the impacts of climate change-induced natural disasters on agricultural production and the macroeconomy under different scenarios. The primary objective is to study and develop strategies to mitigate the effects of natural disasters on agricultural areas, thereby reducing their impact on agriculture and the macroeconomy. Including a discussion on possible mitigation policies allows us to provide specific policy recommendations for addressing the consequences of our findings. We believe that the inclusion of this section is crucial in order to offer comprehensive insights and actionable strategies.

Secondly, while the CGE model itself has the capability to simulate various mitigation policies, it is important to note that our study focused on analyzing the effects of climate change-induced disasters on agriculture and the macroeconomy rather than evaluating specific mitigation policies. The inclusion of additional quantitative analysis or referencing existing literature on mitigation policies would require a different research approach and objective. However, we acknowledge the importance of this suggestion and will consider it for future research.

Taking into account the feedback from both the fourth and the second reviewers, we have made necessary modifications to the conclusions and removed certain content from the section in question. Once again, we sincerely appreciate your valuable feedback and understanding.

The logical structure of the paper also needs improvement. For example:
(1) In lines 67-68, it is stated that "among which droughts, floods, cold waves and typhoons are the primary meteorological disasters that have a greater influence on China". Why only droughts and floods were focused in the later analysis? This should be explained.

Response:

Thank you for your feedback. In the revised version of the paper, we have made modifications to the mentioned sentence. In fact, natural disasters encompass various types, including floods, droughts, storms, hailstorms, frost, pests, and diseases. In this study, we classified the primary natural disasters in China into four categories: droughts, floods, storms, and frost. A descriptive statistical analysis was conducted to provide an initial overview of the occurrence of natural disasters in China, as depicted in the figure. From 1978 to 2008, the occurrence of natural disasters in China showed a fluctuating upward trend. Among the different categories, droughts and floods were the two major types, accounting for an average affected area of 53.71% of the total affected area over the 60-year period. The second major type was floods, accounting for 24.93% of the total affected area.

This analysis was presented in the first section of the Results, titled "Spatial and Temporal Distribution Characteristics of Climate Change and Natural Disasters in China." Given that droughts and floods are the primary types of natural disasters in China and account for nearly 80% of the total affected area, we primarily focused on analyzing the spatial and temporal distribution characteristics of droughts and floods in this study.

We appreciate your valuable comments and suggestions. We hope the improvements to the logical structure of the paper we made have better addressed your concerns and expectations.

(2) The descriptions in sections 3.1 and 3.2 are too detailed. However, they are neither the results of this study nor seem to be directly related to the subsequent CGE analysis. These two sections should be significantly simplified or just removed.

Response:

We appreciate the reviewer's feedback and suggestion regarding the organization of our paper. After carefully considering the reviewer's comments, we have made adjustments to the research content and logical structure of our paper.

In the revised paper, in sections 3.1 and 3.2, we analyzed the spatial and temporal distribution characteristics of temperature, precipitation, droughts, and floods in China based on the available data from 1950 to 2018 and 2000 to 2020, respectively. These analyses provided important background information to understand the climate change and natural disaster patterns in China.

In section 3.3, we utilized the data on the occurrence of natural disasters and their impact on agricultural production to examine the macroeconomic consequences. Specifically, we employed a fixed-effect model to regress the decrease in agricultural production caused by natural disasters and assess its negative effects on the overall economy.

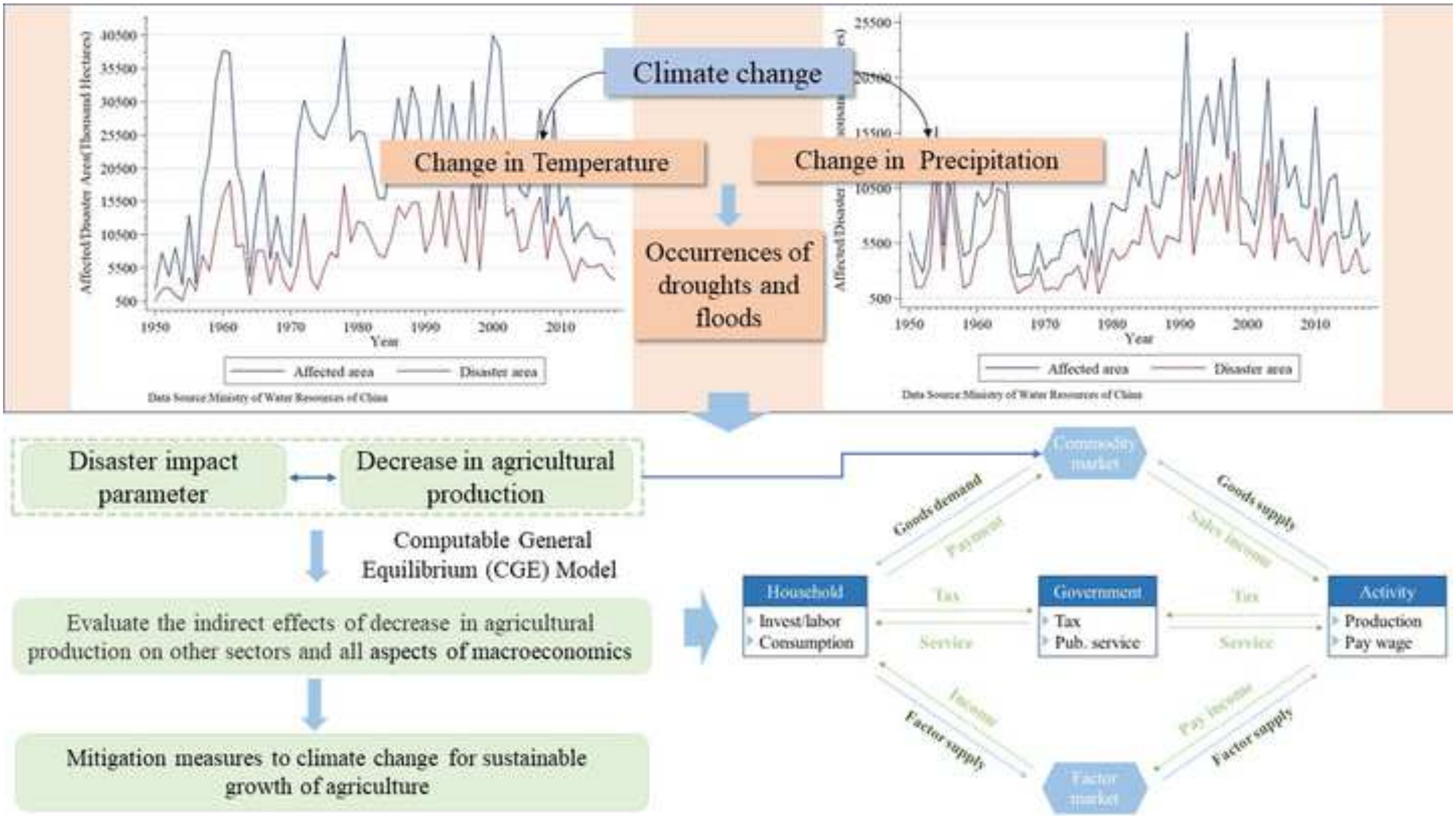
Considering the interconnections between these sections and the logical flow of our research, we believe it is appropriate to include sections 3.1 and 3.2 in the Results section. These sections provide essential contextual information and serve as the foundation for the subsequent analysis of the economic impact of natural disasters on agriculture.

With the revised research content, methods, and logical structure, we believe our modifications address the reviewer's concerns and enhance the overall coherence of the paper. We hope that the you find these changes suitable.

Other specific comments:
Abbreviations such as SAM and CES should be given their full name when first appear.

Response:

Thank you for your valuable feedback. We have made the necessary revisions to provide the full names of abbreviations such as SAM (Social Accounting Matrix) and CES (Constant Elasticity of Substitution) when they first appear in the paper.


Climate change
Change in Temperature
Change in Precipitation
Occurrences of droughts and floods
Affected area
Disaster area
Year
Data Source Ministry of Water Resources of China
Disaster impact parameter
Decrease in agricultural production
Computable General Equilibrium (CGE) Model
Evaluate the indirect effects of decrease in agricultural production on other sectors and all aspects of macroeconomics
Mitigation measures to climate change for sustainable growth of agriculture
Household
Invest/labor
Consumption
Government
Tax
Pub. service
Activity
Production
Pay wage
Goods demand
Goods supply
Factor supply
Factor supply

Research on the Impact of Natural Disasters on China's Agricultural Economic Development in the context of Climate Change

Abstract: Agriculture is an industry that is highly exposed to various natural meteorological risks. In the context of climate change, frequent occurrence of natural disasters inevitably affects agricultural production. This paper analyzes the spatial and temporal distribution characteristics of climate change and drought and flood disasters in China in recent years. It utilizes a fixed-effects model to regressively analyze the negative effects of natural disasters on agricultural production and employs a CGE model to simulate the impact of increased agricultural output due to reduced agricultural disaster-affected areas on macro economy in China. The research indicates that temperature fluctuations in different regions of China range from -1°C to 1°C. Abnormal precipitation events are more frequent in South China, East China, and Central China, while annual precipitation is less in amount but shows more stability in northern and northwestern regions. Drought disasters occur frequently throughout China and have longer durations, whereas flood disasters mainly occur in the middle and lower reaches of the Yangtze River, the Yellow River, the Haihe River, and the Huaihe River. The regression analysis reveals that a 1% increase in agricultural disaster-affected areas leads to a decrease of 0.02% in the total output value of agriculture, forestry, animal husbandry, and fishery, as well as a decrease of 0.027% in total grain production. In the past decade, compared to the previous decade, the reduction in annual average disaster-affected areas in China has avoided 3% of agricultural production losses, resulting in positive effects on all macroeconomic indicators. Additionally, this paper proposes specific policy recommendations and discusses the methods.

Keywords: Natural disasters, Agricultural economy, CGE model, Economic losses from disasters

1.Introduction

Agriculture is an indispensable industry in the modern industrial system. Both in developed and developing countries, the basic position of agriculture needs to be strengthened in the modern industrial system, and modern agriculture also needs to play a leading role in the primary industry. However, as the saying goes, agriculture shows high dependence on weather. To be specific, agriculture is severely constrained by meteorological disasters in land utilization, land changes and agricultural production, therefore has a high degree of vulnerability (Chandio etal., 2023). The Intergovernmental Panel on Climate Change (IPCC) reported that 1970-2020 was the warmest 50 years in the last two thousand years, and the trend of global warming will continue (The Intergovernmental Panel on Climate Change, 2022). Besides, according to the Global Climate report for 2021, the annual mean global near-surface temperature for each year between 2022 and 2026 is predicted to range from 1.1°C to 1.7°C, higher than preindustrial levels (the average over years 1850-1900). And the Arctic temperature anomaly, compared to the 1991-2020 average, is predicted to be more than three times as large as the global mean anomaly when averaged over the next five northern hemisphere extended winters (World Meteorology Organization, 2022). Governments, society, and the scientific community are all becoming increasingly concerned about the worldwide issue of climate change, which is characterized by climate warming, and its effects on the environment, economy, and human existence (Deschênes and Greenstone, 2007; Burke et al., 2015;). From the perspective of extreme events, it is found that historical global warming has increased the severity and probability of the hottest monthly and daily events at more than 80% of the observed area and has increased the probability of the driest and wettest events at approximately half of the observed area (Diffenbaugh et al., 2017). In Europe, Global warming strongly increases the frequency of river floods and drought traits (Alfieri et al., 2015; Cammalleri et al., 2020). Although there are still debates in the scientific community concerning the relationship between the rise of greenhouse gases and global climate change and its causes, the historical evolution of climate change, and the trend of future climate, climate change has had a significant impact on human health and life as well as global social and economic development (Shove et al., 2010; Adedeji et al. 2014; Olper et al., 2021). Among them, frequent meteorological disasters brought on by climate change have resulted in a great deal of serious direct destructive losses to agricultural production. And the impact on agricultural production is not only related to global food production and safe supply, but also may affect the quality of agricultural products and food safety (Schmidhuber et al., 2007; Schlenker and Roberts, 2009; Van Passel et al., 2017).

Natural disasters encompass a range of events such as floods, droughts, storms, hailstorms, frosts, pest infestations, and diseases. These natural calamities exert a direct influence on agriculture, leading to extensive devastation of crops and subsequent reductions in crop yields, potentially resulting in complete crop failures. As a consequence, substantial direct economic losses ensue. Since 2000, the occurrence rate of natural disasters in China has increased to over 60%, with the highest frequency being heavy rain and flood disasters, primarily occurring in the Yangtze River, the Huaihe River, and the Yellow River basins. In 2020, the total area of crop failure caused by natural disasters in China reached 2,706,000 hectares, among which 1,498,000 hectares in total are caused by heavy rain, geological disasters, and typhoons, accounting for 55.36% of the total area of crop failure. The direct economic losses caused by natural disasters in 2020 amounted to a total of 370.15 billion yuan.

Based on the above-mentioned research background, this study aims to explore the spatial and temporal distribution characteristics of climate change and natural disasters in China in recent years. It also investigates the impact of natural disasters on agricultural production in the context of climate change. The study focuses on the directly affected agricultural sectors and utilizes a CGE model to analyze and predict the possible impact of changes in agricultural production on the macroeconomy. The objective is to provide a scientific basis for research and strategies to address climate change and mitigate its impacts on agricultural production, as well as to effectively enhance the level of agricultural development and provide decision support for formulating agricultural economic development strategies to cope with climate change.

2.Literature Review

Global warming has become an undeniable and pervasive trend worldwide. Since the 20th century, the Earth's temperature has experienced an average increase of 0.8 degrees Celsius (Jayatilleke, 2014). This well-established scientific fact is also strongly linked to the escalation of various natural disasters, including tornadoes, tsunamis, droughts, and heatwaves (Wenyi Sun, 2015). The Fourth Assessment Report (AR4) of the Intergovernmental Panel on Climate Change (IPCC) emphasizes the gradual rise in intense precipitation events and the expansion of drought-affected areas in the mid-latitudes of the world since the 1970s (L. Alexander et al., 2006; IPCC, 2007). These empirical findings unequivocally indicate significant changes in the global climate. Agriculture, as a vital sector, is more susceptible to the influences of natural disasters, particularly considering that there is a strong correlation among agricultural production, climate and the environment. The productivity and output of agricultural systems are profoundly shaped by these factors, rendering them more vulnerable to the ramifications of natural disasters.

Scholars have extensively examined the multifaceted impacts of climate change on agricultural production, delving into its multifaceted implications. For instance, Sarker et al. (2014) assessed the impacts of climate variables on the mean and variability in yield of three major rice in Bangladesh and revealed that the effects of changes in climate variables vary among the crops. Baldos et al. (2020) used the sophisticated SIMPLE-G model to simulate the consequences of water resource depletion on agricultural systems. Their findings revealed a potential twofold increase in global agricultural losses by 2050 due to various natural disasters. In another study, Lachaud et al. (2022) investigated the relationship between climate change and agricultural output in 28 Latin American economies. Their research unveiled a significant 9%-12% reduction in agricultural yields within the region from 1951 to 2015, emphasizing the profound effects of climate change on agricultural production. Exploring the long-term effects of climate factors on cereal production, Chandio et al. (2021) discovered that increased precipitation and temperature had positive impacts on crop yields, while carbon dioxide emissions have a constraining effect. Mendis Abeysekara et al. (2022) uses a single-country, static computable general equilibrium model to investigate the economic impacts of climate change-induced agricultural productivity changes on Sri Lanka and found that reductions in the output of most agricultural crops will cause increased consumer prices for the agricultural commodities, with a consequential decline in overall household consumption within next few decades. Additionally, Dao (2023) utilized an advanced autoregressive distributed lag (ARDL) model to analyze the short-term and long-term impacts of climate change on Vietnamese agriculture at the macroeconomic level. The study confirmed the adverse effects of global warming on agricultural performance in Vietnam, both in the short and long term.

China, as the world's second most populous country, places great importance on agricultural security. In recent years, irregular changes in rainfall patterns and temperature have led to significant economic losses and a substantial decline in agricultural output in many regions of China (Chen et al., 2021; Sun et al., 2016). Scholars have started to pay more attention to the relationship between natural disasters and agricultural production in China. For example, Xu et al. (2017) discussed the impact of extreme weather disasters on grain production in Jilin Province, finding that for every 1 % decrease in average rainfall in summer, the grain yield in Jilin Province will decrease by 0.2549 %, and the final yield will decrease by 14.69 %. Similarly, using provincial crop yield sequence data from 1949 to 2012 and probability density function, Zhi-Lan (2015) analyzed meteorological disaster risks in southern China and found that major disasters could cause 13.6% and 15.3% of crop losses in Yunnan Province and Guizhou Province, respectively. Agricultural production is an important economy sector, whose changes will have broader implications on the economy, leading to changes in factors such as GDP, household consumption, and government expenditure and then affecting the operation of national economy. In this process, climate disasters, as exogenous shocks to agricultural production, will be transmitted between economic sectors until a new equilibrium is reached. Therefore, this study utilizes the Computable General Equilibrium (CGE) model to analyze the transmission of the impact of climate disasters on agricultural production to the broader economy.

The CGE (Computable General Equilibrium) model is a internally consistent macroeconomic model rooted in neoclassical microeconomic theory. It is designed to capture the interdependencies and feedback mechanisms within an economy by incorporating a comprehensive set of equations representing different sectors and accounting entities (Taylor, 2016). By introducing exogenous shocks, such as natural disasters or policy changes, the CGE model computes the resulting adjustments and quantifies the subsequent impacts on the economy as a whole and its constituent parts.

In the CGE model, a Social Accounting Matrix (SAM) is constructed to ensure consistency between sectoral production and consumption, factor markets, and national income accounts (Li et al., 2016). Under the assumption of constrained endowments, the model optimizes the allocation of resources by adjusting prices and quantities in response to the shocks. While the original equilibrium state is disrupted by the shocks, the model facilitates the identification of the new equilibrium state through iterative adjustments, allowing for a comprehensive assessment of the associated economic losses incurred by each sector.

The strengths of the CGE model lie in its theoretical foundation and the incorporation of detailed data structures, which can enable more realistic demand response effects of economic systems (Gao et al., 2020). Consequently, the CGE model has been widely applied in policy evaluation, including areas such as taxation, trade, and energy policies, to comprehensively analyze the effects of different policy scenarios (Ryan et al., 2023; Liu et al., 2021; Dixon and Rimmer, 2022; Huang et al., 2019). Moreover, the CGE model has found utility in assessing the economic repercussions of natural disasters by quantifying the losses incurred as a result of such exogenous shocks (Jia and Lin, 2022; Krook-Riekkola et al., 2017).

After a disaster occurs, direct losses such as casualties, property damage, and agricultural losses can be determined through subsequent investigations and statistical analysis. However, the indirect losses resulting from disasters are often overlooked. Within the national economic system, there exists a high level of interdependence among different sectors, and the impact of a disaster on any sector can spread through supply chains to other sectors (Tan et al., 2019). By integrating various sectors of the national economy, the Computable General Equilibrium (CGE) model can not only capture economic phenomena such as prices, supply and demand, and substitution effects, but also measure the interaction between different sectors so as to offer an effective approach to assessing indirect economic losses. Policymakers can utilize this model to optimize resource allocation and develop policies for disaster resilience. Nevertheless, for the CGE model there is still much room to improve in terms of its structural framework, data selection, and modeling of shocks when it is used to quantify economic losses caused by disasters (Zhou and Chen, 2021).

Therefore, this study aims to analyze the spatial and temporal characteristics of climate change and natural disasters in China. It employs the Ordinary Least Squares (OLS) and the Fixed Effects model to quantitatively assess the impact of climate change and natural disasters on agricultural output. The effective regression coefficients of natural disasters on agricultural output will be introduced as parameters in the CGE model to examine the indirect influence of agricultural output changes on the macro economy. By conducting this research, we aim to contribute to a comprehensive quantitative analysis of the effects of natural disasters on agriculture and the macro economy.

Therefore, this study aims to analyze the spatial and temporal characteristics of climate change and natural disasters in China. It employs the Ordinary Least Squares (OLS) and the Fixed Effects model to quantitatively assess the impact of climate change and natural disasters on agricultural output. The effective regression coefficients of natural disasters on agricultural output will be introduced as parameters in the CGE model to examine the indirect influence of agricultural output changes on the macro economy. By conducting this research, we aim to contribute to a comprehensive quantitative analysis of the effects of natural disasters on agriculture and the macroeconomy.

3. Data and Methods

3.1 Data Sources

The data utilized in this study primarily consists of two categories. The first category comprises data required for regression analysis on the impact of climate change and natural disasters on agricultural output. The second category includes model parameter data and data for constructing the Social Accounting Matrix (SAM) required for CGE (Computable General Equilibrium) model construction.

The regression analysis on the impact of climate change and natural disasters on agricultural output primarily involves the following variables: dependent variables include the total output value of agriculture, forestry, animal husbandry, and fisheries (AP) and grain production (GY); key explanatory variables include temperature (TP), precipitation (PRE), crop area affected by natural disasters, and area affected by disasters (AA); control variables include carbon emissions (CE), sown area (SA), effective irrigated area ratio (EI), and fertilizer usage.

AP (Total Output Value of Agriculture, Forestry, Animal Husbandry, and Fisheries): This study utilizes the total output value of agriculture, forestry, animal husbandry, and fisheries at the provincial level as the first measurement indicator of agricultural production. This indicator represents the monetary value of all products and supportive services associated with agricultural, forestry, animal husbandry, and fisheries activities, reflecting the overall scale and outcomes of these sectors during a specific period.

GY (Grain Production): GY serves as the second measurement indicator of agricultural production in this study. It includes the total grain production, including summer crops, early rice, and autumn crops, from provinces (regions/cities).

AA (Crop Area Affected by Disasters): AA is the measurement indicator of natural disasters in this study. It utilizes annual data on the crop area affected by disasters reported by provinces, representing the impact of natural disasters on agricultural production.

TP (Temperature): TP is the first measurement indicator of climate change in this study. It is based on annual temperature statistics monitored by ground meteorological stations within each province, with provincial average temperatures calculated using the arithmetic mean method.

PRE (Precipitation): PRE is the second measurement indicator of climate change in this study. It is based on annual precipitation statistics monitored by ground meteorological stations within each province. Provincial total precipitation data are summarized and divided by the average area of each province to obtain the average precipitation per province.

CE (Carbon Emissions): CE is the third measurement indicator of climate change in this study. Considering coal as a major source of carbon emissions, coal consumption is selected as a proxy for carbon emissions.

SA (Sown Area): SA is the first measurement indicator of human planting behavior in this study. It utilizes annual sown area data reported by provinces.

EI (Effective Irrigated Area Ratio): EI is the second measurement indicator of human planting behavior in this study. It utilizes the ratio of effective irrigated area to total arable land area reported by provinces.

FU (Fertilizer Usage): FU is the third measurement indicator of human planting behavior in this study. It utilizes annual fertilizer usage data reported by provinces.

AM (Total Agricultural Machinery Power): AM is the fourth measurement indicator of human planting behavior in this study. It utilizes annual data on total agricultural machinery power reported by provinces.

Specific data sources are detailed in the Table 1 below:

Table 1. Variable Definitions and Data Source

Variable Type	Variable Name	Unit	Data Source
Dependent Variable	Total Output Value of Agriculture, Forestry, Animal Husbandry, and Fisheries(AP)	RMB 100 million	China Statistical Yearbook 2000-2020（http://www.stats.gov.cn/sj/ndsj/）
	Grain Production（GY）	10,000 tons	
Core Explanatory Variable	Crop Area Affected by Disasters（AA）	Thousand hectares	China Statistical Yearbook 2000-2020（http://www.stats.gov.cn/sj/ndsj/）
	Temperature (TP)	Celsius	Resource and Environment Science and Data Center （https://www.resdc.cn/ ）
	Precipitation (PRE)	mm	
	Carbon Emissions (CE)	10,000 tons	China Energy Statistics Yearbook 2000-2020[1]
Control Variable	Sown area (SA)	Thousand hectares	China Statistical Yearbook 2000-2020（http://www.stats.gov.cn/sj/ndsj/）
	Effective Irrigated Area Ratio (EI)	%	
	Fertilizer Usage (FU)	million tons	
	Total Agricultural Machinery Power (AM)	10,000 kilowatts	

The data foundation of the CGE (Computable General Equilibrium) model mainly consists of two parts: the construction of the Social Accounting Matrix (SAM) and the setting of model parameters. The SAM serves as the data foundation for the CGE model. The data required for constructing the SAM primarily comes from the 2017 input-output tables of 42 sectors (Zhang et al., 2021). Based on economic similarities, functional relationships, and sectoral interactions, the 42 sectors are aggregated into 18 sectors. By reducing the number of sectors, our aim is to capture key economic activities and interdependencies while avoiding excessive complexity that may impede understanding and practical application, thus making the analysis simpler and more interpretable. The constructed macro-SAM incorporates various accounts, including activities, commodities, labor, capital, households, enterprises, government, investment, and the rest of the world (see Appendix 1). In CGE model research, in addition to using the SAM as the base data, exogenously set elastic parameters are also employed, referring to the works of Alaouze (1977), He (2002), and Zheng (1998). Please refer to Appendix 2 for specific elastic parameters.

3.2 Research Methodology

3.2.1 Descriptive Statistical Analysis

Descriptive statistical analysis is primarily used to investigate the basic statistical characteristics of the data, in order to understand the overall distribution pattern and trend of the data. In this study, descriptive statistical analysis is first conducted on long-term temperature and precipitation data to visually depict climate change. The daily temperature and precipitation data from 372 meteorological stations in China, obtained from the China Meteorological Forcing Dataset V3.0, are utilized. The country is divided into seven major regions: North China, Northeast China, Northwest China, South

[1] https://data.cnki.net/v3/Trade/yearbook/single/N2022060061?zcode=Z023

China, Southwest China, East China, and Central China. Deviation values of annual temperature and annual precipitation are calculated for each of these seven regions, by comparing them with the average values of the past 20 years. Temperature anomalies and precipitation anomalies reflect the deviations of temperature and precipitation in China from the 20-year average, revealing abnormal climate variations.

Furthermore, the agricultural area affected by natural disasters in China is categorized and statistically analyzed to identify the major types of natural disasters that significantly impact Chinese agriculture. Taking drought and flood disasters as examples, descriptive statistical analysis is employed to provide an overview of their spatial and temporal distribution characteristics and their effects on agriculture. This lays the foundation for further analysis in the subsequent sections.

3.2.2 Regression Analysis Based on Fixed Effects Model

Regression analysis using the fixed effects model is primarily employed to examine the impact of climate variations, such as precipitation and temperature, as well as the occurrence of natural disasters on agricultural production. In this section, panel data at the provincial level from 2000 to 2020 in China are utilized. Relevant variables related to climate, natural disasters, and agricultural cultivation are selected for each province. The analysis controls for fixed effects at both the provincial and time dimensions. Previous research has indicated that agricultural production is primarily influenced by human planting behaviors, such as sowing, irrigation, and fertilization. In this model, we start from the research topic and incorporate climate variation and natural disaster variables on top of the variables related to human planting behaviors. The specific model construction is as follows:

$$AP, GY = f(AA, TP, PRE, CE, SA, EI, FU, AM) \tag{1}$$

In the above equation, there are two dependent variables, namely AP and GY. AP represents the gross value of agricultural production, while GY represents the grain yield. There are a total of eight independent variables, including AA for the affected area by natural disasters, TP for temperature, PRE for precipitation, CE for carbon emission, SA for sown area, EI for effective irrigation area ratio, FU for fertilizer usage, and AM for the total power of agricultural machinery.

The linear expression of the aforementioned model is as follows:

$$\begin{aligned} LOGAP_{it}, LOGGY_{it} = a_{it} + \beta_1 LOGAA_{it} + \beta_2 LOGPRE_{it} + \beta_3 LOGCE_{it} + \beta_4 LOGTP_{it} \\ + \beta_5 LOGSA_{it} + \beta_5 LOGEI_{it} + \beta_6 LOGFU_{it} + \beta_7 LOGAM_{it} + \varepsilon_{it} + \lambda_i + \mu_t \end{aligned} \tag{2}$$

In the above equation, all variables are logarithmically transformed. The subscript "i" denotes the province, "t" represents the year, and ε_{it} denotes the random disturbance term of the model. The variables λ_i and μ_t represent the dummy variables controlling for individual and time effects, respectively, enabling a fixed effects regression.

3.2.3 Analysis based on the CGE Model

The CGE (Computable General Equilibrium) model is built upon general equilibrium theory, which describes the interrelationships among various sectors of the national economy and the national economic accounting system through equations. Under the conditions of account balance and resource constraints, economic agents can achieve behavioral optimization through price responses. Based on general equilibrium theory, the regional economy under the baseline scenario is typically assumed to be in a state of supply and demand equilibrium. However, the occurrence of exogenous shocks disrupts the equilibrium state of the regional economy under the baseline scenario and triggers ripple effects. It takes a series of adjustments for the economy to return to a new equilibrium state, and the output changes resulting from the transition from the equilibrium state under the baseline scenario to the new equilibrium state represent the impact of exogenous shocks on total output.

The construction of the CGE model under the baseline scenario involves simulating the production, consumption, employment, and other behaviors of economic agents in the form of nonlinear equations. The baseline scenario refers to the development of China's economy, society, and other aspects without any external shocks or policy interventions. Drawing on the principles and programming of computable general equilibrium models as outlined by Chang (2017), a CGE model is constructed, incorporating economic agents such as households, enterprises, and the government, and covering modules related to production, trade, and economic agent behavior.

(1) Production module

Let A denote the set of all production sectors, and C denote the set of all commodity sectors. To simplify the model, we assume that each activity sector produces only one type of product. The production function is nested into two layers. The aggregate output is represented by a CES function, which has two inputs: intermediate inputs and value-added. The relationship between total output, value-added, and intermediate inputs is expressed by Equation (3), while Equation (4) provides the first-order condition for optimizing the total output function. The prices of products produced by activity sectors are synthesized as weighted averages of the prices of intermediate inputs and value-added, as represented by Equation (5).

$$QA_a = \alpha_a^q[\delta_a^q QVA_a^{\rho_a} + (1-\delta_a^q)QINTA_a^{\rho_a}]^{1/\rho_a}, a \in A \tag{3}$$

$$\frac{PVA_a}{PINTA_a} = \frac{\delta_a^q}{1-\delta_a^q}\left(\frac{QINTA_a}{QVA_a}\right)^{(1-\rho_a)}, a \in A \tag{4}$$

$$PA_a \cdot QA_a = PVA_a \cdot QVA_a + PINTA_a \cdot QINTA_a, a \in A \tag{5}$$

In the equations, QA_a represents total output, QVA_a represents value-added, $QINT_{ca}$ represents the total quantity of intermediate inputs, $QINTA_a$ represents the quantity of intermediate input for each sector a. PA_a represents the production price, PVA_a represents the price of value-added, and $PINTA_a$ represents the price of intermediate input quantity.

The lower level consists of two components: intermediate inputs and value-added. The production function for value-added is a CES function with two inputs: labor and capital, represented by equation (6). Since land resources are not quantitatively evaluated and land use changes are not considered, the land production factor is not included here. The first-order conditions for optimizing the value-added function are given by equation (7), and the price of value-added PVA_a is a weighted average of the prices of labor and capital inputs, as shown in equation (8).

$$QVA_a = \alpha_a^{va}[\delta_{La}^{va} QLD_a^{\rho_a^{va}} + (1-\delta_{La}^{va})QKD_a^{\rho_a^{va}}]^{1/\rho_a^{va}}, a \in A \tag{6}$$

$$\frac{WL}{WK} = \frac{\delta_{La}^{va}}{1-\delta_{La}^{va}} \cdot \left(\frac{QKD_a}{QLD_a}\right)^{1-\rho_i} \tag{7}$$

$$PVA_a \cdot QVA_a = WL \cdot QLD_a + WK \cdot QKD_a, a \in A \tag{8}$$

In the above equations, QLD_a and QKD_a represent the inputs of labor and capital, respectively. WL and WK represent the price of labor and capital, respectively. α_a^q and α_a^{va} the scale parameters of the CES production functions for total output and value-added, respectively. δ_a^q and δ_{La}^{va} represent the share parameters of input factors.

The intermediate demand of each sector is described using the Leontief input-output matrix, as shown in equation (9), where ica_{ca} represents the input-output coefficient for the intermediate input component. The price of intermediate inputs is synthesized as a weighted average of commodity prices PQ_c, with weights given by ica_{ca}, as expressed in equation (10).

$$QINT_{ca} = ica_{ca} \cdot QINTA_a, a \in A, c \in C \tag{9}$$

$$PINTA_a = \sum_{c \in C} ica_{ca} \cdot PQ_c, a \in A \tag{10}$$

(2) Trade module

The allocation of domestically produced goods between domestic sales and exports is influenced by the relative levels of domestic and international prices, and their relationship is represented by the constant elasticity of transformation (CET) function. The portion of goods produced for domestic sales is denoted as QD and its price is denoted as PD, while the portion for exports is denoted as QE and its price is denoted as PE. Equations (11) and (12) provide the functional relationships and the first-order conditions for optimization. The production price of each sector is synthesized as a weighted average of the prices for domestic sales and exports, as shown in equation (12).

$$QA_a = \alpha_a^t \left[\delta_a^t QD_a^{\rho_a^t} + (1-\delta_a^t) QE_a^{\rho_a^t} \right]^{1/\rho_a^t} \quad \rho_a^t > \tag{11}$$

$$\frac{PD_a}{PE_a} = \frac{\delta_a^t}{\left(1-\delta_a^t\right)} \left(\frac{QE_a}{QD_a}\right)^{(1-\rho_a^t)}, a \in A \tag{12}$$

$$PA_a \cdot QA_a = PD_a \cdot QD_a + PE_a \cdot QE_a, a \in A \tag{13}$$

Equations (11) to (13) constitute the optimization conditions for domestic firms to choose the allocation between domestic sales and exports. The export price is influenced by the international market price and the exchange rate, where EXR represents the exchange rate and pwe_a denotes the off-shore price of the commodity measured in foreign currency units. Here, the "small country assumption" from international economics is adopted, assuming that the domestic country's actions do not affect international prices. The parameter pwe_a is exogenous, and equation (14) is given as follows:

$$PE_a = pwe_a \cdot EXR, a \in A \tag{14}$$

The goods sold in the domestic market consist of two parts: imports and domestically produced goods for domestic sales. Their relationship follows the Armington assumption, represented by the CES function. Equations (15) and (16) provide the functional relationship and the first-order conditions for optimization. The price of goods sold in the market, PQ_c, is the weighted average of the two, as shown in equation (17):

$$QQ_c = \alpha_a^q \left[\delta_a^q QD^{\rho_c^q} + (1-\delta_c^q) QM^{\rho_c^q} \right]^{1/\rho_a^q} \tag{15}$$

$$\frac{PD_c}{PM_c} = \frac{\delta_c^q}{(1-\delta_c^q)} \left(\frac{QM_c}{QD_c} \right)^{1-\rho_c^q} \tag{16}$$

$$PQ_c \cdot QQ_c = PD_c \cdot QD_c + PM_c \cdot QE_c, c \in C \tag{17}$$

The aforementioned equations (15)-(17) constitute the optimization conditions for the allocation of supply between QQ, QD, and QM according to the Armington condition, considering the PQ, PD, and PM prices in the economy. The price of imported goods, PM_c, is determined by international market prices, exchange rates, and tariffs. tm represents the tariff on imported goods, and pwm is the pre-tariff price of imported goods calculated in foreign currency, determined exogenously by the international market. The specific equation is given by equation (18) as follows:

$$PM_c = pwm_c(1+tm_c) \cdot EXR, a \in A \tag{18}$$

(3) Module of Economic entities' Behaviors

The main economic entities in the model are households, firms, and the government. The labor force is owned by households, and the total labor supply is denoted as QLS. Household income is derived from labor, capital returns, and government transfers, while household expenditures include consumption and personal income tax. Equations (19) and (20) provide the equations for household income (YH) and expenditures (EH) respectively.

$$YH = WL \cdot QLS + shif_{hk} \cdot WK \cdot QKS + transfr_{hgov} \tag{19}$$

$$EH = \sum_c PQ_c \cdot QH_c + ti_h \cdot YH \tag{20}$$

The total supply of capital is denoted as QKS. Capital income is distributed between households and firms, where $s\square if_{\square k}$ represents the share of capital income allocated to households, and $s\square if_{ent\,k}$ represents the share of capital income allocated to firms. The $transfr_{\square gov}$ represents government transfers to households.

The pre-tax income of firms, denoted as *YENT*, represents the income derived from capital inputs. The savings of firms, *ENTSAV*, are equal to their income minus the income tax. The income tax rate for firms is represented by ti_{ent}. Therefore, equations (21) and (22) provide the equations for firm income and savings.

$$YENT = shif_{entk} \cdot WK \cdot QKS \tag{21}$$

$$ENTSAV = (1 - ti_{ent}) \cdot YENT \tag{22}$$

The total investment of the economy, denoted as *EINV*, which represents capital formation, is composed of investments from various sectors. Additionally, it is assumed that investment is exogenously determined, as shown in equation (23):

$$EINV = \sum_{c} PQ_c \cdot \overline{QINV_c}, c \in C \tag{23}$$

The government's revenue mainly comes from the net production tax collected from economic activities, income tax collected from residents, income tax collected from firms, and import tariffs. Equation (24) provides the equation for government revenue.

$$YG = \sum_{a} taxp \cdot \left(WL \cdot QLD_a + WK \cdot QKD_a\right) + ti_h \cdot YH + ti_{ent} \cdot YENT + \sum_{c} tm_c \cdot pwm_c \cdot QM_c \cdot EXR \tag{24}$$

In the equation, YH represents household income, YG represents government income, QLS and QKS represent the labor and capital supply of households, WL and WK represent the prices of labor and capital, $transfr_{hgov}$ represents government transfers to households, QLD and QKD represent the labor and capital demand in production activities, $taxp$, ti_h and ti_{ent} represent the production tax rate, personal income tax rate, and corporate income tax rate, respectively, and the last term represents import tariff revenue.

Government expenditure includes government consumption on goods and transfers to households, as shown in equation (25).

$$EG = \sum_{c} PQ_c \cdot \mathrm{QG}_c + transfr_{hgov} \tag{25}$$

(4) Equilibrium Module

The system equilibrium conditions, i.e. market clearing, include the domestic market supplying goods equal to consumer demand, factor demand equal to factor supply, and balance of payments equilibrium. Equations (26)-(29) give the systemic equilibrium conditions.

$$QQ_c = \sum_{a} QINT_{ca} + \sum_{h} QH_{ch} + \overline{QINC_c} + QG_c, c \in C \tag{26}$$

$$\sum_{a} QLD_a = QL \tag{27}$$

$$\sum_{a} QKD_a = QK \tag{28}$$

$$\sum_{c} pwm_c \bullet QM_c = \sum_{a} pwe_a \bullet QE_a + FSAV \tag{29}$$

In the above equation, QQ_c is the total quantity of goods sold on the domestic market, including imports but excluding the export component; $QINT_{ca}$、QH_{ch}、$QINV_c$、QG_c represents in turn the quantity of intermediate inputs to production activities, the quantity of goods consumed by the population, and the quantity of goods consumed by investment and government; pwm_c represents the price of imports, QM_c represents the quantity of imports, pwe_a represents the price of exports, QE_a represents the quantity of exports, and $FSAV$ is the net foreign savings, which are used to ensure the foreign exchange balance of the economy.

The occurrence of natural disasters and the resulting changes in agricultural yields have external impacts on the economic system. The specificity of the agricultural production sector determines that it is inevitably the earliest and most deeply affected industry. Whether it is flood disasters or droughts, they will directly bring about changes in agricultural production. Under the influence of market mechanisms and the internal interconnections within the system, the affected scope and entities will further expand, thereby disrupting the original economic equilibrium and seeking a new equilibrium state. Compared to the original equilibrium, the new equilibrium determines changes in output, prices, income, investment levels, and other economic indicators. Comprehensive economic impact assessments often take changes in output of directly affected industry sectors as input variables and use CGE models or IO models to study the effects of disasters on output, consumption, and other economic indicators. Therefore, to further simulate the exogenous impact of natural disasters on the economic system, the quantitative coefficient of the impact of natural disasters on agricultural yields is introduced into the agricultural production function. The model equation is represented as:

$$QA_{agr}^{dis} = \left(1-\eta_{agr}^{dis}\right)QA_{agr} \tag{31}$$

$$\eta_{agr}^{dis} = \frac{\frac{\Delta AA}{AA_{t-1}} \times \beta_{aa} \times AY_t}{AY_{t-1}} \tag{32}$$

In the equation, QA_{agr}^{dis} represents the output of the agricultural sector in period t under the scenario of changes in disaster-affected areas. η_{agr}^{dis} represents the coefficient of the impact of changes in disaster-affected areas on the agricultural sector caused by natural disasters. $\frac{\Delta AA}{AA_{t-1}}$ represents the percentage change in disaster-affected crop area from the current period to the previous period. β_{aa} is the coefficient obtained from the fixed effects model, representing the impact of the logarithm of disaster-affected area on the logarithm of agricultural yield. AY_t represents the current agricultural total output, and AY_{t-1} represents the previous agricultural total output. Thus, the quantitative coefficient of the impact of natural disasters on agricultural yields is transformed into a parameter embedded in the CGE model.

4.Results

4.1Spatial and Temporal Distribution Characteristics of Climate Change and Natural Disasters in China

Due to data availability and other reasons, only provincial balanced panel data for 30 provinces in China, for a total of 21 years from 2000-2020, with a sample size of 630, were ultimately retained in this paper. The results of the descriptive statistics of the data are shown in the table 2 below.

Table 2. Descriptive Statistics of Variables.

Variable	Mean	p50	SD	Min	Max	N
LOGAP	7.300	7.453	1.095	4.060	9.229	630
LOGGY	7.033	7.254	1.201	3.393	8.938	630
LOGAA	6.385	6.847	1.591	0	8.909	630
LOGTP	2.612	2.773	0.437	1.275	3.275	630
LOGPRE	6.161	6.243	1.294	2.949	9.487	630
LOGCE	5.596	5.362	1.525	0.593	10.89	630
LOGSA	7.740	8.050	1.189	3.861	9.578	630
LOGEI	7.222	7.329	1.002	4.703	8.729	630
LOGFU	4.761	4.959	1.065	1.864	6.575	630
LOGAM	7.485	7.665	1.076	4.554	9.500	630

This table presents the average value, the median value, the standard deviation, the minimum and the maximum of the variables across the dataset, also the number of observations available for the variables.

Based on the variable data described above, the research has assessed the spatial and temporal distribution characteristics of the agricultural disaster-affected areas caused by climate change and natural disasters in China.

4.1.1 Analysis of Spatial and Temporal Characteristics of Temperature and Precipitation Changes in China

The following composite graphs have been created using the temperature and precipitation data from China Daily Surface Climate Dataset V3.0 and 372 weather stations to calculate the annual temperature and annual precipitation anomalies for seven regions in China. They display temperature and precipitation information of North, Northeast, Northwest, South, Southwest, East, and Central China. See Figure 1.

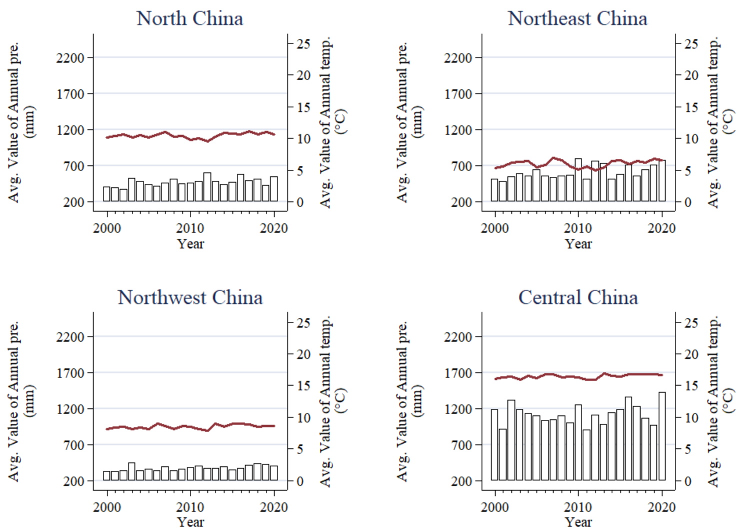


Figure 1-A. Temperature and precipitation information of North, Northeast, Northwest and Central China. The red line represents the temperature information and the column represents the precipitation information.

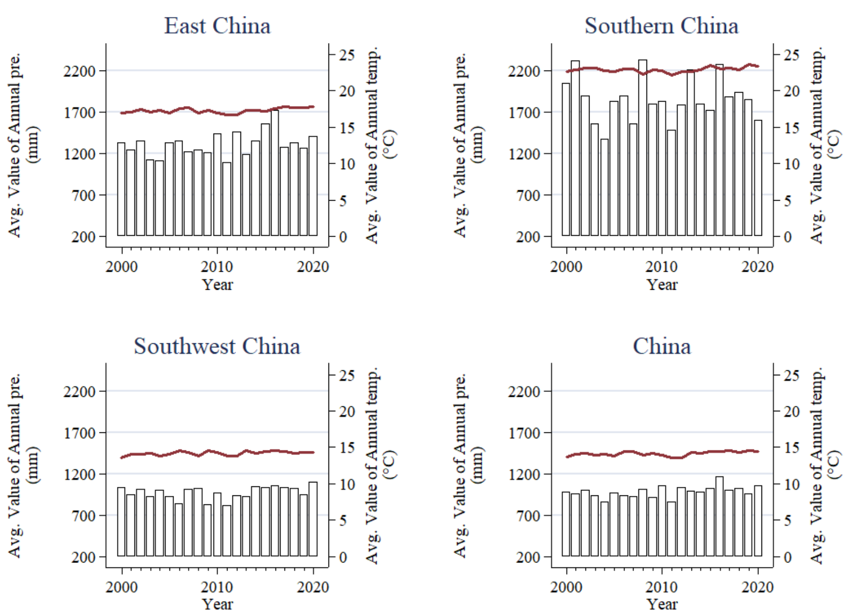


Figure 1-B. Temperature and precipitation information of East, Southern, Southwest and the whole China. The red line represents the temperature information and the column represents the precipitation information.

The deviation degree between the temperature and precipitation and the average value in recent 20 years in China can be reflected using the temperature anomalies and precipitation anomalies, thereby revealing the abnormal changes in climate. The outcomes are displayed in Figure 2 below.

As shown in the figures, all regions in China have had temperature fluctuations during the past 20 years ranging from -1°C to 1°C, and the trend of the total temperature anomaly value is comparable. From 2006 to 2007, the temperature in China was generally in a state of positive anomaly, and the climate was warmer, and the positive anomaly value ranged from 0.02°C to 0.91°C. In 2007, the national average temperature was 10.6°C, and the temperatures in Beijing, Tianjin, Shandong and Henan provinces had reached the highest level since 1951. From 2011 to 2012, the temperature in China was generally in a state of negative anomalies, and the climate was colder, with the negative anomalies ranging from -1.02°C to -0.26°C. China was experiencing abnormally cold winter during that time, with the country's average temperature dropping to its lowest level in the past 27 years. China's climate has been in an unusual warm-wet pattern since 2012, and the country's average temperature has been trending significantly higher, mostly in the northwest, north, and northeast of the country.

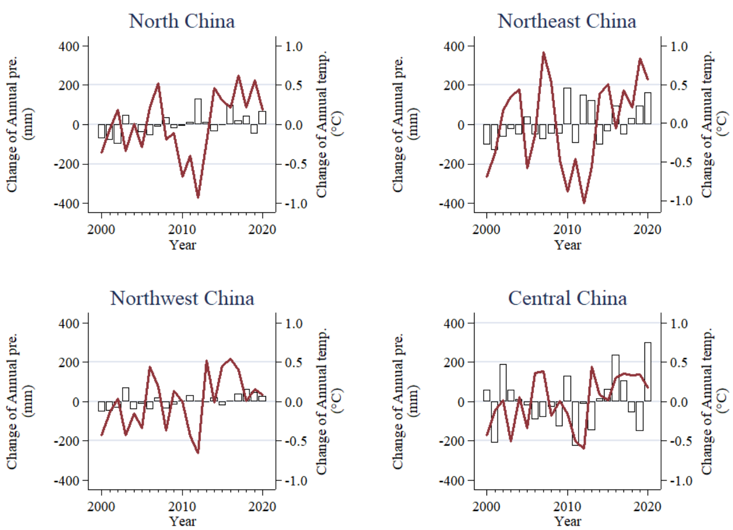


Figure 2-A. The temperature anomalies and precipitation anomalies in North, Northeast, Northwest and Central China. The red line represents the temperature anomalies and the column represents the precipitation anomalies.

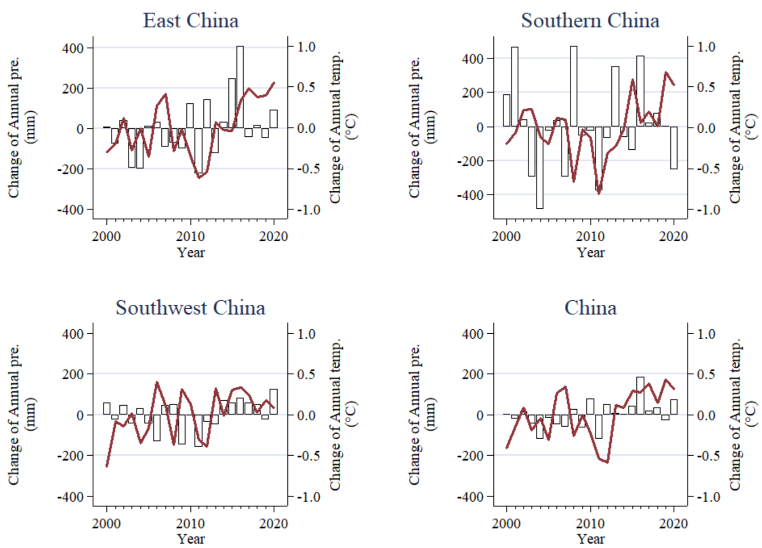


Figure 2-B. The temperature anomalies and precipitation anomalies in East, Southern, Southwest and the whole China. The red line represents the temperature anomalies and the column represents the precipitation anomalies.

The monsoon has a huge impact on China, with the majority of precipitation occurring in the summer months and a spatial distribution pattern of decreasing precipitation from the south-eastern coast to the north-western inland. In the past 20 years, South China has been vulnerable to typhoons with high precipitation anomalies. Precipitation anomalies are more common in East or Central China. North China and Northwest China are close to the interior, with lower but relatively stable annual precipitation and low precipitation anomalies. In 2016, the precipitation anomaly in all regions of China was greater than 0, with the national average precipitation reaching the highest in history, up to 729.7 mm, and the precipitation in North China, South China and Northeast China increased by more than 16%. In general, the frequency of floods in South China and Central China is significantly higher than that in other regions.

4.1.2 Types and Spatial-Temporal Distribution Characteristics of Natural Disasters in China

The natural disasters mainly include flood, drought, wind, hail, frost, insect, and disease-related catastrophes. In this paper, natural disasters that occur in China are categorized into the four main kinds as follows: drought, flood, wind, hail, and frost. To do a preliminary descriptive statistical assessment of the natural disasters in China, the following graphic is generated. The frequency of natural catastrophes in China rose in fluctuation between 1978 and 2008. Drought and flood are the two categories of natural disasters that have caused the most damage in China, with the average affected areas caused by drought over the previous 60 years making up 53.71% of the total affected areas and flood making up 24.93%. Frost is the natural disaster that has caused the least damage in China, whose affected areas account for only 7.21% of the total affected areas, whereas affected areas caused by hail account for 10.65% of the total affected areas. In 1991, when crops in the majority of the country were affected by extensive drought and flood, the affected areas in China reached the highest, reaching 55,472 thousand hectares.

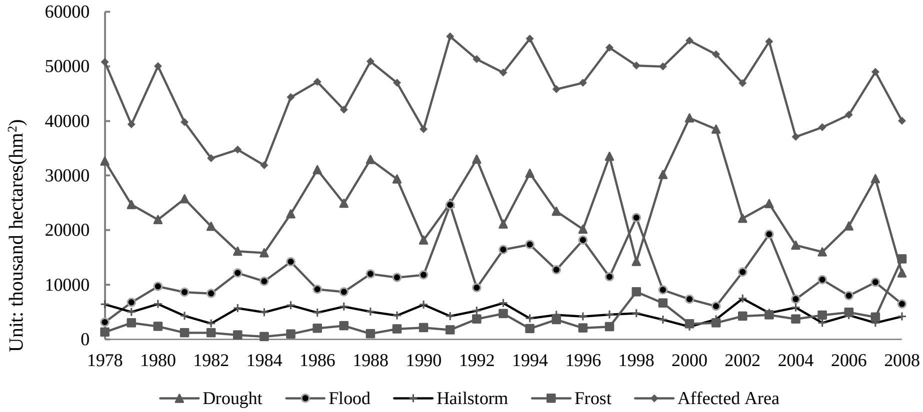


Figure 3. Affected Area and Total Affected Area of Major Meteorological Disasters in China from 1978 to 2008.

The pattern of "drought in the north and flood in the south" typically appears given that drought and flood are the two main meteorological disasters in China. Therefore, this paper presents a line chart of the drought and flood conditions in the country and conducts specific analysis based on the data of the affected and disaster areas caused by drought and flood in the statistics of the Ministry of Water Resources of People's Republic of China from 1950 to 2018.

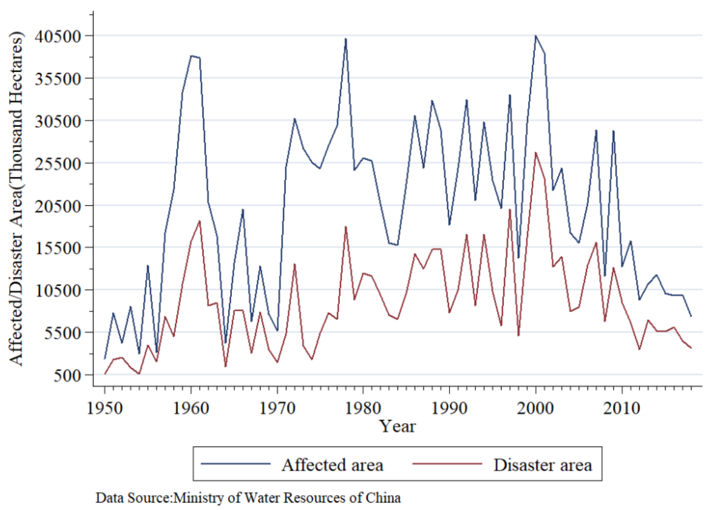


Figure 4. Occurrences of droughts in China from 1950 to 2018. The blue line represents the affected area, where crops in the field suffered 10%-30% of yield losses because of droughts, and the red line represents the disaster area where crops in the field suffered yield losses of more than 30% (including 30%) as a result of droughts.

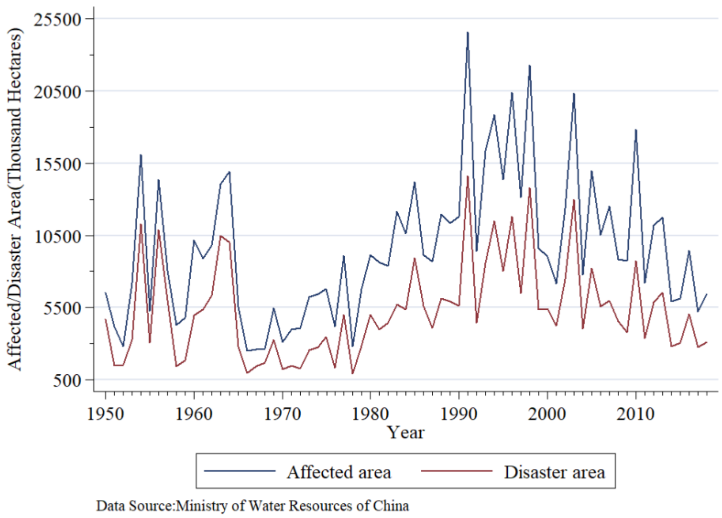


Figure 5. Occurrences of floods in China from 1950 to 2018. The blue line represents the affected area, where crops in the field suffered yield losses of 10%-30% because of floods, and the red line represents the disaster area, where crops in the field suffered yield losses of more than 30% (including 30%) as a result of floods.

Drought occurred frequently and lasted for a long time in China, according to the findings. The regional drought occurred almost every year, and mostly during the January-September period, and lasted for several months. There were three peaks in drought affected and damaged areas in China between 1950 and 2018, covering the years from 1958 to 1961, from 1978 to 1983, and from 2000 to 2003.

The Great Drought that occurred in the late 1950s and early 1960s was a severe disaster that lasted for many years. In fact, the disaster impact of this drought lasted for four years, with a total affected areas of more than 1.32 trillion square hectares and a total disaster area of more than 510 million square hectares. From 1959 to 1960, the Yellow River Basin, South China and Southwest China experienced the drought disasters mainly in summer and autumn, while from1961 to 1962, the Yellow River Basin, North China and Northeast China experienced the drought disasters mainly in spring, summer, and autumn, showing a general trend of development, peak, and decline. Beijing, Tianjin, Hebei, Henan, Shandong, and other provinces in northern China experienced a series of severe drought disasters in 1978. It was one of the few greatest droughts that lasted for six years. In 1979, autumn and winter were the main seasons when drought occurred, and in 1980, summer was the main season of drought. The total area affected by the catastrophe was 1.53 billion square hectares. Drought and a lack of water severely affected the normal life of the people. From February to July 2000, a severe drought occurred in North China, Northwest China and other regions, hampering spring ploughing and spring sowing, greatly reducing the national grain output, and causing heavy losses to the agricultural economy. The effects of the drought kept getting worse in 2001. In spring and summer, the direct economic losses to agriculture from the prolonged drought in the north of the Yangtze River exceeded 100 billion yuan. From 2002 to 2003, the drought situation eased, but was still moderately severe.

Flood disasters in China are divided into flood, waterlogging and post-waterlogging, which mainly occur in the middle and lower reaches of the Yangtze River, Yellow River, Haihe River and Huaihe River. The area affected by floods peaked in 1991, 1998 and 2003. The worst flood disaster occurred in 1991. Hubei, Jiangsu, Zhejiang, Shanghai and other provinces with an area of 246 million square hectares were severely affected by the torrential rains during the plum rain season. In 1998, terrible floods hit Jiangxi, Hunan, Hubei and other provinces, affecting a wide range of areas. The affected area of farmland reached 222 million square hectares. In 2003, Huaihe River Basin and the middle reaches of the Yellow River experienced a historically severe flood, resulting in a direct economic loss of 130.3 trillion yuan, exceeding the average flood disaster level since the 1990s.

4.2 Empirical Regression Analysis of the Impact of Climate Change and Natural Disasters on Agricultural Production

This paper further conducted an empirical analysis of the impacts of climate change and natural disasters on agricultural production, and obtained the empirical regression results as shown in the following table. This analysis was based on the fixed effects model built above and the analysis of the temporal and spatial characteristics of the impacts of climate change and natural disasters on agriculture. The overall degree of explanation of the explained variables was high for each explanatory variable, as can be observed from the regression results and test results in the table.

Table 3 shows the regressions with the gross value of agricultural production (LOGAP) as the explanatory variable. First of all, the climate change index shows that temperature has no discernible effect on the gross value of agricultural production, while OLS regression and the random effect model show that precipitation has a significantly positive impact, indicating that an increase in precipitation is favorable for the gross output of agricultural production and can significantly increase the total output value of agriculture. The three regression models show that carbon emissions are highly significant, because the agricultural sector is an important carbon sink as well as a source of greenhouse gas emissions. The increase in total carbon emissions has a positive contribution to the increase in China’s gross value of agricultural production.

Table 3. Gross Value of Agricultural Production (LOGAP) and Natural Disasters.

	(1)	(2)	(3)	(4)	(5)	(6)
Variables	OLS	OLS_R	FE	FE_R	RE	RE_R
LOGAA	-0.135***	-0.135***	-0.020***	-0.020	-0.147***	-0.147***
	(-7.34)	(-6.16)	(-2.68)	(-1.52)	(-11.05)	(-5.66)
LOGTP	-0.038	-0.038	0.008	0.008	0.022	0.022
	(-0.60)	(-0.67)	(0.06)	(0.04)	(0.17)	(0.16)
LOGPRE	0.084***	0.084***	0.000	0.000	0.143***	0.143***
	(4.43)	(5.11)	(0.01)	(0.01)	(3.43)	(2.89)
LOGCE	0.163***	0.163***	0.094***	0.094***	0.144***	0.144***
	(12.66)	(12.58)	(6.96)	(3.22)	(16.16)	(8.30)
LOGSA	-0.174***	-0.174***	-0.015	-0.015	-0.386***	-0.386***
	(-3.72)	(-3.70)	(-0.44)	(-0.19)	(-6.33)	(-2.84)
LOGEI	-0.035	-0.035	0.292***	0.292**	0.025	0.025
	(-0.63)	(-0.78)	(5.91)	(2.13)	(0.30)	(0.13)
LOGFU	0.761***	0.761***	0.317***	0.317*	0.645***	0.645***
	(11.79)	(13.52)	(6.86)	(2.00)	(8.21)	(3.84)
LOGAM	0.394***	0.394***	0.245***	0.245***	0.803***	0.803***
	(9.07)	(9.43)	(8.03)	(2.88)	(15.66)	(5.24)
Constant	1.866***	1.866***	1.537***	1.537*	0.220	0.220
	(6.40)	(7.37)	(3.03)	(1.79)	(0.43)	(0.24)
Observations	630	630	630	630	630	630
R-squared	0.876	0.876	0.991	0.991		

Time Effect	NO	NO	YES	YES	NO	NO
Province Effect	NO	NO	YES	YES	NO	NO
Number of id					30	30
chi-squared					366.714	
p-value for the chi-squared					0.000	

This table presents the results of OLS regression, fixed effect regression and random effect regression, and reports the regression results under the robust standard error. In the fixed effects regression, dual fixed effects controlling for province and time are used. Gross value of agricultural production (LOGAP) is the explained factor. The t-statistics are in parentheses, * denotes statistical significance at 10% level, ** at 5% level, and *** at 1%.

An increase in sown area may not always lead to an increase in the gross value of agricultural production, which may be due to other factors such as inadequate agricultural breeding technology. The influence of sown area on the gross value of agricultural production is significantly negative in the OLS regression and the random effects model, among the three indicators of human planting behavior. The coefficient results for the effective irrigated area ratio were significantly positive in the fixed effects model, indicating that the increase in the effective irrigated area of agriculture can guarantee the normal irrigation of China's agriculture, resist drought and thus increase the gross output value of agricultural production. As for the amount of fertilizer application, which illustrates the soil nutrients of cultivated land, if the coefficient is positive, it suggests that increasing the amount of fertilizer application is helpful to improving the gross value of agricultural production. In the regression results of the three models, the total power of agricultural machinery is significantly positive, showing that as major planting machinery, an increase in total power of agricultural machinery is beneficial for increasing the value of agricultural production.

Table 4 takes the total grain yield (LOGGY) as the regression of the explained variable. Among the indicators of climate change, the influence of temperature on total grain yield is significant only in OLS regression and the fixed-effect model, but the positive and negative coefficients are the opposite. The outcomes of fixed-effect model are more convincing in light of the substantial disparities between the provinces. The influence of temperature on total grain yield is considerably positive in the fixed effects model, showing that an increase in average temperature was beneficial to grain crops' capability to photosynthesise and an increase in total grain production. The three models all indicate significant beneficial effects of precipitation, showing that the increase in precipitation helps to meet the water needs of crops, which positively contributes to our agricultural production, thereby increasing our total grain yield. In OLS regression and the random effects model, the impact of carbon emissions on total grain yield is likewise shown to be significantly positive. Increased carbon emissions help local food crops to synthesize nutrients and increase total grain yield.

Table 4. Total Grain Yield (LOGGY) and Natural Disasters.

Variables	(1) OLS	(2) OLS_R	(3) FE	(4) FE_R	(5) RE	(6) RE_R
LOGAA	-0.075***	-0.075***	-0.027***	-0.027***	-0.049***	-0.049***
	(-10.86)	(-11.46)	(-6.52)	(-4.51)	(-11.66)	(-6.10)
LOGTP	-0.113***	-0.113***	0.131*	0.131	-0.019	-0.019
	(-4.85)	(-3.56)	(1.76)	(1.24)	(-0.38)	(-0.49)
LOGPRE	0.051***	0.051***	0.101***	0.101***	0.074***	0.074***
	(7.21)	(6.31)	(5.36)	(4.93)	(4.76)	(3.35)
LOGCE	0.022***	0.022***	0.011	0.011	0.028***	0.028***
	(4.52)	(4.63)	(1.41)	(0.64)	(9.79)	(5.04)
LOGSA	0.812***	0.812***	1.006***	1.006***	0.895***	0.895***
	(46.41)	(52.50)	(51.69)	(24.46)	(43.75)	(22.39)

LOGEI	0.262***	0.262***	0.091***	0.091	0.027	0.027
	(12.38)	(10.85)	(3.33)	(1.15)	(0.98)	(0.35)
LOGFU	0.152***	0.152***	0.210***	0.210***	0.241***	0.241***
	(6.29)	(5.22)	(8.22)	(3.58)	(9.40)	(3.64)
LOGAM	-0.091***	-0.091***	-0.123***	-0.123***	0.002	0.002
	(-5.62)	(-6.29)	(-7.26)	(-3.27)	(0.12)	(0.05)
Constant	-0.846***	-0.846***	-2.341***	-2.341***	-1.493***	-1.493***
	(-7.75)	(-6.42)	(-8.36)	(-6.29)	(-7.51)	(-3.08)
Observations	630	630	630	630	630	630
R-squared	0.986	0.986	0.998	0.998		
Time Effect	NO	NO	YES	YES	NO	NO
Province Effect	NO	NO	YES	YES	NO	NO
Number of id					30	30
chi-squared					181.438	
p-value for the chi-squared					0.000	

This table presents the results of OLS regression, fixed effect regression and random effect regression, and reports the regression results under the robust standard error. In the fixed effects regression, dual fixed effects controlling for province and time are used. Total grain yield (LOGGY) is the explained factor. The t-statistics are in parentheses, * denotes statistical significance at 10% level, ** at 5% level, and *** at 1%.

The increase in sown area, an important observable indicator of human cultivation behaviour, has contributed to an increase in total grain yield, thanks to the strong development of large-scale mechanized crop planting technology. Only in the OLS regression and the fixed effects model did the effective irrigated area ratio reveal a significant positive trend, showing that an increase in this ratio might ensure the basic water needs of food crops and promote an increase in total grain yields. The three models have shown a strong correlation between the fertilizer application rate per unit area and grains, suggesting that the increase in fertilizer application rate per unit area will provide food crops with the nutrients they need to grow, ensuring normal growth and increasing the total yield of food crops. According to OLS regression and the fixed effects model, the total power of agricultural machinery can improve grain yields, showing how the increase in agricultural machinery power can greatly increase grain yields.

The most important explanatory variable in this study is the area affected by natural disasters (LOGAA), which significantly lowers the gross value of agricultural production (LOGAP) and total grain yields (LOGGY) with coefficients of -0.020 and -0.027, respectively. This result suggests that there is a negative relationship between the frequency of natural disasters and the output value of agriculture. The gross value of agricultural production and grain yields will all drastically decrease as the area affected by natural disasters increases.

4.3 Analysis of the Impact of Agricultural Output Changes on the Macroeconomy

4.3.1 Changes in Macroeconomic Variables

In this study, the quantitative effect coefficients of natural disasters on agricultural output are incorporated into the constructed CGE model. Changes in the parameters of the agricultural production function imply variations in agricultural production efficiency, leading to changes in agricultural output. Then, the indirect macroeconomic effects of changes in agricultural output resulting from variations in disaster-affected areas are assessed through the economic principles included in the CGE model, such as price mechanisms and supply-demand relationships.

With the improvement of economic development, the construction of agricultural infrastructure in China has been strengthened. These include the increased use of agricultural machinery, the expansion of rural electricity facilities, the enhancement of water resources infrastructure, and the improvement of agricultural cultivation techniques. From 2011 to 2021, the average disaster-affected area of crops significantly decreased by 49.5% compared to the period of 2000 to 2010, as indicated in Table 6. Consequently, the reduction in disaster-affected areas resulted in an annual avoidance of nearly 3% of agricultural production losses.

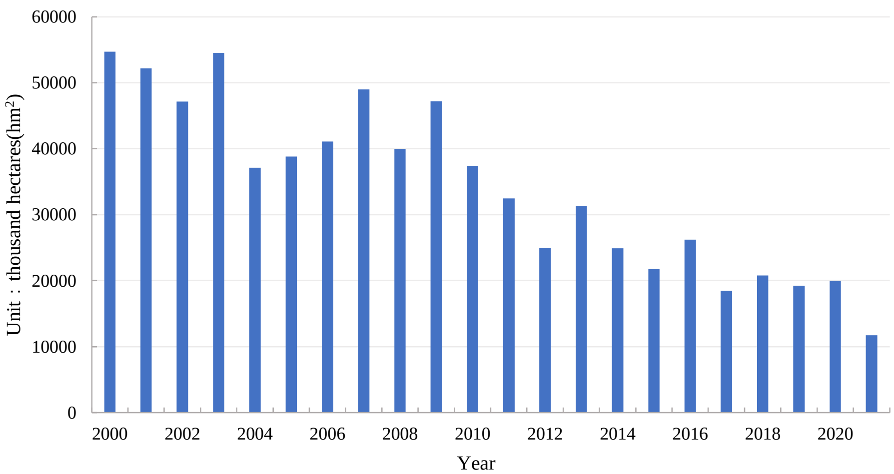


Figure 6. Disaster-affected area of crops in China from 2000 to 2020.

Therefore, an increase of 3% as well as additional possibilities of 6% and 9% in agricultural output would have the following corresponding effects on the macroeconomy, as shown in the presented Table 5.

Table 5. The Impact of Agricultural Output Growth on the Macroeconomy (Unit: %)

	Change rate of η_{agr}^{dis} =3%	Change rate of η_{agr}^{dis} =6%	Change rate of η_{agr}^{dis} =9%
GDP	0.547	1.05	1.303
Total Investment	0.22	0.35	0.476
Total Consumption	0.483	0.607	0.712
Total Trade Volume	0.681	0.968	1.139
Household Income	0.64	0.763	1.051
Household Consumption	0.421	0.553	0.705
Household Savings	0.241	0.34	0.369
Enterprise Income	0.534	0.908	1.124
Enterprise Savings	0.308	0.534	0.780
Government Revenue	0.412	0.662	0.828
Government Consumption	0.384	0.507	0.623

Total Imports	0.779	1.13	1.33
Total Exports	0.591	0.838	0.967

Based on the simulation results, it can be observed that, in the past 10 years, due to the decline in the area affected by agricultural disasters, agricultural output has avoided losses of 3 per cent per year on average, and in the scenario of a 3 per cent increase in agricultural output, all macro indicators have shown a certain degree of rise. Residents' income increased by 0.64 per cent. Currently, China still has nearly 40 per cent of the agricultural population, so the decline in the area affected by the agricultural disaster and the increase in production will first bring about an increase in farmers' income, which in turn will play a certain role in promoting the growth of residents' income, with the growth rate being more obvious. Consequently, household consumption and savings show growth rates of 0.421% and 0.241%, respectively. Additionally, due to inter-industry linkages, the increase in agricultural output stimulates production through direct and indirect consumption, resulting in higher returns to capital, leading to an increase in business income and savings of 0.534% and 0.308%, respectively. The simulation also reveals a significant increase in the import volume of various commodities, with the total export volume increasing by 0.779%. From the export perspective, the improvement in agricultural output leads to an overall increase in export volume by 0.591%. These simulation results, from another perspective, validate the research findings of Gassterbner (2010), that is avoiding or mitigating the losses caused by natural disasters and ensuring steady growth in agricultural output led to an increase in both imports and exports. According to the simulation results, the increase in agricultural output leads to a growth of 0.22% and 0.483% in total investment and total consumption, respectively. The total volume of imported and exported goods shows the fastest growth rate, increasing by 0.681%. Currently, China has become the world's largest importer and the third-largest exporter of agricultural products; thus, the increase in agricultural output inevitably contributes to the further growth of total imports and exports. Although the contribution of increased agricultural output to the Gross Domestic Product (GDP) is limited, with a growth rate of 0.547%, the absolute growth value is still noteworthy based on China's huge economic volume.

To explore future wide-ranging uncertainties and elucidate the potential macroeconomic impacts of further mitigating the effects of natural disasters on agricultural production, we have established two additional scenarios based on disaster impact coefficients and conducted corresponding predictive analyses. When agricultural output increases to 6% and 9%, China's GDP is projected to rise by 1.05% and 1.303%, respectively. As agriculture serves as a foundational industry, the increase in agricultural sector output and the subsequent decrease in agricultural product prices will have significant effects on household income and consumption. Consequently, household income is expected to increase by 0.763% and 1.051%, while household consumption is projected to grow by 0.553% and 0.705%. These will notably enhance consumer welfare and effectively alleviate the living difficulties of poverty-stricken individuals. Moreover, with increased agricultural production and higher household consumption, demand will stimulate production, leading to increased final output in various industrial sectors. Enterprise Income is expected to rise by 0.908% and 1.124%. On top of the agricultural sector, other industrial sectors will experience an increase in production tax revenue, resulting in an increase in government revenue of 0.662% and 0.828%. Simultaneously, both business savings and government expenditure are expected to increase correspondingly. Therefore, it is important for the government to formulate favorable policies and implement robust measures to effectively prevent the occurrence of natural disasters and ensure effective post-disaster recovery efforts, thereby reducing future disaster.

4.3.2 Changes in Production Sectors

Examining the specific production sectors, we can observe the impact of increased agricultural output on each sector can be observed. Taking a 3% increase in agricultural output as an example, the simulation results indicate that almost all industries experience growth in intermediate inputs and total outputs (Table 6).

Table 6. Growth in Intermediate Inputs and Total Outputs. (Unit: %)

	Total output	Intermediate input
Agriculture, forestry, animal husbandry, and fishery products and services	1.121	0.667
Petroleum, coke, nuclear fuel processing products, and chemical products	1.037	0.53
Food and tobacco	0.730	0.433
Machinery equipment, transportation equipment, electronics and electrical equipment, and other equipment	0.31	0.01
Other services	0.304	0.06
Transportation, warehousing, and postal services	0.288	0.431
Wholesale and retail	0.267	0.02
Finance and real estate	0.247	0.05
Mining products	0.233	0.06
Production and supply of electricity, heat, gas, and water	0.188	0.01
Metal smelting, processing, and products	0.121	0.046
Wood processing, furniture, paper printing, and cultural, educational, and sports goods	0.067	0.03
Textile, clothing, footwear, hats, and leather down products	0.04	0.027
Information transmission, software, and information technology services	0.04	0.014
Non-metallic mineral products	0.027	0.017
Other manufacturing products and repair services	0.015	0.006
Construction	0.009	0
Research and Experimental Development	0	0

From Figure 7 below, it can be observed that the industry most affected by the increase in agricultural output is the agricultural production itself. Due to the close correlation between inputs and outputs within the agriculture sector, it is more sensitive to changes in agricultural output. The growth in agricultural output will drive an additional increase of 0.667% in intermediate inputs and 1.121% in total output in this sector. The next significant impact is observed in the petroleum, coke, nuclear fuel processing, and chemical products industry, where an increase in agricultural output leads to a rise of 0.53% in intermediate inputs and 1.037% in total output. This is because of the supply chain relationship between the petroleum, coke, nuclear fuel processing, and chemical products industry and agriculture. The agricultural production process requires a significant amount of chemical fertilizers, pesticides, and other products, thus the growth in agricultural output stimulates the demand for intermediate inputs and final products in this industry, resulting in increased output.

The next five industry sectors most affected by the increase in agricultural output are, in descending order, food and tobacco, machinery and equipment, transportation equipment, electronics, electrical, and other equipment, other services, and transportation, warehousing, and postal services, wholesale and retail. The total output of above-mentioned 5 industries are projected to grow by 0.73%, 0.31%, 0.304%, 0.288%, and 0.267%, respectively. As agricultural output increases, consumer demand for agricultural products rises, leading to increased output in industries directly related to the processing of agricultural products, such as food and tobacco, wholesale and retail. As for other industries, their relatively smaller sensitivity to agricultural output increase may be due to their lower association with agriculture or their position further down the supply chain. Significant differences in the impact of agricultural output on different industries' output are attributed to factors such as industry interconnections, supply chain effects, and changes in consumer demand. These mechanisms interact and collectively influence output changes in various industries.

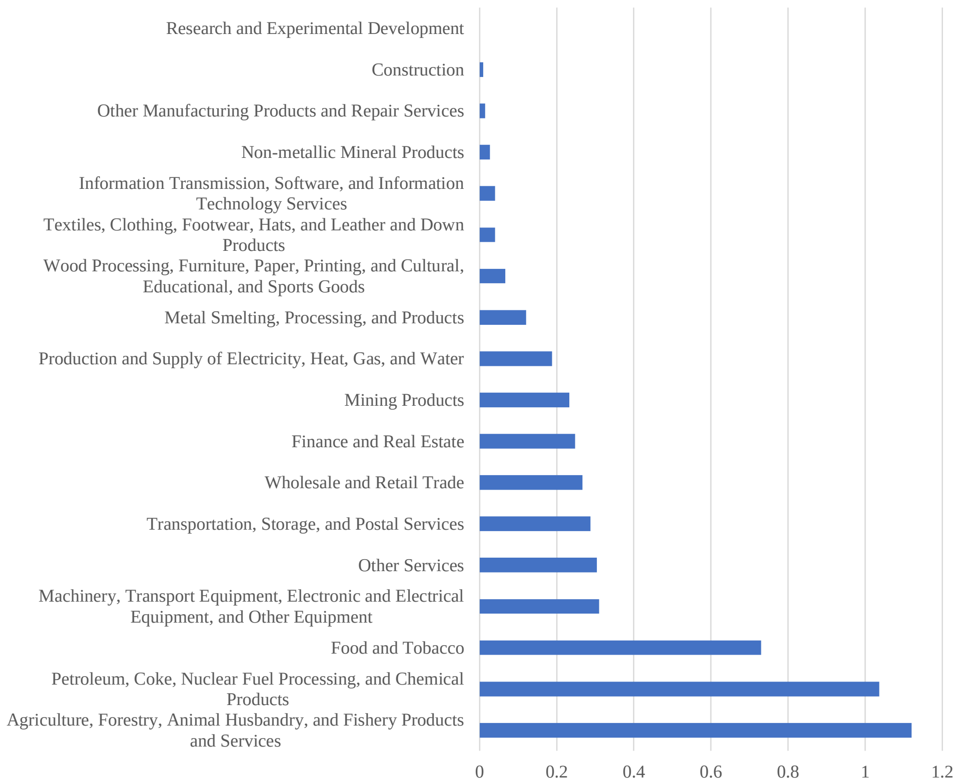


Figure 7. The impact of increased agricultural output on each sector’s total outputs. Taking a 3% increase in agricultural output as an example.

4.3.3 Sensitivity Analysis of Elasticity Parameters

This study quantitatively assessed the impact of changes in agricultural output on China's macroeconomy using a CGE model. However, there are still some uncertainties in the model. In the CGE model, the setting of elasticity parameters significantly influences the robustness of the simulation results. To ensure the robustness of the results obtained from this CGE model, sensitivity tests were conducted on the total output elasticity parameter (ρ^a), import substitution elasticity parameter (ρ^q), and export substitution elasticity parameter (ρ^t). Following the approach of MAH-MOOD et al., the above elasticity parameters were expanded and reduced by 10% from their baseline values, and the simulation results are presented in the following Table 7.

Table 7. Sensitivity Analysis of Elasticity Parameters

Changes in ρ^a	**-10%**	**0**	**10%**
Gross Domestic Product (GDP)	0.522	0.547	0.523
Total investment	0.224	0.22	0.197
Household income	0.614	0.64	0.643
Household consumption	0.41	0.421	0.427
Firm income	0.525	0.534	0.536
Government revenue	0.449	0.412	0.463
Changes in ρ^q	**-10%**	**0**	**10%**
Gross Domestic Product (GDP)	0.525	0.547	0.557
Total investment	0.224	0.22	0.22
Household income	0.644	0.64	0.68
Household consumption	0.411	0.421	0.45
Firm income	0.546	0.534	0.51
Government revenue	0.414	0.412	0.423
Changes in ρ^t	**-10%**	**0**	**10%**
Gross Domestic Product (GDP)	0.546	0.547	0.548
Total investment	0.22	0.22	0.22
Household income	0.64	0.64	0.64
Household consumption	0.42	0.421	0.421
Firm income	0.534	0.534	0.534
Government revenue	0.412	0.412	0.412

From the Table 7 above, it can be observed that variations in the total output elasticity parameter (ρ^a), import substitution elasticity parameter (ρ^q), and export substitution elasticity parameter (ρ^t) do not affect the direction of the macroeconomic variables' changes; they only have a slight impact on the numerical values. Among the three parameters, changes in ρ^a have a relatively larger impact on the numerical values, while changes in ρ^t have almost no effect on the values. As ρ^a increases, the magnitude of GDP growth decreases appropriately. When ρ^a is increased by 10% from its baseline value, the change in GDP growth rate is 4%. Among all macroeconomic variables, government revenue shows the largest variation, reaching 12.3%, while the changes in other indicators remain within 10%. Regarding ρ^q, changes in household consumption growth and GDP growth have relatively larger magnitudes, with changes of 6.9% and 4.2%, respectively, while the changes in other variables are within 5%. Based on this, it can be concluded that the total output elasticity parameter (ρ^a), import substitution elasticity parameter (ρ^q), and export substitution elasticity parameter (ρ^t) have all passed the sensitivity analysis.

5 Conclusion and Discussions

5.1 Conclusion

This study conducted an analysis of the spatial and temporal distribution characteristics of climate change and the impacts of natural disasters on agricultural production in China. The analysis utilized comprehensive data on temperature, precipitation, drought and flood affected areas, and disaster areas. To assess the negative effects of natural disasters on agricultural production, a fixed effects model was employed, and regression analysis was conducted. The findings obtained from the regression analysis were then utilized to simulate the macroeconomic consequences of reducing disaster-affected areas on agricultural output using a CGE model.

The study revealed that China exhibits a distinct pattern of "drought in the north and flood in the south" in terms of natural disaster distribution, with drought and flooding being the primary types of natural disasters observed. Drought disasters occur frequently and often persist for extended durations. On the other hand, flooding disasters predominantly occur in the middle and lower reaches of major rivers such as the Yangtze, the Yellow, the Haihe, and the Huaihe. While temperature and precipitation changes demonstrate relative stability across regions, certain areas experience frequent deviations from normal precipitation patterns.

It is important to note that the increase in sown area does not necessarily result in a proportional increase in the total output value of the agriculture, forestry, animal husbandry, and fishery sectors. Several factors, including immature agricultural and farming technologies, as well as the recurrence of natural disasters, can impact overall output. However, improvements in effective irrigation areas and increased fertilizer usage have the potential to ensure normal irrigation practices and aid in mitigating droughts, thereby fostering an increase in the total output value of the agriculture, forestry, animal husbandry, and fishery sectors.

Furthermore, investments made in China's agricultural infrastructure, such as the expanded utilization of agricultural machinery, rural electricity facilities, water resource infrastructure, and enhanced agricultural cultivation techniques, have contributed to a reduction in disaster-affected agricultural areas. Consequently, agricultural output has managed to avoid annual losses of nearly 3% owing to the decline in affected areas caused by natural disasters.

5.2 Discussion

5.2.1 Research Method Discussion

A necessary discussion on the methods employed in this study is warranted. Firstly, the CGE model constructed in this study is a comparative static model, which does not allow for intertemporal analysis and has limited capacity to provide comprehensive information on disasters. In reality, the impacts of climate change and major disasters on the economy often manifest over the long term. In future research, we intend to construct a dynamic CGE model to evaluate the effects of climate change and disaster occurrences from a dynamic intertemporal perspective.

Secondly, in setting the value-added function within the CGE model, only labor and capital factors were considered, while land input was disregarded. However, land resources are important scarce resources, and land rent constitutes a significant component of production costs. Thus, the exclusion of land input may have some influence on the research outcomes. Nevertheless, incorporating land input into CGE models is a complex and challenging task, involving quantitative assessment of land resources and simulation of land use changes. This is one of the directions for future model improvement.

Lastly, the assumption of optimal behavior by economic agents and the elasticity settings in the model equations often lead to extreme fluctuations in prices and quantities, potentially underestimating the comprehensive impact of disasters on the economy due to limitations in data availability and other factors. Parameters used in this study, such as the CES substitution elasticity between different sector products and the CET substitution elasticity, mostly drew from previous scholars. In the future, alternative methods could be explored to obtain parameter values that better align with real-world economic characteristics, thereby improving the accuracy of the assessment. Despite these limitations, relative to input-output models that fail to reflect substitution relationships among variables resulting from various price changes or incorporate many important national economic accounting variables, and only represent partial equilibrium of the production process, the CGE model employed in this study achieves global equilibrium that encompasses both supply and demand in an economic sense. Therefore, the simulation results in exploring the effects of climate change-induced agricultural production variations on the macroeconomy provide valuable insights.

5.2.2 Discussion of Research Findings

The aforementioned research findings demonstrate that under the backdrop of climate change, agricultural areas affected by natural disasters have a clear negative impact on agricultural output and production. Conversely, a decrease in the affected agricultural areas leads to an increase in agricultural production, thereby generating positive effects on the macroeconomy and various industry sectors. In the long run, effectively reducing the affected agricultural areas will contribute to national food security and social stability. Therefore, this study further discusses possible mitigation policies.

Establishing a comprehensive mechanism for climate change prevention and protection to minimize the affected areas is crucial. In China, the affected areas are primarily concentrated in the North China and Northeast regions, with drought accounting for a significant proportion of the total affected area from natural disasters. Therefore, improving climate system monitoring and diagnostic technologies and enhancing climate warning mechanisms in agricultural areas are essential. Specifically, considering the climate characteristics of "drought in the north and floods in the south" in China, particular emphasis should be placed on detecting and monitoring three major climate disasters: drought, floods, and typhoons during the spring-summer, summer-autumn, and spring-summer-autumn periods. The climate system, as a pioneer in monitoring climate change, can predict and diagnose various types of natural disasters before their occurrence. The government should prioritize the development and improvement of climate monitoring systems, enhance the sophistication of equipment, and focus on improving the technical expertise of personnel to enhance the capacity for monitoring and diagnosing disaster changes.

Strengthening the development of agricultural technology and improving agricultural infrastructure and supporting facilities are vital. Studies have shown that increased use of fertilizers, expanded areas of effective irrigation, and greater agricultural machinery power significantly contribute to the increase in agricultural output. Therefore, enhancing agricultural technology to mitigate the impact of disasters is essential, particularly through the development of scientific irrigation and fertilizer application techniques. Additionally, governments should vigorously promote the use of rural machinery and implement large-scale mechanized farming to reduce unit agricultural production costs. Simultaneously, emphasis should be placed on the construction of agricultural production infrastructure, with a focus on quality management in engineering projects. Agricultural production infrastructure encompasses various machinery and equipment that serve agricultural production, including water conservancy irrigation, flood control, and agricultural machinery facilities. Increasing investment in rural electricity and water facilities helps mitigate the loss of agricultural output resulting from decreased affected areas. To better cope with future climate change, attention should be given to facility maintenance and repair, timely quality control, and maximizing the efficiency of existing facilities to minimize the affected areas during natural disasters.

Establishing a comprehensive government-led response and safeguard mechanism for meteorological disaster reduction and prevention is crucial. Meteorological disasters not only affect agricultural production but also have a significant impact on the overall level of the Chinese economy, extending beyond the agricultural sector to nearly all industries. Therefore, it is essential to establish a government-led comprehensive response and safeguard mechanism for meteorological disaster reduction and prevention. Although the occurrence of natural disasters cannot be avoided, timely and accurate rescue and recovery measures need to be taken by the government as crisis responders. All stakeholders, including various industry entities, should adapt to climate change through various means, including disaster insurance, early warning systems, strategic reserves, and modern technologies.

The qualitative mitigation policies discussed above are only provided in this study. In fact, the CGE model itself can simulate various mitigation strategies. Therefore, a more in-depth exploration of the aforementioned mitigation policies and the selection of appropriate proxy variables as exogenous variables in the CGE model for quantitative evaluation of their effectiveness is an important direction for future research.

Author Contributions

SY and MZ contributed to the study conception and design. Material preparation, data collection was performed by MZ, LZ, HZ and XP, Analysis was performed by MZ, XP and JZ. MZ, SY, HZ, LZ and YD contributed to the discussion. MZ and HZ, XP prepared the original draft. SY, LZ, JZ and YD edited and reviewed the manuscript. All authors commented on previous versions of the manuscript. All authors read and approved the final manuscript.

Author statement

This manuscript has not been previously published and is not currently in press, under review, or being considered for publication by another journal. All authors have read and approved the manuscript being submitted, and agree to submit to this journal.

Data Availability Statement

The data used in this manuscript is publicly available. Further information is provided in the manuscript methods section.

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Supplementary Material

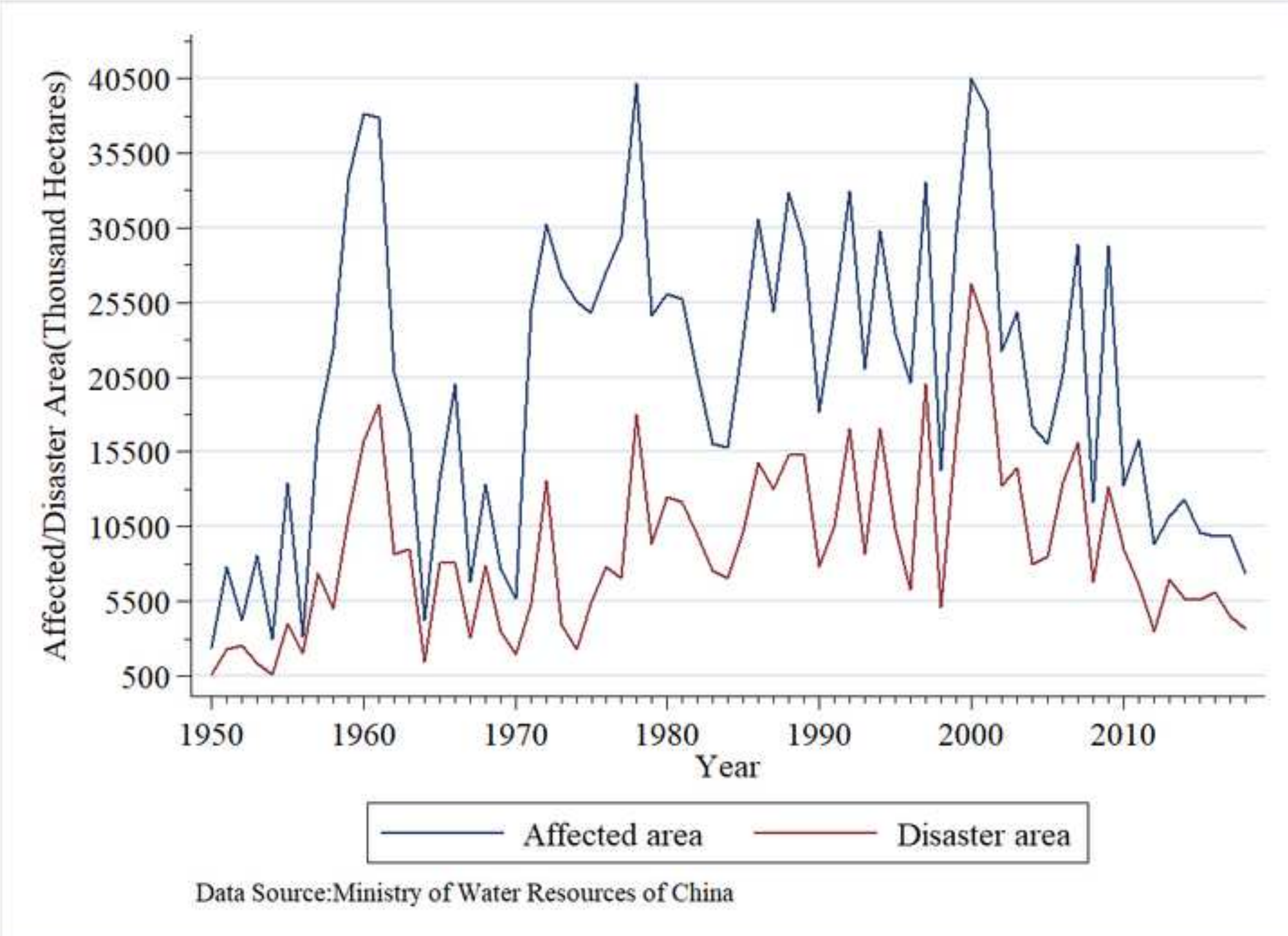
Supplementary Table 1. 2017 Social Accounting Matrix for China (Unit: Billion RMB)

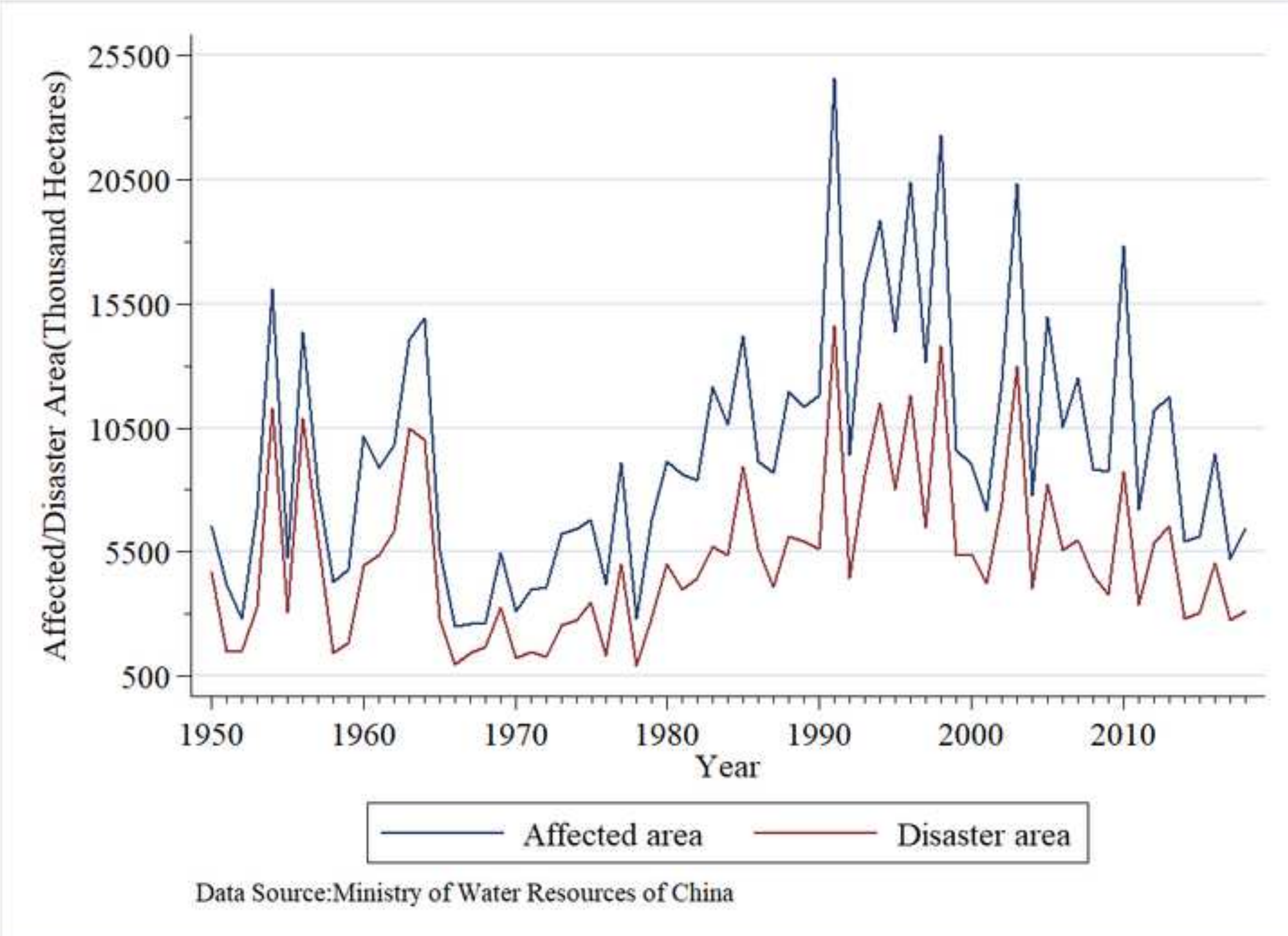
	Activity	Commodity	Capital	Labor	Households	Enterprises	Government	production taxes	Tariffs	Savings/ investment	Row	Aggregation
Activity		2093886.71									163846.82	2257733.53
Commodity	1434517.82				320426.69		123750.31			364460.27		2243155.09
Capital	304969.07											304969.07
Labor	423268.03											423268.03
Households			30627.80	423268.03		29899.68	29710.27				-548.62	512957.16
Enterprises			277640.55									277640.55
Government					11966.37	32117.29		94978.60	12501.26		-204.76	151358.77
production taxes	94978.60											94978.60
Tariffs		12501.26										12501.26
Savings/ investment					180564.10	215623.59	-2711.93				-29015.50	364460.27
Row		136767.12	-3299.28				610.11					134077.95
Aggregation	2257733.53	2243155.09	304969.07	423268.03	512957.16	277640.55	151358.77	94978.60	12501.26	364460.27	134077.95	

Supplementary Table 2. The setting of elasticity coefficients in CGE model.

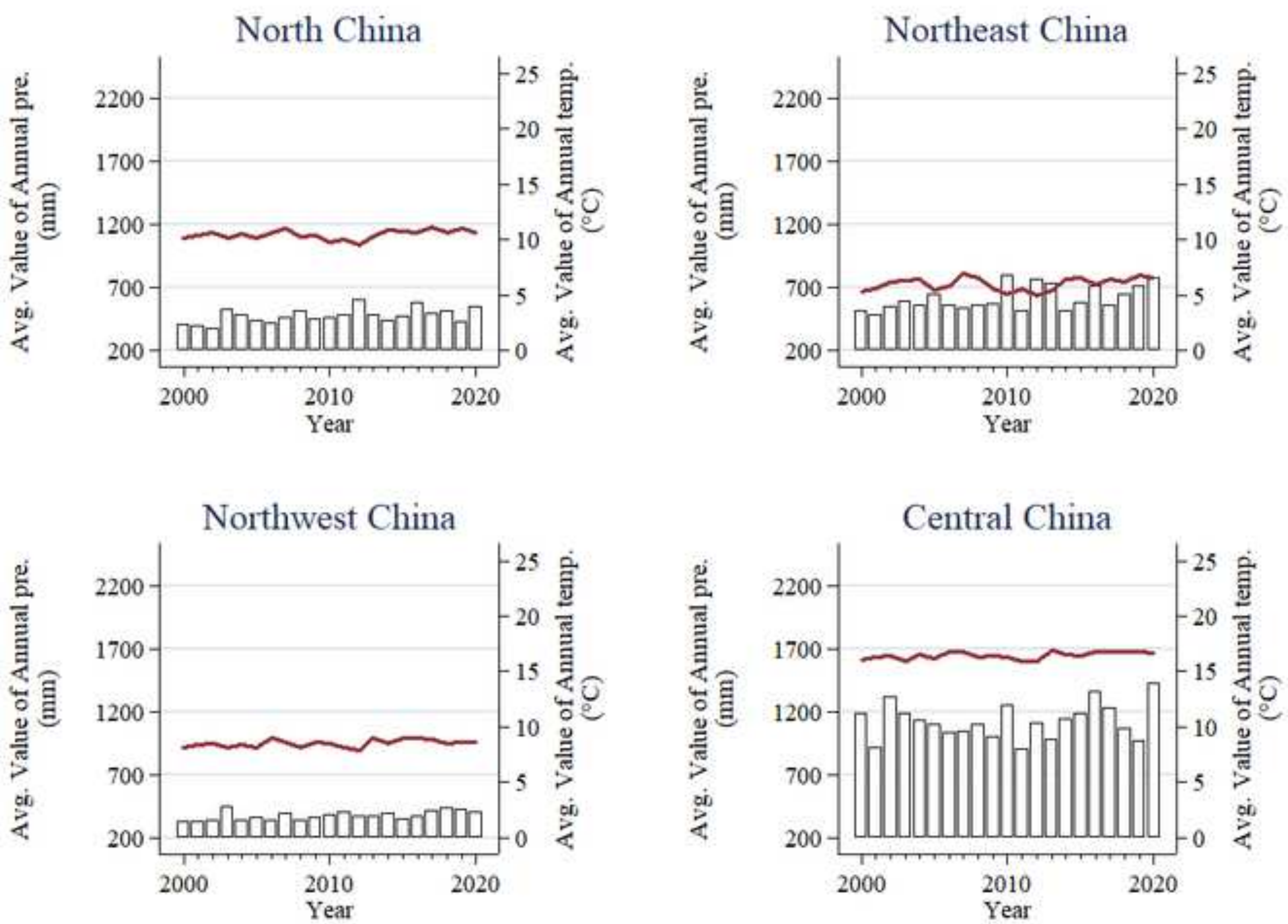
	rhoAa(a)	rhoVA(a)	rhoCET(a)	rhoQq(c)
Agriculture, forestry, animal husbandry, and fishery products and services	-2.33	-0.11	0.77	0.79
Petroleum, coke, nuclear fuel processing products, and chemical products	-2.33	-0.11	0.77	0.79
Food and tobacco	-2.33	-0.11	0.64	0.72
Machinery equipment, transportation equipment, electronics and electrical equipment, and other equipment	-2.33	-0.11	0.64	0.72
Other services	-2.33	-0.11	0.64	0.72
Transportation, warehousing, and postal services	-2.33	-0.11	0.64	0.74
Wholesale and retail	-2.33	-0.11	0.64	0.72
Finance and real estate	-2.33	-0.11	0.64	0.72
Mining products	-2.33	-0.11	0.64	0.72
Production and supply of electricity, heat, gas, and water	-2.33	-0.11	0.64	0.72
Metal smelting, processing, and products	-2.33	-0.11	0.64	0.72
Wood processing, furniture, paper printing, and cultural, educational, and sports goods	-2.33	-0.11	0.64	0.72
Textile, clothing, footwear, hats, and leather down products	-2.33	-0.11	0.64	0.72
Information transmission, software, and information technology services	-2.33	-0.11	0.64	0.72
Non-metallic mineral products	-2.33	-0.11	0.64	0.72
Other manufacturing products and repair services	-2.33	-0.11	0.64	0.72
Construction	-2.33	-0.11	0.64	0.72

Click here to access/download;Figure;Fig 1.Occurrences of droughts.tif

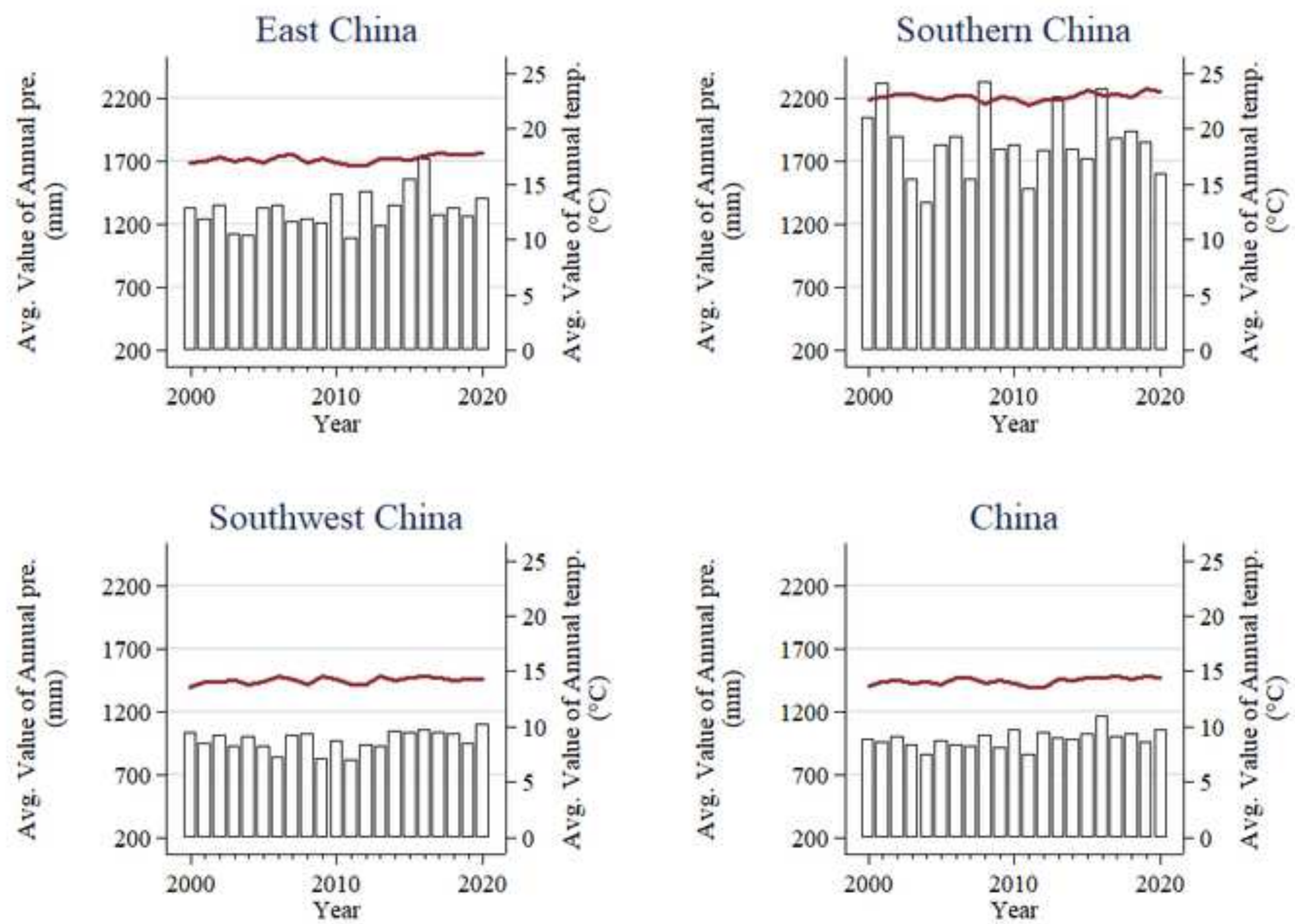


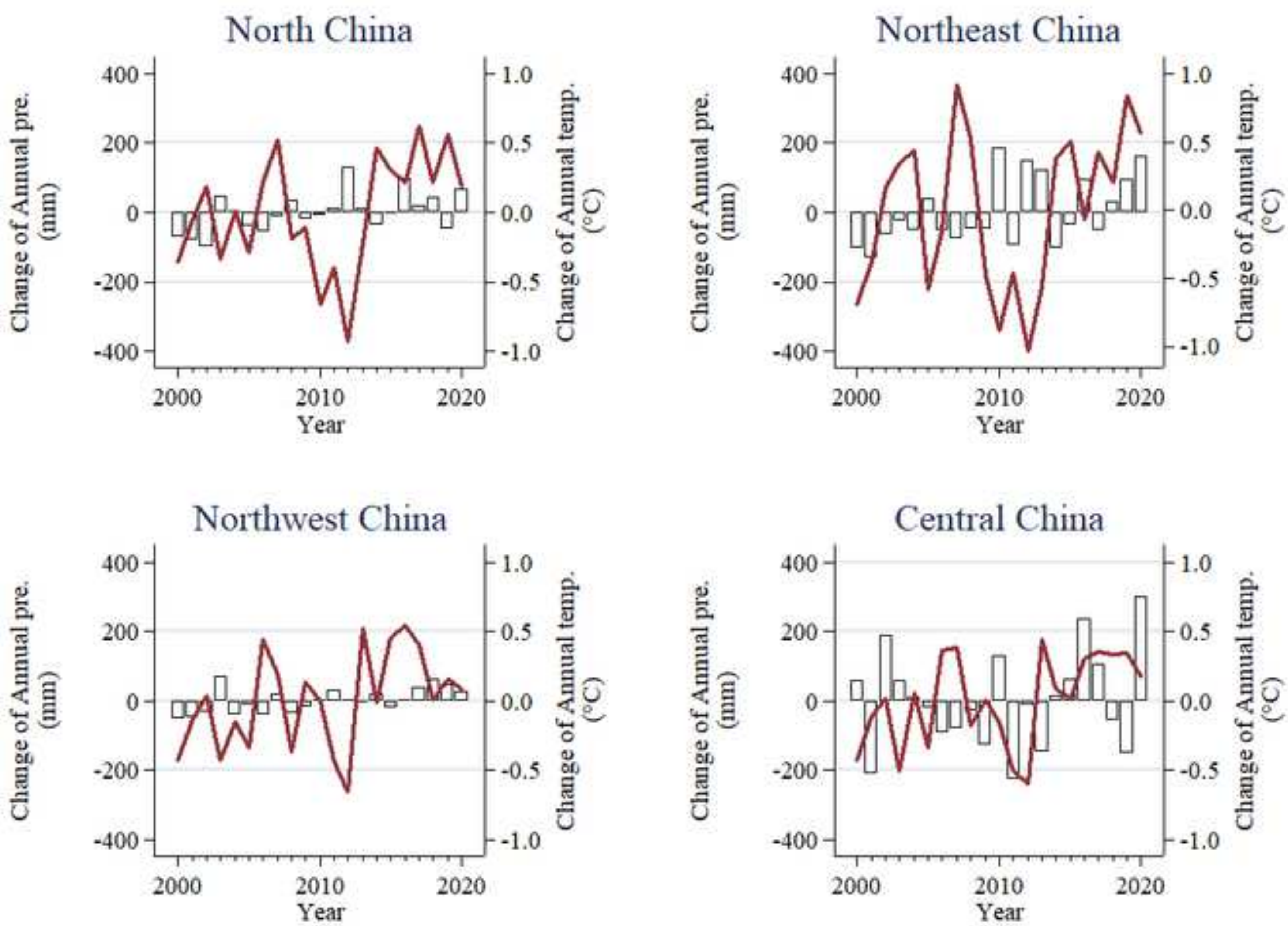


25500
20500
15500
10500
5500
500
Affected/Disaster Area(Thousand Hectares)
1950
1960
1970
1980
1990
2000
2010
Year
Affected area
Disaster area
Data Source:Ministry of Water Resources of China


North China
Northeast China
Northwest China
Central China
Avg. Value of Annual pre. (mm)
Avg. Value of Annual temp. (°C)
Year
2200
1700
1200
700
200
25
20
15
10
5
0
2000
2010
2020

Click here to access/download;Figure;Fig 3-B. Temperature and precipitation information.tif




North China
Northeast China
Northwest China
Central China
Change of Annual pre. (mm)
Change of Annual temp. (°C)
400
200
0
-200
-400
1.0
0.5
0.0
-0.5
-1.0
2000
2010
2020
Year

Click here to access/download;Figure;Fig 4-B. The temperature and precipitation anomalies.tif