Xingchen Chen

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July 28, 2025

Dear Climate Finance PhD Workshop Committee:

I am writing to express my strong interest in the Graduate Student Workshop on Climate Finance and to submit my application for your consideration. I am currently a Ph.D. student in the Nicholas School of Environment and the Sanford School of Public Policy at Duke University, where I specialize in environmental policy. My research broadly focuses on climate finance, with a particular emphasis on the impact of climate change on rural finance and the climate adaptation strategies of small to medium-sized banks.

My current research (my research paper) examines the impact of climate change on rural credit and how rural financial institutions respond to such risks. I am particularly interested in the effects of credit supply-side measures, such as price reductions and contract renegotiations, on the credit risk of loans with varying usage, term structures, and collateral statuses. I intend to explore these questions within the context of climate risk integration under the Basel III framework, specifically focusing on how comprehensive risk management—guided by the Three Pillars—can adapt to and effectively manage climate-related financial risks. My long-term goal is to advance research on the supervisory treatment of climate risk under the three pillars of Basel III, with a particular focus on how banks and regulators can adapt capital planning, stress testing, and governance frameworks to account for climate-related financial risks.

I expect to complete my Ph.D. by May 2028. My principal adviser is Professor Junjie Zhang (junjie.zhang@duke.edu), who is familiar with my academic work and would be happy to serve as a reference. Additional references can be provided upon request.

Thank you very much for considering my application. I would welcome the opportunity to discuss my research and potential fit with your program further.

Sincerely,

Xingchen Chen

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EDUCATION

Ph.D., Environmental Policy(Env Econ), Duke University	2023-now
MSc, Ag & Applied Economics, University of Wisconsin-Madison	2019-2021
Bachelor of Economics, Peking University	2017-2019
Bachelor of Management, Fujian Agriculture and Forestry University	2012-2016

PROFESSIONAL EXPERIENCE

Duke Kunshan University, Kunshan, Jiangsu, China
Research Specialist in Environmental Modelling 2021-2023

WORKING PAPER

Climate Risk and Rural Credit Risk

TEACHING

Duke:

ENV 520/521 Resource & Environmental Economics I/II (TA)	Fall 2024
ENV 531 Economic Valuation of the Environment (TA)	Spring 2025
ENV 710 Applied Statistical Modeling for Environmental Management (Lab Instructor)	Spring 2025

SEMINARS & CONFERENCE

2024:
25th Annual CU Environmental and Resource Economics Workshop
Duke International Population, Health and Development Seminar
UPEP Seminar
2023:
UPEP Seminar

RESEARCH PROJECT

GF60 & Guangxi Rural Commercial Union Bank 2023-2024
"Climate Risks in the Rural Credit Cooperatives

REVIEWER SERVICES

China Economic Review(x2)

LANGUAGE

Chinese(native); English(fluent)

COMPUTER SKILL

LaTex, R, Stata

Climate Change Deteriorates Rural Finance*

Xingchen Chen† Xiaomeng Cui‡ Chengtao Deng§ Jun Luo¶
Junjie Zhang‖**

July 29, 2025

Abstract

Climate risk has become an emerging risk for the financial system. Rural financial institutions are among the most vulnerable financial institutions to climate shocks. Using a unique set of rural microcredit data and climate meteorological data, we demonstrate that extreme temperatures can significantly increase the probability of default on loans related to agricultural production. While the rural financial institutions have limited adaptation tools, active price reduction is a way to mitigate the impact of climate risk under the most extreme climate change conditions. Under some non-extreme conditions, policy support is needed, but it is not overly costly compared to most of the existing policy support in agricultural sectors.

Keywords: Climate Risk, Climate Finance, Microfinance, Climate Adaptation

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Significance Statement

Climate change can affect the rural finance significantly, but the adaptation tools are limited for these institutions. Using a unique dataset of rural credit records, we comprehensively assess the impact of climate change on rural credit quality and how rural financial institutions are adapting to the risk by adjusting their lending rates. We demonstrate unambiguous evidence that a lower pricing strategy leads to a reduction of the impact of additional extreme temperatures on the likelihood of default. We also show that the lower pricing strategy can be cost-efficient under some extreme conditions. Even when the policy support is needed, the cost of such a policy is much lower than many of the existing agrarian policies around the world.

1 Introduction

Physical risk of climate change has become an emerging risk in the financial sector (Basel Committee on Banking Supervision, 2021a,b, 2022). Rural financial institutions are particularly vulnerable to the impacts of climate change (Deng et al., 2025). These institutions mainly serve rural areas and farming areas using microcredit, a specialized form of loan designed to provide access to credit in rural areas centered on agriculture (Morduch, 1999; Cull et al., 2009). Climate change has a significant influence on agricultural production (Mendelsohn et al., 1994; Chen et al., 2016; Zhang et al., 2017; Hultgren et al., 2025). It can increase the rate of default on farm loans (Burney et al., 2024). These loans are often issued without collateral, which complicates and increases the cost of collecting on defaulted loans. Evaluating the impact of climate change at the loan level can help lenders manage risk more effectively. However, rural financial institutions usually lack the ability or resources to assess this risk within their portfolios. In addition, limited access to portfolio-level data hinders research institutions from analyzing the climate risk associated with microcredit. Most current analyzes focus on loans to households or firms, rather than loans to agricultural production by rural financial entities (Gallagher and Hartley, 2017; Aguilar-Gomez et al., 2024).

The evaluation of climate risk exposure can inform banks to choose the corresponding mitigation tools (Basel Committee on Banking Supervision, 2022), such as increasing insurance coverage, increasing the interest rate, leaving risky areas, etc. (Javadi and Masum, 2021;

Correa et al., 2022; McConnell et al., 2022; Do et al., 2023; Meisenzahl, 2023; Kim et al., 2024). However, these options are often limited for rural financial institutions. The insurance coverage rate in rural areas of developing countries is typically low, and the social safety net is generally inadequate in these regions (Klomp, 2014; Carter et al., 2017). They are often responsible for their duty to provide access to credit to local farmers and lower-income communities. This duty limits their autonomy to increase interest rates or reduce the credit supply in high-risk areas. Regional competition in credit markets is another factor that encourages rural financial institutions to remain in rural areas with relatively lower prices. This lower price behavior has the potential to mitigate the negative impact of unexpected shocks on borrowers (Bernanke and Gertler, 1995; Altunbas et al., 2010; Di Maggio et al., 2017; Matthys et al., 2018). In practice, access to lower-priced credits can improve farmers' climate resilience in areas with higher climate risk, but requires substantial subsidies (Da Mata and Resende, 2020). In the absence of a subsidy, the price-cutting strategy as a climate adaptation tool shifts the burden of climate resilience from farmers and the government to rural financial institutions. It creates a dilemma between climate risk management and profit seeking for these institutions.

We navigate this dilemma by evaluating the impact of climate change on microcredit and simulating the efficiency of price reduction as a risk mitigation tool. This paper constructs a two-way fixed effect model to identify the causal effects of climate change on microcredit quality. The empirical analysis is based on unique and anonymous microcredit records, which contained more than two million microcredit loans over 8 years, from a rural provincial financial institution in China. To the best of our knowledge, this research is the first to assess the climate change associated with microcredit in rural financial institutions and the first to propose a novel approach for rural financial institutions to adapt to climate risk through active price reduction.

Our sample region, Guangxi, is located in the southwest part of China. The area has a subtropical monsoon climate, which provides a rich variation in extreme events, including extreme heat and cold. This area is also an agriculturally centered region, with more than 42% of its population residing in rural areas, and its primary industry accounts for approximately 16% of its GDP in 2024. It is also the largest producer of fruit and sugarcane in China. The climate conditions, population, economic structure, and agricultural production are quite similar to those of many Asian and Latin American countries, such as India, Vietnam, Malaysia, and

Brazil. These countries also have a large proportion of rural residents who rely on microfinance from profit-seeking institutions. Our analysis would also serve as a valuable reference for many other rural financial institutions around the world.

2 Results

The regression analysis leverages the randomness of extreme weather events as exogenous shocks to assess the impact of climate risk on the likelihood of default in microcredit. Such a method shows suitability in evaluating the impact of climate change on agricultural production (Deschênes and Greenstone, 2007; Auffhammer et al., 2013; Burke et al., 2015). We first evaluate the impact of extreme weather on the quality of micro-credit and the pricing strategy of a rural financial institution. In addition, the randomness of extreme weather events in different years creates an opportunity for us to use the previous year's climate shocks as an instrument variable to address the endogeneity of the price and the probability of default. We employ the two-stage least squares process to evaluate the mitigation effect of the spread on climate risk.

Exposure to extreme temperature after the loan is issued will significantly increase the likelihood of default on agricultural production-related loans. Fig. 1-a illustrates the estimated effects of extreme temperature on different types of microcredit. The estimates indicates the effect of additional extremes one year after the loan issuance. An additional day of extreme heat (degree-by-day above 35° C) increases the probability of default by 0.03 percentage points, which is statistically significant at the significance level of 0.01. The likelihood of default at the end of the first year of a new loan is 0.8%. So, the estimated effect of additional extreme hot day is equivalent to a 3.75% increase in default risk.

An additional extreme cold day (degree-by-day below 0°C) can increase the likelihood of default by 0.29 percentage points, which is equivalent to a 36.25% increase in the probability of default. It is also statistically significant at the 0.01 significance level. The impact of extremely cold days is greater than that of extremely hot days. This result reflects the relative rarity of extreme cold days in subtropical areas. Meanwhile, climate risk has a significant impact only on agricultural production-related loans, rather than on other types of loans. The magnitudes of the estimates for other loans are much smaller than those of agricultural production-related loans and do not show statistical significance. This result aligns with the fact that climate

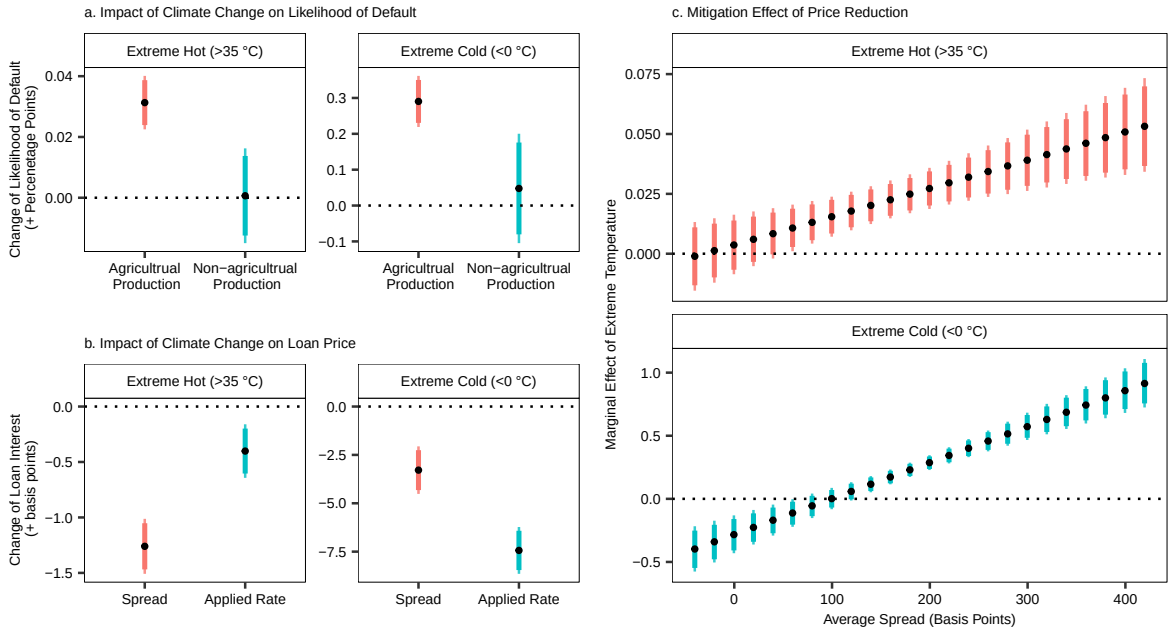


Figure 1: **Impact of climate change on the likelihood of default and pricing behavior**. Figure-a shows estimated coefficients (central points) and their 95% (thin lines) and 90% (thick lines) CIs of extreme weather on the probability of defaults on agricultural production loans (red) and non-agricultural production loans (blue) using Eq. 1. The estimates can be found in *SI Appendix Table S2* columns 1 and 6. Figure-b shows estimated coefficients (central points) and their 95% (thin lines) and 90% (thick lines) CIs of extreme weather on the interest level (spread and applied rate) on agricultural production loans using Eq. 2. The estimates can be found in *SI Appendix Table S3* columns 1 and 5. Figure-c shows the simulation of the marginal effect of additional extremes (on the Y-axis) under different spread levels (on the X-axis). The central point is the estimated marginal effect of extreme weather under different levels of spread changing, and their 95% (thin lines) and 90% (thick lines) CIs. The confidence intervals are calculated based on 3,000 bootstrap replications. The marginal effect is calculated by estimates from Eq. 3.

change has a significantly larger impact on the agriculture sector.

Rural financial institutions will lower the interest rate in riskier areas, which can help mitigate the marginal effect of extreme weather on default risk In response to climate risk, rural financial institutions in China adopt a price-cutting strategy. Fig. 1-b presents the impact of one additional extreme temperature days within the one year before the loan's issuance on the interest rate of the new agricultural production loan. Each additional day of extreme heat in the year preceding loan issuance will reduce the average spread of the new agricultural production loan by 1.26 basis points. The effects of additional cold days are even greater, with a reduction of 3.29 basis points. Both estimates are statistically significant at the 0.01 significance level. This pattern is consistent with the impact of extreme temperature on

default risk. Higher climate risk will result in greater default risk, and rural financial institutions will reduce the spread more in riskier areas.

In theory, a lower interest rate will reduce the financial burden on borrowers and enhance their resilience in the face of unexpected shocks. It suggests that the price reduction strategy can serve as a risk mitigation tool for rural financial institutions. We test the mitigation effect of lower prices using Eq. 3. The estimated marginal effects of extreme temperatures under different levels of spread are shown in Fig. 1-c. If the average spread is cut by 100 basis points, the marginal effect of extreme heat days will decrease by 0.011 percentage points (standard deviation = 0.0036). The marginal effect of extreme cold days will decrease by 0.277 basis points (standard deviation = 0.0454).

A price-cutting strategy can mitigate climate risk in the future. Climate change is expected to lead to more frequent extreme weather events in the future. In our sample region, we expect a significantly higher number of extremely hot days and a relatively lower number of extremely cold days (see *SI Appendix Fig.S3*). The changing frequency of extreme weather in the future will significantly increase the likelihood of default.

In Fig. 2, the cells along the line where the spread change equals zero represent the probability of default in the future, assuming no price change. Under SSP1-2.6, the average probability of default ranges from 0.76% to 0.97%. Under SSP5-8.5, the average likelihood of default ranges from 0.77% to 2.29%. We decompose the effect of extreme weather in the future and find that such an impact is mainly driven by the extreme heat days (*SI Appendix Fig.S5*).

Fig. 2 also shows that the price reduction strategy can mitigate the future default risk. In the cells on each column of the year, from the top to the bottom, we see that the price change is positively correlated with the likelihood of default. In other words, a lower spread can result in a lower level of default risk. The dots indicate the level of spread change in future years that can reduce the future risk to the current default level (0.8%). Rural financial institutions only need to reduce their spread up to 21 basis points to achieve the risk reduction goal under SSP1-2.6, while a reduction up to 118 basis points is needed under SSP5-8.5.

The efficiency of the price-cutting strategy is conditional on the level of climate risk. In Fig. 3, we show the net benefit of different levels of price cut under the future climate risk. The red shade indicates that the price cut in that specific year yields a positive net benefit,

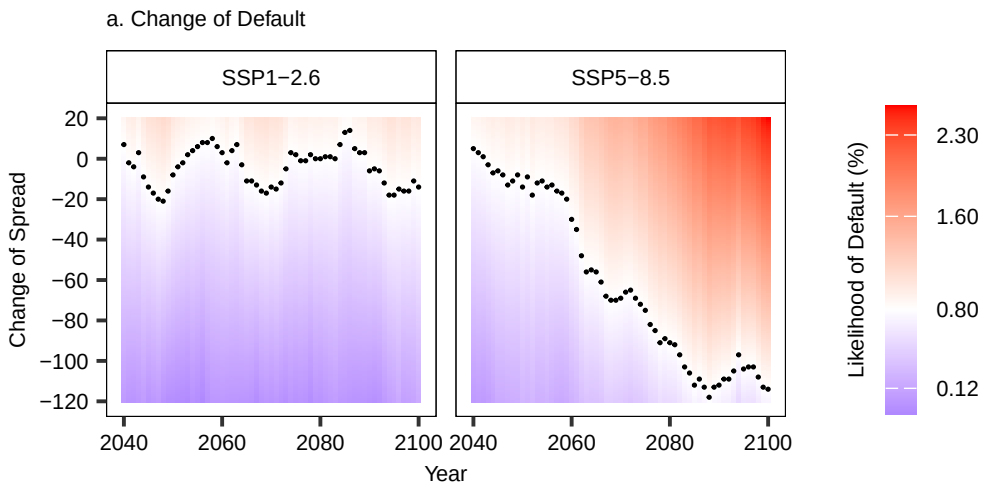


Figure 2: Default risk under different levels of price cuts in the future. This figure shows the likelihood of default in the future years (x-axis) associated with different levels of spread change (y-axis). The red shade indicates a likelihood of default higher than the current average default (0.8%), and the blue shade indicates a likelihood of default lower than the current average default. The dot in the figure marks the price cuts that are sufficiently large enough to press the future default risk to the current level. In *SI Appendix S6*, we also present two examples of future default risk in 2040 and 2100 under SSP5-8.5, associated with different levels of price cuts as an example.

and the blue shade indicates vice versa. Under SSP5-8.5, after 2085, the price-cutting strategy is expected to yield a positive net benefit, ranging from zero to around 4,208 per million CNY loans. The black dots in the figure mark the price reduction aiming to offset the additional default risk in the future years induced by climate change. Such a policy goal will yield a net benefit ranging from 140 to 4,209 per million loans from 2085 to 2100 and -14 to -1,653 per million loans from 2040 to 2084 under SSP5-8.5.

Figs. 4 a and b show the breakdown of cost and benefit across future years when the price reduction strategy aims to press down the future default risks to the current default levels (the dotted situation in Fig. 2).

The green area shows the cost of the price reduction. From 2040 to 2100, the price cut will lead to a cost ranging from 100 to 2,100 CNY per million of loans under SSP1-2.6 and from 300 to 11,800 CNY per million of loans under SSP5-8.5.

The purple area shows the benefit of preventing the expected loss of additional risk in the future. Under SSP1-2.6, the price reduction strategy can avoid the loss of additional default risk from 36 CNY per million loans to 907 CNY per million loans. Under SSP5-8.5, the price reduction strategy can save such a loss by about 98 to 7,689 CNY per million loans.

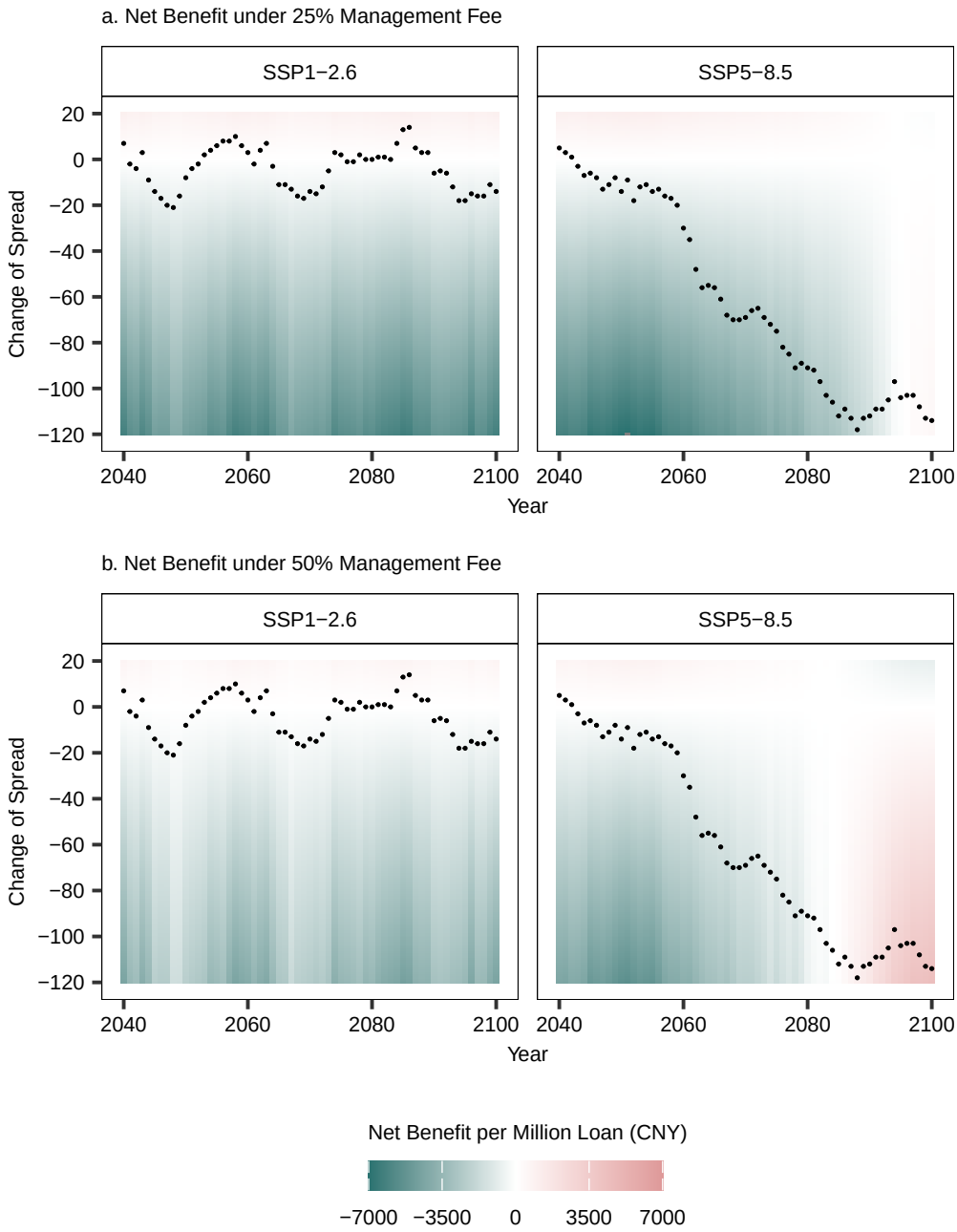


Figure 3: **Net benefit of price-cutting strategy.** This figure shows the net benefit of the price-cutting strategy in the future years (x-axis) associated with different levels of spread change (y-axis). The red shade indicates a positive net benefit, and the blue shade indicates a negative net benefit. The dot in the figure marks the net benefit of price cuts that are sufficiently large to press the future default risk to the current level. Figure-a shows the net benefit at 25% default management fee, which indicates that the benefit shown here is the upper bound of the net benefit. Figure-b shows the net benefit at a 50% default management fee, indicating that the benefit shown here represents the upper bound of the net benefit.

The blue area illustrates the benefit of avoiding the management fee associated with the default loan. The management fee can vary from 25% to 50% in most developing countries

(World Bank Group, 2019). In other words, the 25% management fee indicates the lower bound of this benefit, while the 50% management fee indicates the upper bound of this benefit. The blue area in Fig. 4-a shows the benefit under the management fee 25%, which is approximately 17 CNY per million loan to 434 CNY per million loan under SSP1-2.6, and 47 CNY per million loan to 3,719 CNY per million loan under SSP5-8.5. This benefit will be doubled when the management fee rate is set at 50% (shown as a blue area in Fig. 4-b).

The yellow area shows the benefit of the avoided opportunity cost of default loans. In China, the regulatory authority requires banks to set aside reserves for potential loan losses, which is at least 150% of the amount of unpaid loans. This ratio often exceeds 200% in rural financial institutions. We use 200% loan loss prevention and a 2% capital cost to calculate the opportunity cost associated with the loan. The opportunity cost ranges from 2 to 57 CNY per million loans under SSP1-2.6 and from 6 to 482 CNY per million loans under SSP5-8.5. This benefit is the lowest among the three.

The gray area in Fig. 4-a and b illustrates the gap between the cost and benefit of the price reduction strategy under different level of management fee. This gap can be interpreted as the additional cost of climate resilience imposed on the rural financial institution. Such a gap can be used as a reference in policy design. In *SI Appendix Table S10 to S11*, we show different types of subsidies that are commonly used in the agricultural sectors. This summary presents the typical compensation rate in the farming sector worldwide, using either monetary or fiscal policy. Banks can usually receive over 1% compensation for the loan issued, while in Fig. 4-c, we show that the subsidy rate per CNY loan is only 0.04% to 0.08% under SSP1-2.6 and a maximum of 0.23% under SSP5-8.5. These results indicate that most current policy tools can effectively incentive banks to lower interest rates in exchange for reduced default risk.

Non-monetized incentives might also help in promoting such policy. In the absence of monetized policy support, rural financial institutions may also have incentives to lower the interest rate in exchange for a lower default rate. One of the reasons is the obligation of microfinance. Microfinance was designed to support low-income communities that lack formal access to credit services, rather than profit maximization. However, with the growing demand in the microfinance market, profit-seeking institutions are also beginning to issue microfinance products (Cull et al., 2009). For these institutions, setting the price at a higher level generally

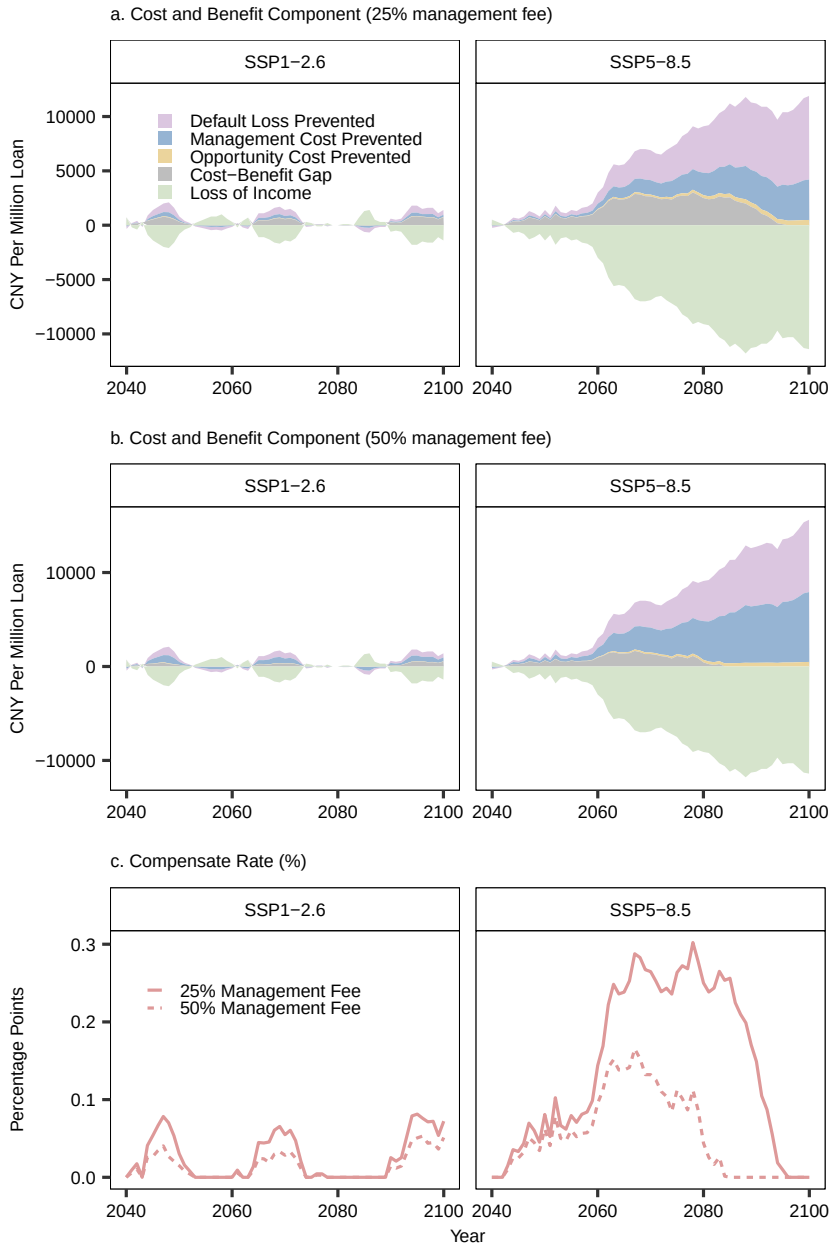


Figure 4: **The cost and benefit distribution of price cutting strategy when the strategy goal is to offset the entire future climate risks.** This figure shows the decomposed cost and benefit when the price reduction strategy aims to offset the effect of additional future extreme weather. In other words, it aims to press down the future default risk to the current level. Figure-a shows the cost and benefit distribution when the management fee is 25% of the default loan. Figure-b shows the cost and benefit distribution when the management fee is 50% of the default loan. Figure-c shows the different subsidy rates that compensate for the loss of the price cut.

receives criticisms about their moral and legal legitimacy due to the departure from the social mission of financial inclusion (Yunus, 2007; Rosenberg, 2007; Malkin, 2008; Cull et al., 2009). Maintaining their reputation as an inclusive finance institution is one of the motivations for lowering their rate in the risky area rather than increasing it.

Political obligations are another form of incentive for Chinese rural financial institutions to reduce the price. This comes from institutional inertia at the very beginning when they were formed. Rural financial institutions were established as rural credit cooperatives (RCCs), covering nearly every rural township in China (Ping, 2003), and have been defined as a collective of financial organizations and grassroots institutions within the state banking system in rural areas (China Reform Information Database, 2011). They were created around the 1950s during the agricultural cooperative campaigns. Between 1979 and 1996, RCCs were led and managed by the Agricultural Bank of China (ABC), a policy-oriented bank that focused on serving rural areas. The RCCs decoupled from ABC after 1996, indicating the individual operation of China's rural financial institutions and the commercialization of these institutions (Zhang, 2025). In 2003, China initiated the deepening reform of the RCCs, with the aim of reforming the ownership structure and transfer of supervision responsibility to the local government (State Council of the People's Republic of China, 2003). Each province started to form provincial-level RCCs to uniformly manage local RCCs, representing the promotion of shareholding reform and the establishment of modern rural banking systems. After 2021, RCCs began to reform into commercial banks. Although rural financial institutions are now becoming profit-seeking institutions, the previous bureaucratic structure and the close interactions with local government and regulatory authorities have formed a path dependence. On this path, rural financial institutions continue to maintain their inclusive pricing design and fulfill their necessary political obligations, particularly serving and supporting rural development. The other constraint faced by the institution behind the reform of the RCCs is to reduce the higher than average NPLs (*SI Appendix Fig.S4*)(Ping, 2003). This regulatory requirement formed another non-monetized incentive for the institution.

3 Discussion

This paper demonstrates that microcredit used for rural agricultural production is significantly deteriorated by climate risk. The magnitude of the effect of additional extreme heat on the likelihood of default is 0.03 percentage points. It is similar to the estimated effect (0.029) on agricultural firms in Mexico (Aguilar-Gomez et al., 2024). The similarity of the estimates results from the regional similarity of the climate norm. Our samples were collected in Guangxi province, a subtropical region in China with a latitude similar to that of Mexico. However, the scale of the impact is smaller compared to a study at the institutional level in China (Zhang et al., 2024), which finds that one more extreme hot day can lead to an increase in the probability of default by around 0.096 to 0.134 percentage points. This difference is primarily due to the significant spatial heterogeneity of climate norms, which leads to divergent marginal effects between regional and national analyses. Our findings underscore the importance of regional heterogeneity in assessing climate risk because the marginal contribution of climate risk to the probability of default plays a critical role in estimating future credit risk trajectories.

This paper also sheds important light on policies related to climate resilience within the financial system. We discovered a new approach that enables rural financial institutions to adapt to climate risk by reducing the interest rate on loans. We show that price reductions can significantly mitigate the negative impact of future climate risk. This can be explained by the finance theory that a lower interest rate can help the borrower cope with unexpected shocks (Bernanke and Gertler, 1995; Altunbas et al., 2010; Di Maggio et al., 2017; Matthys et al., 2018; Da Mata and Resende, 2020). The level of price cut depends on the level of future default risk caused by climate risk. This shifts the cost of climate resilience from the borrowers to the banks. We show that when climate shocks lead to sufficiently higher default risk, the benefit of default risk reduction will compensate the cost of interest rate loss and yield a nonnegative net benefit. In some cases, when the policy results in a negative net benefit, the maximum cost gap is less than 0.3%, which is significantly lower than many of the subsidy rates in agricultural policy.

Monetary policy and fiscal policy can both efficiently support banks under their commitment to price cuts. The central banks can implement the climate resilience relending project. Relending is a structural monetary policy tool that provides support to specific sectors without

generally loosing liquidity. Central banks can design such a lending project by providing low-interest loans to commercial banks, conditional on their commitment to cut prices to reduce the spread. On average, a typical supporting level of monetary policy targeting the agricultural sector is approximately 1% to 2%. It is sufficiently high to cover the spread cutting loss, which is estimated at 0.3%.

Governments can also design fiscal policies such as interest subsidies. The compensation rate can be based on different levels of price reduction. For example, under SSP5-8.5, in year 2078 with 25% of management fee of default loan, the compensation rate is at a maximum of 0.3%. The optimal price cut required under this scenario is 91 basis points. This indicates that the interest subsidy should be approximately .32% (0.003/0.0091) of the price cut to compensate for the loss. A more direct way is to provide risk compensation for each of the loans that the banks committed to cut prices. Direct compensation only requires a maximum of 0.3% subsidy under the SSP5-8.5 scenario.

This research contributes to the growing literature on climate finance by evaluating the impact of climate change on microcredit in a profit-seeking institution. We also contribute to the climate finance literature by documenting a unique pricing strategy, characterized by a lower spread level in riskier areas. This strategy is different from other studies that suggest increasing the price to hedge the risk. We demonstrate that the price-cutting strategy is a novel climate adaptation tool that can effectively mitigate the impact of climate risk. It contributes to the limited discussions on banks' adaptation to climate risk (Kim et al., 2024). It also adds value to the traditional finance paper, which discusses the relationship between interest rate and default risk (Bernanke and Gertler, 1995; Altunbas et al., 2010; Di Maggio et al., 2017; Matthys et al., 2018), and adds value to the discussion on the pricing of microcredit and inclusive finance (Cull et al., 2009, 2018). The non-monetized incentives faced by these rural financial institutions, such as reputation and political constraint, can also motivate these institutions to implement price cutting regardless of the net profit. The uniqueness of rural financial institutions can be seen as a hybrid of bureaucracy and a firm. This result links our paper to a broad literature on bureaucracy within the field of political economy (Besley et al., 2021).

We acknowledge that in this paper, our result is based on the assumption that in the absence of other forms of adaptation behavior. If other adaptations are included, the actual

magnitude of climate risk might be lower than the current result. Hence, the interpretation of the magnitude of our estimates is that it represents the upper bound of the impact of climate risk on microfinance. The second limitation is that the estimated net benefit represents the lower bound of the benefits. Other benefits, which are not included in our research, are difficult to measure. One of them is the effect of local credit market competition. Research has shown that market competition may influence the adaptation behavior of a financial institution. The competition in the local credit market may motivate institutions to keep their prices at a relatively low level, as increasing them to a higher level could result in the loss of customers due to market competition. The third limitation is the geographic scope of our study. Our analysis is based on a single province in China. As pointed out in our discussion, in practice, the cost-benefit analysis is highly reliant on estimates of the effect of climate risk and the mitigation effect of the loan price at a specific location. However, our sample province has a subtropical climate and a predominantly agricultural-based economy, which shares characteristics common to many developing countries. So, our findings may still offer relevant information for other developing regions.

4 Data

4.1 Microcredit Data

The microcredit data are obtained from a provincial-level rural financial institution in China. This database documents detailed information on the date, usage classification, length, rate, and default classification at the loan level. An advantage of this dataset is that it contains a monthly default classification for each loan. It enables us to track changes in loan quality over time. We mainly use the information on the issuance date and township where the branch issues this loan to match the loan record with the climate data. Our main outcome variable, default or not, is using the mark of default status 15 months after the loan is issued. We use the 15 months of issuance to guarantee the whole year (12 months) climate risk exposure and 3 3-month window for the default to be fully disclosed in the data. The second main outcome we measured is the spread, which is calculated using the applied rate and benchmark rate for each record provided by this dataset. (See *SI Appendix- Data- Microcredit Data* for more details)

4.2 Meteorology Data

The meteorological data are obtained from the China Daily Meteorological Observation Dataset, available at the Resource and Environmental Science Data Center of the Institute of Geographic Sciences and Natural Resources Research, Chinese Academy of Sciences (IGSNRR, CAS). The dataset contains daily stationary observation data. We use the daily maximum temperature and daily minimum temperature to construct the climate risk proxy, extreme heat and extreme cold. We use this dataset to construct the number of extreme hot days and extreme cold days (*SI Appendix- Data- Meteorology Data*)

4.3 Climate Projection Data

We use these to simulate the impact of future climate change. We construct the changing number of extreme days in the future using the future climate projection data. The climate projection data we use are from the Coupled Model Intercomparison Project Phase 6, specifically the HadGEM3-GC31-MM model. We obtain the down-scale projection data from NASA. The data contains daily maximum temperature and daily minimum temperature from 2015 to 2100. We obtain two different emission scenarios, SSP1-2.6 and SSP5-8.5, which represent the moderate warming scenario and extreme scenario. The downscaled projection data is a gridded dataset with a resolution of 0.5 °×0.5 °. We use this dataset to construct the changes of future extremes (*SI Appendix- Data- Climate Projection Data*)

5 Method

We present the main equations for each of the estimations in this section. Details on each of the methods can be found in SI Appendix.

5.1 Baseline Model

Using the near-random fluctuation of climate risk from year to year, we employ a two-way fixed-effects model to estimate the impact of climate risk on loan default rates. For loan i in township j issued on date t, the specification of the baseline model is given by:

$$
\begin{aligned}
Y_{ijrnt} =& \alpha_1 \text{PostExtremeHeat}_{jrnt} + \alpha_2 \text{PostExtremeCold}_{jrnt} \\
&+ \alpha_3 \text{PostPrcp}_{jrnt} + \alpha_4 \text{PostPrcp}^2_{jrnt} \\
&+ \delta_{jr} + \lambda_{nt} + \eta_{rn} + \epsilon_{ijrnt}. \qquad (1)
\end{aligned}
$$

In this form, the term Y_{ijrnt} denotes the default status of the loan i in towns j in the region r issued on date t in season n. It equals 1 when marked as default and 0 otherwise. There are various types of definition of the default we have defined in the *SI Appendix Data* part.

The term $\text{PostExtremeHeat}_{jrnt}$ denotes the cumulated number of days above 35° C in the 365 days after the issue date t in the township j. The term $\text{PostExtremeCold}_{jrnt}$ is the corresponding number of days below 0° C and daily precipitation above 50 mm. The terms β_1 and β_2 capture the effect of extreme heat and extreme cold on the probability of default.

We control the non-linear effect of cumulated precipitation one year after the loan is issued in linear and quadratic terms PostPrcp_{jrnt} and PostPrcp^2_{jrnt}. In addition, we include the township fixed effect δ_{jr} to control for unobservable location attributes that are time-invariant. The time fixed effect indexed by λ_{nt} absorbs time-specific unobservables at the issuance. We also include η_{rn}, which controls for unobservables by region. The region r is defined by its geographical climate character, including the north, south, east, west, and coastal region of Guangxi. The season n is divided into four seasons: spring from March to May; summer from June to August; fall from September to November; and winter from December to February. This will further control the common region by the seasonal climate norms of the specific region. The term ϵ_{ijrnt} is an unobserved error term, which we clustered at the county-by-date level. We describe a various of robustness check in *SI Appendix- Method- Baseline MOdel*.

5.2 Pricing Behavior Model

The second model we develop is to evaluate the price decision of rural financial institutions that face climate risk. We employ a similar two-way fixed effect model to estimate the pricing behavior, and the specification is given by:

$$
\begin{aligned}
S_{ijrnt} =& \beta_1 Pre\text{ExtremeHeat}_{jrnt} + \beta_2 Pre\text{ExtremeCold}_{jrnt} \\
&+ \beta_3 \text{PrePrcp}_{jrnt} + \beta_4 \text{PrePrcp}^2_{jrnt} \\
&+ \delta_{jr} + \lambda_{nt} + \eta_{rn} + \epsilon_{ijrnt}. \qquad (2)
\end{aligned}
$$

In this form, Y_{ijrnt} denotes the spread level of the loan i, which is calculated using the applied rate minus the benchmark rate. The $\text{PreExtremeHeat}_{jrnt}$ denotes the cumulated number of days above 35°C in the 365 days **before** the issue date t in the township j. The term $\text{PreExtremeCold}_{jrnt}$ is the corresponding number of days below 0°C. The terms β_1 and β_2 capture the effect of extreme heat and extreme cold before issuance on the loan spread. We also control for the nonlinear effect of cumulated precipitation one year before the loan is issued in linear and quadratic terms PrePrcp_{jrnt} and PrePrcp^2_{jrnt}. The rest of the parameters are the same as in the previous equation. We also describe a various of robustness check in *SI Appendix*.

5.3 Mitigation Effect Model

The third model we develop aims to evaluate whether a lower price can mitigate the marginal impact of extreme weather. We estimate the mitigation effect by interacting the spread with the post-issurance extremes. We use Eq. 2 as our first stage estimation to obtain a predicted spread level $\hat{S}_{ijrnt}$, which is the predicted spread of the loan i from the township j at time t. This instrument is a strong instrument (Wald Test $= 44.3 > 10$ (Staiger and Stock, 1997; Stock and Yogo, 2002)) and satisfying both relevance and exclusion restrictions assumption (See *SI Appendix Method*).

We then used the predicted spread level to interact with the climate variables as our second-stage specifications in the following form:

$$
\begin{aligned}
Y_{ijrnt} =& \gamma_1 \hat{S}_{ijrnt} \times \text{PostExtremeHeat}_{jrnt} \\
&+ \gamma_2 \hat{S}_{ijrnt} \times \text{PostExtremeCold}_{jrnt} \\
&+ \gamma_3 \times \text{PostExtremeHeat}_{jrnt} + \gamma_4 \times \text{PostExtremeCold}_{jrnt} \\
&+ \alpha_5 \text{PostPrcp}_{jrnt} + \alpha_6 \text{PostPrcp}^2_{jrnt} \\
&+ \alpha_7 \hat{S}_{ijrnt} \times \text{PostPrcp}_{jrnt} + \alpha_8 \hat{S}_{ijrnt} \times \text{PostPrcp}^2_{jrnt} \\
&+ \alpha_9 \hat{S}_{ijrnt} + \delta_{jr} + \lambda_{nt} + \eta_{rn} + \epsilon_{ijrnt}
\end{aligned} \tag{3}
$$

In this specification, γ_1 and γ_2 capture the mitigation effect of spread on extreme hot and extreme cold shocks, where $\gamma_1 \times \overline{S} + \gamma_3$ will be the marginal effect of extreme hot days under the average spread level $\overline{S}$, $\gamma_2 \times \overline{S} + \gamma_4$ will be the marginal effect of extreme cold days under the average spread level $\overline{S}$.

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