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How Does Deleveraging Affect Outreach Productivity of Mfis in China? New Evidence from Dynamic Threshold Role of Green Finance

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Abstract: The literature suggests ambiguity regarding the impact of microfinance institutions (MFIs) deleveraging on their outreach for promoting financial inclusion, notably within the context of China's economic transition emphasizing credit reallocation toward small businesses. This study investigates the relationship between MFIs' deleveraging and outreach productivity, considering the threshold effects of green finance and macroprudential measures. Employing an improved dynamic threshold model with system GMM estimation, the analysis utilizes a panel dataset of 204 Chinese MFIs spanning from 2012 to 2021. The empirical findings indicate that: firstly, MFIs' deleveraging enhances their outreach productivity directly; secondly, the presence of a threshold effect in green finance leads to a nonlinear impact of deleveraging on MFIs' outreach productivity, where the effect shifts from negative to positive as green finance increases up to the threshold; thirdly, the threshold effect of macroprudential green finance also exhibits a nonlinear relationship with MFIs' deleveraging, but the positive impact is statistically significant only within a specific range of green finance below the threshold. These results bear relevant policy implications.

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1. Introduction

Following China's reform and opening up, the economy experienced a prosperous "honeymoon" period, marked by decades of rapid growth. However, this era also saw a disregard for the negative aspects associated with the expansive economy, whether deliberate or inadvertent. There has been a growing awareness that significant misallocations of investments have occurred on a substantial scale within China. Consequently, these misallocations have led to the emergence of excess production capacity and the accumulation of leverage, presenting substantial challenges to both the present economic condition and the prospective sustainability of future growth trajectories (Morrison, 2019; Pettis, 2013). To address this, a significant economic transition involving deleveraging was undertaken to facilitate the transition and upgrading of the industrial structure. Deleveraging involves reallocating credit from debt-heavy sectors to credit-starved sectors through the transmission of financial intermediation (Fratianni & Marchionne, 2017; Zhang, 2023). Although the prevailing scenario suggests potential, it prompts inquiry into whether economic transition alone can effectively mitigate excessive leverage and foster economic growth. While scholars have extensively analysed the mechanisms of credit reallocation through leveraging or deleveraging activities of major financial institutions using capital structure theories, the role of MFIs in this process has been notably disregarded. Notably, a substantial portion of credit-starved sectors comprises numerous small businesses, primarily reliant on MFIs for financing (Committeri et al., 2021). Small businesses, often perceived as financially vulnerable and marginalized by major financial institutions, constitute a significant economic segment. This marginalization is perpetuated by major financial institutions in China, which can alleviate deleveraging pressures through capital idling within the financial and fiscal systems (Lin & Wang, 2021).

Fig. 1 illustrates the leverage dynamics, which remained relatively stable until 2011, except for the 2009 financial crisis. Subsequently, with the onset of economic downturn pressures, leverage issues became increasingly prominent, leading to a new round of deleveraging processes since 2015. Notably, the deleveraging effect was observable in the financial sector, with a tendency for leverage fluctuations (deviation between funding sources and uses) to diminish. However, the anticipated role of financial intermediation in credit reallocation appeared to be impeded in transmitting the deleveraging effect to economic entities, as the leverage fluctuations of economic entities (deviation between loans by the financial sector and GDP of the entity economy) continued to expand. This underscores the proliferation of capital idling in financial and fiscal systems, rather than genuine capital reallocation to economic entities, and suggests a failure in reallocating credit towards credit-starved small businesses. Recognized as pivotal financial intermediaries for sustaining financial inclusion and supporting the welfare of small businesses, MFIs in China play a central role (Sohn & Ju, 2023). The obstruction of deleveraging transmission underscores a significant gap between the financing needs of small businesses and the lending supply by MFIs for financial inclusion. As the primary financial institutions serving small businesses, it raises questions regarding whether MFIs' deleveraging affects their capacity and willingness to engage in financial inclusion efforts for small businesses. These issues in economic transition provide a unique perspective for this paper, focusing on the primary research objective of examining the impact of MFIs' deleveraging on their lending outreach productivity for financial inclusion.

Furthermore, China faces a longstanding challenge of carbon emissions, ranking first globally with nearly 28.87% of total emissions in 2022, as per the Global Carbon Atlas. This issue, stemming from the extensive economic growth model, has drawn considerable criticism. To address this concern, China has pledged to undergo a green transition, aiming to peak carbon emissions by 2030 and achieve carbon neutrality by 2060. Green transition, a key aspect of economic transformation, places greater emphasis on green finance by financial institutions. Drawing on Bernanke and Gertler's (1995) "financial accelerator" theory, fluctuations in economic and environmental indicators can be amplified by credit market dynamics in response to positive or negative impacts on enterprises. Diverse green finance instruments, guided by preferential policies, play a vital role in expediting deleveraging processes and meeting various economic entity needs, including capital, mergers and acquisitions, and mixed reforms, by providing affordable funding for green and low-carbon projects (Ma, 2020). Following the inclusion of green finance regulation in the macroprudential assessment system in 2017, there has been an observed upward fluctuation in GDP (refer to Fig. 1), likely due to the incentivized transmission of funds for green projects by financial institutions, endorsed by supervisory measures. While green finance, emphasizing long-term and low-cost funding, is suitable for the "greenization" of existing financial relationships, connecting with the promotion of environmentally-friendly lending, MFIs encounter challenges in adopting it (Zhang, 2020). Specifically, MFIs may find it difficult to adapt to stricter green assessments, particularly concerning their focus on financially vulnerable small businesses that may struggle to meet the conditions of long-term green lending despite policy support (Xing, Zhang, & Tripe, 2021). This raises concerns for MFIs regarding the risks associated with lending for financial inclusion in the context of deleveraging through green finance. While integrating green intentions into deleveraging processes may enhance the health and sustainability of MFIs, an excessive emphasis on green intentions could potentially hinder their support for financial inclusion due to more stringent regulations. While MFIs appear to improve their health and sustainability by integrating green intentions into deleveraging efforts, an excessive focus on green initiatives could impede their support for financial inclusion due to stricter regulations. Therefore, there is interest in investigating the potential threshold of green finance that may trigger nonlinearities in MFIs' lending for financial inclusion during the deleveraging process. Furthermore, macroprudential objectives impose obligations on MFIs to adhere to green finance standards (Vargas, 2023). The inquiry into whether macroprudential interventions influence the adherence of microfinance institutions to green finance policies prompts an additional objective of this paper. Specifically, it aims to elucidate the role of macroprudential green finance in the relationship between deleveraging and the outreach productivity of MFIs. Within the current economic transition in China, this study makes several contributions concerning the role of MFIs in

facilitating financial inclusion for small businesses. Firstly, it introduces a novel method for quantifying MFIs' deleveraging, which evaluates the deviation of individual financing-based leverage from regional leverage. Secondly, it emphasizes financial inclusion as the primary outreach goal of MFIs and thoroughly assesses its effectiveness in supporting small businesses considering deleveraging effects. Thirdly, the study investigates the influence of green finance expansion on the relationship between deleveraging and MFIs' outreach productivity. Lastly, it extends existing literature by examining the impact of green finance within the context of macroprudential oversight.

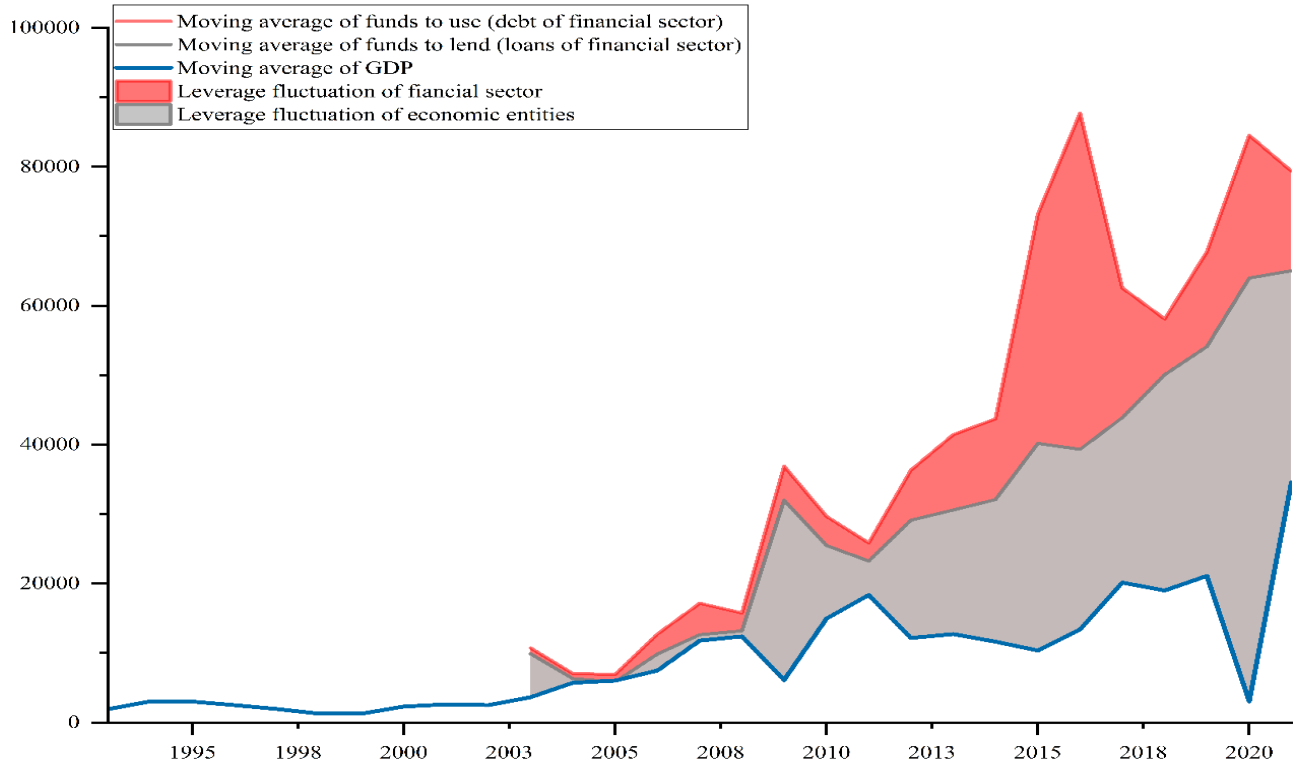

Figure 1: Trend of Leverage Fluctuation.

Source: The moving average is computed by author in terms of the average of standard deviation rolling over four quarters with data source from National Bureau of Statistics of China and People's Bank of China.

2. Literature Review

2.1 Outreach of MFIs

In the financial sector, outreach denotes the extent to which financial activities incorporate social missions. Addressing the trade-off between profit and societal responsibility is a subject of extensive study to advocate for socially responsible financial institutions. Microfinance initially emerged to provide access to microcredits for the unbanked, particularly the poorest individuals. Since its inception, MFIs have relied on a steady stream of subsidies and donor funds to reach out for poverty alleviation efforts (Kamble, 2022). Through thorough investigation, Zerai & Rani (2012) as well as Abdullah (2019) deconstruct the outreach of MFIs into two distinct dimensions: depth and breadth. In an empirical context, Awaworyi Churchill (2020) introduces microloan size as a measure of breadth and poor coverage as a measure of depth to evaluate the outreach performance of MFIs in aiding impoverished populations.

With subsidies and donor funding to MFIs significantly decreasing in recent years, commercialization has emerged as a prevalent trend, urging MFIs to seek self-sufficient funding (Addae-Korankye, 2020). Covering more impoverished individuals is often associated with higher costs, given the smaller size of loans demanded, which may result in insufficient income to sustain profitable operations. Consequently, the heightened focus on financial performance presents a dilemma regarding mission drift for MFIs (Copestake, 2007). Henceforth, MFIs grapple with the concept of the "double bottom line," which entails extending outreach to encompass more impoverished individuals while simultaneously striving for enhanced financial sustainability (Blanco-Oliver & Irimia-Diéguez, 2021). With this objective in mind, MFIs aim to mitigate the elevated transaction costs associated with serving impoverished populations by diversifying their microfinance activities, encompassing small loans, small savings, small insurance, and other non-credit services (Awaworyi Churchill, 2020). This suggests that MFIs are increasingly resembling traditional banks in their operations. Diversifying their services can attract additional private capital, ensuring funding sufficiency, and enhance their capacity to lend to small and medium-sized enterprises or self-employed households. This, in turn, indirectly generates employment opportunities for the impoverished, aiding in poverty alleviation efforts (Hipsher, 2020). Consequently, MFIs enhance their financial sustainability while concurrently fostering social welfare among marginalized populations. Thus, by facilitating collaboration among microfinance stakeholders, MFIs attain outreach objectives aimed at bolstering financial inclusion efforts (Dorfleitner, Nguyen, & Röhe, 2019; Jamal & Mazhar, 2019;

Sangwan & Nayak, 2020). In accordance with significant advocacy by the China Banking and Insurance Regulatory Commission, the credit line for financial inclusion loans, capped at CNY 10 million per client, facilitates a collaborative approach between the breadth and depth of outreach. This allows MFIs to allocate loans into smaller sizes (breadth) to encompass a broader spectrum of small businesses (depth) (Chai et al., 2019; Chen & Yuan, 2021; Mhlanga, 2022). Financial inclusion aids in facilitating deleveraging transmission to some degree by limiting individual debt capacity and redistributing funding opportunities to vulnerable and poorer clientele through inclusive microcredits. This study focuses on the outreach of MFIs in promoting financial inclusion.

2.2 Deleveraging and Productivity

From an economic perspective, leverage is considered a neutral instrument; however, its efficiency can vary significantly depending on the macroeconomic policy environment in which it is employed (Hamdi-Cherif, Li, & Ó Broin, 2021). Deleveraging is perceived as a macroprudential regulatory approach aimed at addressing excessive leverage, thereby mitigating the risks associated with high leverage and revitalizing the efficiency of capital turnover. Hou et al. (2018) elucidate that deleveraging fundamentally involves reallocating capital to alleviate societal debt pressures through financial intermediation. They underscore the pivotal role of financial intermediaries in guiding debt flow from high-leveraged sectors to low-leveraged ones, thereby facilitating deleveraging transmission. With respect to China's structural reform, Lu & Zhang (2022) assert that deleveraging transcends mere quantitative reduction and is essentially a structural concern. They emphasize the necessity of dismantling implicit guarantees in low-efficiency sectors to liberate occupied social resources gradually. Zhao (2022) supplements this notion by elucidating that deleveraging aims to mitigate systemic risks in the financial system and the real economy through structural credit reallocation, facilitated by financial institutions' intermediation to support emerging industries and small businesses. Consequently, the implementation of deleveraging by financial institutions is advocated to mitigate credit discrimination against small businesses.

During economic downturns, it becomes evident that the residential sector and small-medium enterprises, positioned outside the financial and fiscal systems, are particularly susceptible to the effects of deleveraging by financial institutions (Eggers, 2020). Furthermore, given that the deleveraging process is not a singular occurrence, it frequently alternates with episodic re-leveraging efforts aimed at stabilizing the economy. During these phases, state-owned enterprises and local financing platforms within the financial and fiscal systems are the primary beneficiaries of resources for re-leveraging. Consequently, there is a proliferation of liquidity within the financial and fiscal systems, which does not adequately benefit small businesses (Dalio, 2022). Viewed through this lens, the credit discrimination exhibited by financial institutions embodies an inherent dynamic that contributes to the systematic exclusion of small businesses from financial access. Within the context of deleveraging, the recurrent occurrence of asset shortages exacerbates the imbalance, leading financial institutions to disproportionately allocate credit to the internal concentration of the financial and fiscal systems as a risk aversion strategy (Cao, 2023). Thus, the risk posed by microfinance and small credit assets hinders financial institutions' ability to effectively support small businesses, despite the substantial gap in financial demand from small businesses. According to Githaiga, Soi, & Buigut (2023) special consideration is given to the operational efficiency of MFIs catering to small businesses. The commercialization of MFIs places heightened emphasis on financial sustainability, compelling them to elevate lending thresholds to minimize risk exposure, thereby potentially limiting the effective accessibility of small businesses. Indeed, deleveraging represents a "double-edged sword": while it necessitates a reallocation of credit towards small businesses from debt-laden sectors, it also exacerbates the burden of risk associated with financial inclusion efforts. Therefore, this paper proposes hypothesis 1: Deleveraging of MFIs have significant impact on their outreach productivity.

2.3 Deleveraging, Green Finance and Productivity

The rise of green finance not only promotes environmental protection and the development of green industries, but also improves fund allocation efficiency for green projects by prioritizing financial support for innovative green technologies (Wang & Wang, 2021). Nevertheless, as the environmental benefits per unit of capital increase, the practice of "green" leveraging is also being accepted during the financial deleveraging process (Diluiso et al., 2021). In essence, reconciling the contradiction between green finance, which aims to leverage capital allocation towards green projects, and financial deleveraging presents a significant challenge. Huang, Punzi, & Wu (2021) contend that the unique characteristics of green initiatives, including extended investment cycles, substantial uncertainty, and limited short-term profitability, pose obstacles for financial institutions striving to maintain financial sustainability during the deleveraging process. Despite green finance aiding financial institutions in transitioning towards environmentally friendly practices by optimizing their asset structure, these challenges persist. Raberto et al. (2019) express scepticism regarding the appeal of green finance to financial institutions, noting strong opposition due to concerns about straining capital reserves and risk management. Nonetheless, it is evident that the essence of green finance calls for a shift from mere quantitative expansion to qualitative efficiency or productivity (Ezroj, 2020). With growing emphasis on environmental considerations across industries, finance serves as an intermediary in driving various projects, including initiatives for green innovation and capital allocation towards environmentally friendly production. Particularly in the context of economic transition away from resource and carbon-intensive growth models, green finance has emerged as a priority measure for financial institutions to facilitate structural reform and deleveraging in China (Sachs et al., 2019; Yang & Suh, 2023). In a broader perspective, Lee (2020) delineates the significant role of green finance in enabling financial institutions to develop competitive advantages through diverse green financial products, facilitating flexible access to small businesses and emerging industries. Beyond

financial gains, local financial institutions provide a stable platform to mobilize social capital in support of the green transition of economic entities. Moreover, Xi, Wang, & Yang (2022) uncover the hesitancy of large banks to adopt green finance compared to smaller banks. This reluctance stems from the fact that a significant portion of revenue for large banks is derived from lending to asset-intensive and heavy-industry enterprises, whereas green finance typically yields lower returns due to longer repayment periods and reduced yields.

While conclusive findings remain elusive in the existing literature, evidence suggests the possibility of an inflection point in the growth of green finance, wherein financial institutions attain financial performance or other economic objectives during deleveraging or leveraging processes. For instance, scholars note the nonlinear nature of the impact of green finance on leverage, indicating that preferential policies may temporarily incentivize financial institutions to leverage for green projects (Bose, Khan, & Monem, 2021). However, to ensure the long-term sustainability of green projects, financial institutions must deleverage to mitigate associated risks (Kaminker et al., 2013; Kedward, Ryan-Collins, & Chenet, 2020). Despite some existing tension between the promotion of green finance and the context of deleveraging, both aim to drive long-term structural reform from quantitative expansion to quantitative productivity by optimizing capital allocation. Therefore, it is crucial to accurately identify the inflection point in the existing relationship between deleveraging and productivity by incorporating the development of green finance into a dynamic threshold model as an endogenous threshold variable. This is because various financial instruments of financial institutions constitute green finance (Lee, 2020). Moreover, green finance compels financial institutions to engage in herd activities that are interconnected with it (Paradi-Dolgos et al., 2023; Zhuang & Wei, 2022). Thus, Hypothesis 2, which focuses on the sample of MFIs, posits that: Green finance dictates a threshold making nonlinear effects of deleveraging on outreach productivity of MFIs.

2.4 Deleveraging and Macroprudential Green Finance

Macroprudential initiatives post-financial crisis, notably Basel III, establish risk-based capital limits aimed at curbing overleveraged positions across specific asset sets by restraining both on- and off-balance sheet leverage (BCBS, 2014). Within the macroprudential framework, financial leverage is deemed a fundamental indicator governed by a "one veto" principle, where failure to meet leverage standards renders a financial institution's macroprudential assessment inadequate (Chen, 2018). Given the current countercyclical deleveraging narrative within today's financial regulatory framework, financial institutions prioritize short-term "brown" investments over long-term "green" investments (Mazzucato & Semieniuk, 2018; Thanassoulis, 2014). This preference stems from the fact that green projects, with their extended payback periods, typically incur higher leveraging weights compared to brown projects within the risk-weighted asset measurement mechanism (D'Orazio & Popoyan, 2019). This discrepancy represents a latent divergence between macroprudential regulation aimed at deleveraging and green finance aimed at leveraging.

To address this divergence, scholars and practitioners advocate integrating green finance into the macroprudential assessment system. Klioutchnikov & Kliuchnikov (2021) propose dynamically adjusting macroprudential green regulation in accordance with the development of green finance to ensure the financial and social sustainability of financial institutions by differentiating leverage administration. Similarly, Zhang (2020) suggests evaluating green finance separately within the macroprudential system and granting it a higher tolerance for leverage compared to traditional finance, as observed in green finance policies in Germany and China. This approach fosters environmentally-friendly advancements within existing relationships between financial institutions and borrowers. However, assessments of macroprudential green finance impose mandatory norms on financial institutions to meet green finance standards (D'Orazio & Popoyan, 2019; Dikau & Volz, 2021), potentially disregarding the heterogeneity of financial institutions. The impact of macroprudential green finance on the credit allocation process towards small businesses, especially MFIs, remains unclear, as small businesses may struggle with long-term financing for green projects. Therefore, it is essential to assess the inflection point between MFIs' deleveraging and their practice of financial inclusion based on a reference value in macroprudential green finance. This gap prompts the study's interest in exploring Hypothesis 3: the existence of a nonlinear relationship between deleveraging and outreach productivity of MFIs, with macroprudential green finance as the threshold variable. The research framework of this study is illustrated in Fig. 2, aligning with the proposed hypotheses.

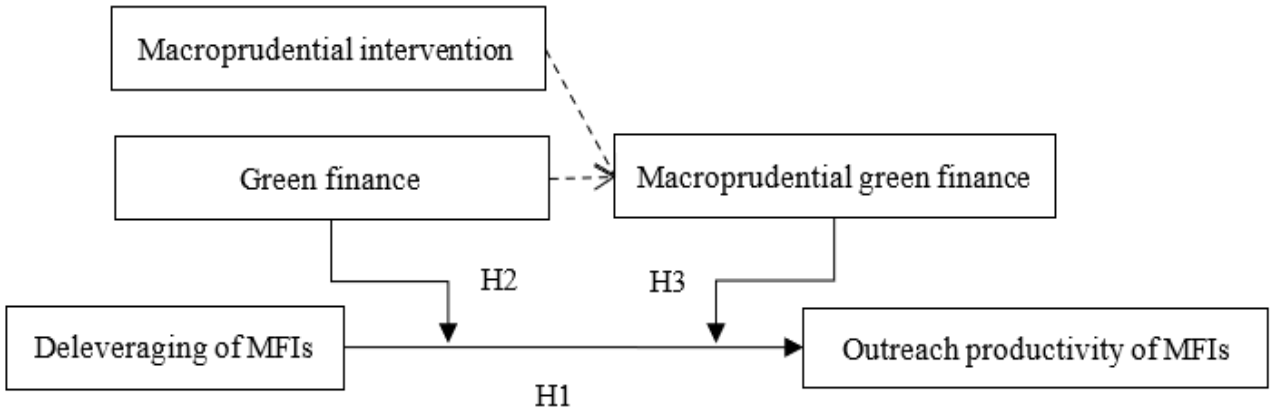

Figure 2: The Research Framework Routing the Relationships with Key Variables.

3. Measurement Methods of Key Variables

3.1 Method for Computing Deleveraging

As previously discussed, deleveraging represents a top-down process aimed at reducing the overall debt burden of the entire economy through the reallocation of credit by financial institutions. Achieving deleveraging transmission to economic entities hinges on the implementation of deleveraging measures by financial institutions, with the level of leverage serving as a determinant of the extent of deleveraging. Endogenous leverage, stemming from economic entities' voluntary decisions regarding capital structure during economic operations, exacerbates macroeconomic fluctuations. Conversely, exogenous leverage serves as a policy instrument to curtail indebtedness among microeconomic entities, mitigating financial instability resulting from unpredictable fluctuations in asset prices (Coimbra, 2020; Lojak, 2020). In theory, macro leverage represents the collective outcome of the micro leveraging behaviours of individual economic entities, and micro leverage should be subject to adjustments in macro leveraging (or deleveraging) (Kuchler, 2020). In this context, the study assesses the leverage level of MFIs by considering the deviation of micro leverage from macro leverage rather than solely focusing on capital structure. Consequently, a Z-score, following the approach proposed by MacKie-Mason (1990), can be developed to quantify the impact of micro leverage in alignment with macro leverage. The Z-score for leverage is formulated as follows:

$$LEV = \frac{\mu_{macroleverage} - microleverage}{\sigma_{macroleverage}} \quad (1)$$

Here, LEV denotes the Z-score representing the leverage level of MFIs, while micro leverage refers to the capital structure assessed by the liability-to-equity ratio. Considering the developmental discrepancies among various regions and the limited duration spanning from 2012 to 2021, this study utilizes the rolling 3-year regional leverage. This metric, calculated as the ratio of provincial debts of non-financial sectors to provincial GDP, is employed to derive its mean ($\mu_{macroleverage}$) and standard deviation ($\sigma_{macroleverage}$). Additionally, to address potential distortions from periodic fluctuations in macro indicators, the regional leverage examined in this study is smoothed using the Hodrick–Prescott filter to eliminate periodic fluctuation terms (Drehmann & Yetman, 2018).

The next step involves reversing the LEV to derive the deleveraging indicator (DEL) while maintaining the original distribution. The min-max reversed standardization method proposed by Fostel & Geanakoplos (2015) is utilized to convert LEV to DEL as:

$$DEL_{i,t} = \frac{\max(LEV_{i,t}) - LEV_{i,t}}{\max(LEV_{i,t}) - \min(LEV_{i,t})} \quad (2)$$

Where $\max(LEV)$ and $\min(LEV)$ represent the maximum and minimum values of leverage respectively. The reversed standardization process yields, $DEL_{i,t}$ denoting the deleveraging level of specific MFI i at period t. A higher magnitude indicates a more significant downward deviation from the regional leverage of economic fundamentals, and consequently, a deeper deleveraging transmission to the regional entity economy by the MFI.

3.2 Construction of Outreach Productivity

Productivity serves as an alternative metric to performance, evaluating how effectively financial institutions generate outputs from given resource inputs. This study employs Data Envelopment Analysis (DEA) to assess decision-making units (DMUs) within MFIs regarding their outreach in providing loans for financial inclusion. Tone (2001) enhances DEA through a non-radial approach called slack-based measure (SBM), which accommodates slack indicators when evaluating DMUs, considering undesirable outputs such as non-performing assets inherent in actual production processes. Addressing DEA's limitations related to non-solutions, incomparability of efficient DMUs, and non-transitivity of intertemporal DMUs, Oh (2010) further advances the global-directional distance function (GDDF) based on sequential super-SBM. The GDDF is formulated in linear programming as follows:

$$\vec{D}_0^G(\mathrm{x}^t, \mathrm{y}^t, \mathrm{b}^t; -\mathrm{x}^t, \mathrm{y}^t, -\mathrm{b}^t) = max\beta$$
$$s.t. \sum_{t=0}^{T}\sum_{k=1}^{K} z_k^t y_{km}^t \geq (1+\beta) y_{k'm}^t, \mathrm{m} = 1, \cdots, \mathrm{M};$$
$$\sum_{\mathrm{t}=0}^{\mathrm{T}}\sum_{k=1}^{K} z_k^t b_k^t = (1-\beta) b_{k'}^t,$$
$$\sum_{t=0}^{T}\sum_{k=1}^{K} z_k^t x_{kn}^t \geq (1-\beta) y_{k'n}^t, \mathrm{n} = 1, \cdots, \mathrm{N};\ z_k^t \geq 0, \mathrm{k} = 1, \cdots, \mathrm{K} \quad (3)$$

Where, x^t , y^t and b^t indicate the vectors of inputs, desirable outputs and undesirable outputs in period t. The production possibility frontier of GDDF offers a method to overcome the limitation of the technical frontier by ensuring continuity across periods. On account of advantage of GDDF, the global Malmquist-Luenberger (GML) index is derived to interpret productivity of DMU as:

$$GML_t^{t+1} = \frac{1+\vec{D}_0^G(\mathrm{x}^t, \mathrm{y}^t, \mathrm{b}^t; -\mathrm{x}^t, -\mathrm{b}^t)}{1+\vec{D}_0^G(\mathrm{x}^{t+1}, \mathrm{y}^{t+1}, \mathrm{b}^{t+1}; -\mathrm{x}^{t+1}, \mathrm{y}^{t+1}, -\mathrm{b}^{t+1})} \quad (4)$$

Where, GML_t^{t+1} measures the change of productivity from t period to t+1 period. If GML_t^{t+1} is greater than 1, productivity increases; if GML_t^{t+1} is equal to 1, productivity remains unchanged; if GML_t^{t+1} is less than 1, productivity decreases. GML can be transitive, that is $GML_t^{t+1} \times GML_{t+1}^{t+2} = GML_t^{t+2}$. Moreover, GML_t^{t+1} can be composed into the technical efficiency change index ($GEFFCH_t^{t+1}$) and technological change index ($GTECH_t^{t+1}$), In order to delve deeper into the primary factors driving efficiency fluctuations, thereby expressed as:

$$GML_t^{t+1} = GTEC_t^{t+1} \times GTC_t^{t+1}$$
$$GEFFCH_t^{t+1} = \frac{1+\vec{D}_0^t(\mathrm{x}^t, \mathrm{y}^t, \mathrm{b}^t; -\mathrm{x}^t, \mathrm{y}^t, -\mathrm{b}^t)}{1+\vec{D}_0^{t+1}(\mathrm{x}^{t+1}, \mathrm{y}^{t+1}, \mathrm{b}^{t+1}; -\mathrm{x}^{t+1}, \mathrm{y}^{t+1}, -\mathrm{b}^{t+1})} \quad (5)$$
$$GTECH_t^{t+1} = \frac{(1+\vec{D}_0^G(\mathrm{x}^t, \mathrm{y}^t, \mathrm{b}^t; -\mathrm{x}^t, \mathrm{y}^t, -\mathrm{b}^t))/(1+\vec{D}_0^t(\mathrm{x}^t, \mathrm{y}^t, \mathrm{b}^t; -\mathrm{x}^t, \mathrm{y}^t, -\mathrm{b}^t))}{(1+\vec{D}_0^G(\mathrm{x}^{t+1}, \mathrm{y}^{t+1}, \mathrm{b}^{t+1}; -\mathrm{x}^{t+1}, \mathrm{y}^{t+1}, -\mathrm{b}^{t+1}))/(1+\vec{D}_0^{t+1}(\mathrm{x}^{t+1}, \mathrm{y}^{t+1}, \mathrm{b}^{t+1}; -\mathrm{x}^{t+1}, \mathrm{y}^{t+1}, -\mathrm{b}^{t+1}))}$$

Where,$GEFFCH_t^{t+1}$ measures the approximation degree of each observed DMU to the production front from t to t+1. When $GEFFCH_t^{t+1} > 1$, it indicates that the corresponding point is closer to the production possibility frontier. In

empirical analysis, advancements in sales efficiency or managerial efficiency propel productivity forward (Ansari, 2006; Berger & Humphrey, 1997). $GTECH_t^{t+1}$ measures the variation of the production possibility frontier from t to t+1. When $GTECH_t^{t+1} > 1$, it empirically interprets that technological innovation roots the increase in productivity (Neal, 2004; Wang & Ren, 2022). As the production possibility frontier adjusts in alignment with a greater emphasis on desirable outputs and reduced undesirable outputs.

Drawing on efficiency metrics from Quaranta, Raffoni, & Visani (2018) and Sukmana et al. (2020), this study integrates the intermediation and production approaches. It selects personnel expenses, operating expenses, and assets as inputs, and gross loans for financial inclusion and financial revenue as desirable outputs, along with non-performing loans as undesirable output. These input-output indicators establish the outreach productivity of MFIs, as outlined in Table 1.

Table 1: Input-Output Indicators for Outreach Productivity.

	Indicator	Description
Input	Personnel	Gross salary of staffs employed by MFI
	Operating expenses	Total operating expenses generated in MFI's operation
	Assets	Total assets available to MFI
Output	Loan portfolio	Outstanding loans of MFI for financial inclusion
	Financial revenue	Revenue from gross loan portfolio
	Nonperforming loans	Balance of non-performing loans

3.3 Construction of Index for Green Finance

To address extensive misallocation issues, China pursues countercyclical deleveraging for structural reform, reallocating capital from debt-heavy to credit-scarce sectors, fostering a transition to a more environmentally friendly economy. Financial institutions are urged to incorporate green finance into deleveraging efforts. Despite lacking a unified framework, scholars have yet to develop a comprehensive and reliable green finance evaluation index system. Thus, precise evaluation criteria tailored to regional circumstances are essential. Leveraging the entropy method, this study enhances the approach by Lee & Lee (2022), constructing a dimensional green finance index system using provincial indicators detailed in Table 2. Data for these indicators are sourced from provincial statistical yearbooks, the China Energy Statistical Yearbook, China Statistical Yearbook of Environment, and China Statistical Yearbook of Science and Technology.

Table 2: Green Finance Index System.

1st-level indicator	2nd-level indicator	Description	Sign
Green credit	Proportion of green credit issuance	Total loans for environmental protection projects / total credit	+
	Ratio of interest expenditures of the high energy-intensive industries	Interest expenditures of the top six energy-intensive industries / Total industrial interest expenditure	-
Green insurance	Extent of environmental pollution liability insurance promotion	Premium income of environmental liability insurances / gross premium income	+
Green bond	Popularity of green bonds	Green bonds issuance / total bonds issuance	+
Green fund	Proportion of green funds	Market value of green funds / Total market value of all funds	+
Green equity	Depth of environmental equity development	Amount of carbon emission trading / total trading in equity market	+
Green investment	Proportion of environmental pollution control investment in GDP	Investments in environmental pollution control / GDP	+
	Proportion of fiscal expenditure on environmental protection	Fiscal expenditures on environmental protection / general budgetary expenditures	+

In the construction of an index system, it is crucial to allocate weights to each indicator judiciously during the evaluation process. The entropy method inherently involves assigning random weights to each index based on their relative importance, as determined by the differences in values among objects on the same indicator (Wang, Zhao, & Bi, 2021). The utilization of random assignment in this method offers advantages by mitigating bias in subjective weighting and addressing the issue of overlapping information among multiple indicators. Expanding upon this foundation, the spatiotemporal entropy method broadens the scope of information content to encompass both temporal and spatial dimensions. This extension overcomes the limitation of the traditional entropy method, which is typically limited to identifying information content at specific points in time (Gu, Zhang, & Zhang, 2021). Hence, this study employs the spatiotemporal entropy method to dynamically adjust index weights based on the dispersion degree of samples over time, aiming to assess the comprehensive green finance level of each province. The measurement involves first standardizing the indicator values as follows:

$$y_{ijt} = \begin{cases} [x_{ijt} - \min(x_{ijt})]/[\max(x_{ijt}) - \min(x_{ijt})], X_j \text{ is postive indicator} \\ [\max(x_{ijt}) - x_{ijt}]/[\max(x_{ijt}) - \min(x_{ijt})], X_j \text{ is negative indicator} \end{cases} \quad (6)$$

Where, index system of $k \times n$ matrix contains k indicators, n provinces, and m periods, the index system can be expressed as $X_j\ (i = 1, 2, \cdots, k)$. Then, $x_{ijt}\ (i = 1, 2, \cdots, n)$ presents indicator X_j of i^{th} province in the period t. Then, the information entropy matrix of each indicator X_j is E_j and its weight of W_j is assigned according to its relative importance in the process of evaluating objects. The expressions are derived as:

$$E_j = -\ln(mn)^{-1} \sum_i \sum_t p_{ijt} \ln\left(p_{ijt}\right)$$
$$W_j = (1 - E_j)/(k - \textstyle\sum_i E_j) \quad (7)$$

Where $p_{ijt} = y_{ijt} / \sum_j \sum_t y_{ijt}$. If $p_{ijt} = 0$ then $p_{ijt} \ln(p_{ijt}) = 0$ can be defined. Finally, the value of composite index of green finance of i^{th} province in the period t is that $GF_{it} = \sum_j W_j\, y_{ijt}$.

3.4 Measurement of Macroprudential Green Finance

Macroprudential interventions target overleveraged positions to initiate deleveraging, while green finance accelerates leveraging to some extent. This study examines the interplay between macroprudential interventions and green finance, focusing on the role of macroprudential green finance. The International Monetary Fund offers a MPI derived from dummy-type indicators reflecting tightening and loosening actions of macroprudential policy instruments. As depicted in Figure 3, the MPI responds accurately to changes in China's macroprudential policies. For instance, a surge in macroprudential strength occurred in 2016 amid a new round of deleveraging efforts, while the inclusion of green finance in the macroprudential assessment system in 2017 eased restrictions on leverage for financial institutions involved in green projects. China's MPI demonstrates sensitivity to macroprudential regulation corresponding to policy adjustments. The study aims to develop the variable "macroprudential green finance" $(MPI * GF)$ to examine the growth of regional green finance under the influence of macroprudential regulation.

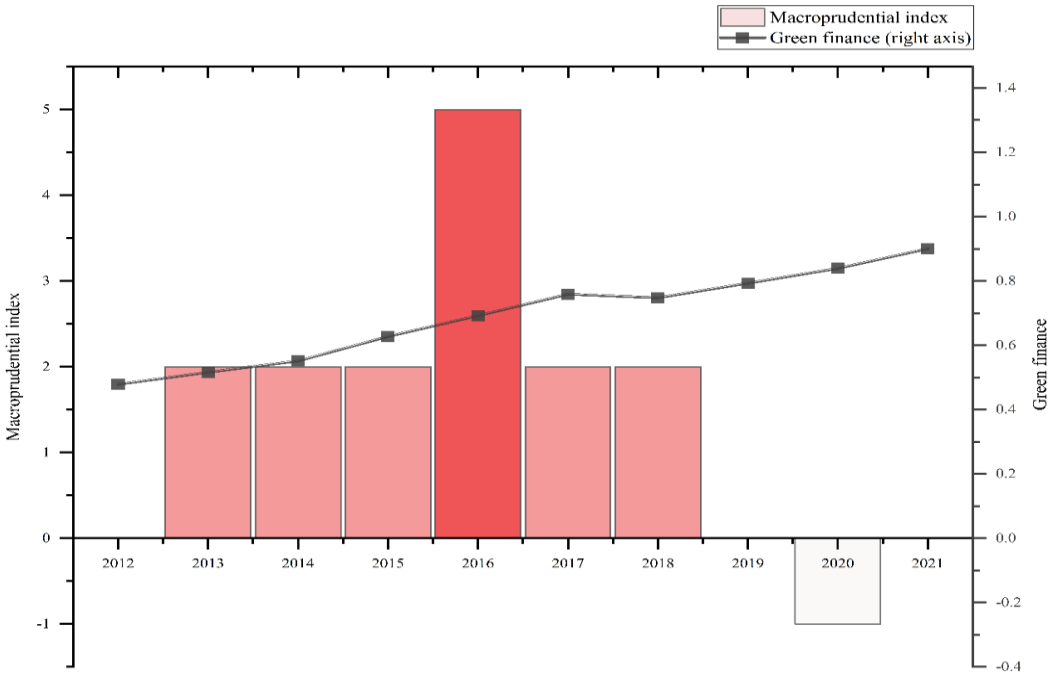

Figure 3: Trends of macroprudential index and green finance in China.
Source: Macroprudential index is collected from iMaPP Database; green finance is computed by authors using entropy method

4. Methodology and Data

4.1 Econometric Modelling

To mitigate the impact of serial correlation, this study employs a dynamic panel model to ensure the consistency of estimation. Initially, the Generalized Method of Moments (GMM) estimation is utilized to illustrate the direct mechanism of Hypothesis 1, which examines how the implementation of deleveraging affects the outreach productivity of MFIs. In contrast to other estimators for dynamic models, system GMM offers the advantage of addressing endogeneity using more information within a finite sample (Blundell & Bond, 1998). Thus, Model 1 is formulated to investigate Hypothesis 1, as follows:

$$Y_{i,t} = \alpha + \beta_0 Y_{i,t-1} + \beta_1 DEL_{i,t} + \partial_\tau X_{control\,i,t} + u_i + \lambda_t + \varepsilon_{i,t} \quad (8)$$

Where, i and t represent institution and time respectively. the dependent variable, Y, deployed in left side of equation including GML, $GEFFCH$ and $GTECH$. In right side, deleveraging, DEL, is the core explanatory variable; $X_{control}$ is the vector of control variables comprised by a series of relevant indicators that depict reginal economic environments. Therefore, consumer price (CPI), producer price (PPI), real estate price (RPI), economic contribution (EC) and government fiscal expenditures (GOV) jointly control exogenously regional economic development (specific demonstration of control variables refers to Table A1 in Appendices). Furthermore, α means the intercept term of regression. β and ∂ represent respective parameters of variables and control vector to be estimated. u_i indicates the individual effects, and λ_t captures the special idiosyncratic shock of public health event of Covid-19 to differentiate before and after 2020. The residual error term $(\varepsilon_{i,t})$ is assumed as independent and identical distribution.

Furthermore, this study delves into the plausible threshold effect of green finance and assesses if it induces an asymmetric reaction in the outreach productivity of MFIs concerning deleveraging. Hansen (2000) proposes a static threshold panel model, which has constraints regarding strict exogeneity. To ensure maximum exogeneity, the control variables in Equation (8) reflecting local economic conditions are retained for constructing the threshold model. Nevertheless, the issue of endogeneity, particularly stemming from unobserved individual effects, cannot be overlooked in practice (Dang, Kim, & Shin, 2012). In this regard, Seo & Shin (2016) and Seo, Kim, & Kim (2019) developed a dynamic threshold panel model with first-difference GMM estimators, enabling endogenous determination of threshold values based on constraint variables' characteristics. This approach better addresses potential endogeneity issues within kink restrictions. However, it's important to note that while the model removes unobserved individual effects through first-difference transformation, the GMM estimators may suffer from possible downward bias due to weak instrumental variables in finite samples (Blundell & Bond, 1998). Therefore, this paper advocates for the use of system GMM estimators to enhance the dynamic threshold panel model, ensuring consistent estimates and a valid testing procedure for threshold effects. Thus, Model 2, which tests Hypothesis 2, is formulated as:

$$Y_{i,t} = \alpha + \delta_0 Y_{i,t-1} + \delta_1 DEL_{i,t} \cdot I(GF_{i,t} < \gamma) + \delta_2 DEL_{i,t} \cdot I(GF_{i,t} \geq \gamma) + \varphi_\tau X_{control\ i,t} + u_i + \lambda_t + \varepsilon_{i,t} \quad (9)$$

On the basis of model 1, an indicative equation $I(\cdot)$ is extended in model 2 to grasp the nonlinear effects of deleveraging by introducing a threshold of green finance (GF) at threshold value of γ. If the arguments in parentheses are valid then its value will be 1, otherwise will be 0.

The macroprudential regulatory mechanism pertaining to leverage implementation involves a macroprudential assessment structured around leverage. This assessment aims to identify financial institutions that are excessively leveraged, prompting regulators to veto their leveraging activities (Chen, 2018). The degree of leverage in financial institutions is notably regulated by macroprudential measures. Hence, it is imperative to explore in Hypothesis 3 whether the inclusion of green finance indicators in the macroprudential assessment system significantly affects the deleveraging strategies of MFIs. In this context, the threshold variable is substituted with the interaction between GF & MPI to assess the influence of macroprudential green finance on the relationship between deleveraging strategies and the outreach productivity of MFIs. Model 3 is accordingly adjusted to test Hypothesis 3 as follows:

$$Y_{i,t} = \alpha + \delta_0 Y_{i,t-1} + \delta_1 DEL_{i,t} \cdot I(GF_{i,t} * MPI_t < \gamma) + \delta_2 DEL_{i,t} \cdot I(GF_{i,t} * MPI_t \geq \gamma) + \varphi_\tau X_{control\ i,t} + u_i + \lambda_t + \varepsilon_{i,t} \quad (10)$$

4.2 Data Source

The sample comprises 204 MFIs operating during the mature development phase from 2012 to 2021. Among these, 159 deposit-taking MFIs are identified from a list of small banks, while 45 profit-making MFIs consist of microloan companies and microfinancing guarantee companies, as detailed in Table A2 in the Appendices. Both types of MFIs specialize in providing microfinance services within their respective regions. Data pertaining to the 204 MFIs are primarily obtained from annual reports published by China's National Interbank Funding Center, supplemented by the Wind database, which is the largest economic database in China. Additionally, data for assessing regional economic conditions are sourced from the annual Statistical Yearbooks of the relevant provinces. Descriptive statistics of the variables used in the study are summarized in Table 3.

Table 3: The statistical description of variables

Variables	No. of obs.	Mean	Standard deviation	Min	Max
Dependent Variables					
Financial outreach productivity (GML)	1836	1.010	0.427	0.039	3.671
Technical efficiency change ($GEFFCH$)	1836	1.062	0.494	0.274	4.139
Technological change ($GTECH$)	1836	1.131	0.735	0.053	4.425
Explanatory Variable					
Deleveraging (DEL)	2040	0.171	0.118	0.000	1.000
Threshold Variable					
Green finance (GF)	2040	0.222	0.078	0.071	0.421
Macroprudential green finance ($GF * MPI$)	2040	-0.008	0.247	-0.656	0.753
Control Variables					
Consumer price (CPI)	2040	102.182	0.538	100.6	103.9
Producer price (PPI)	2040	99.482	3.448	82.40	119.4
Real estate price (RPI)	2040	106.860	5.344	88.26	126.9
Economic contribution (EC)	2040	0.059	0.032	0.028	0.110
Government fiscal expenditure (GOV)	2040	0.189	0.082	0.120	0.758

5. Analysis of MFIs' Outreach Productivity

By selecting input-output indicators, the method identifies desired and undesired outputs, enabling the GML-SBM approach to overcome scale changes' limitations and proportionally achieve efficient outputs. Table 4 displays the annual average measurements of MFIs' outreach productivity using the GML-SBM method.

Table 4: Annual average of MFIs' outreach productivity in 2013-2021

Year	GML	$GEFFCH$	$GTECH$
2013	0.760	1.033	0.724
2014	0.997	1.156	0.853
2015	0.906	0.959	0.925
2016	0.956	0.938	1.028
2017	1.062	0.993	1.135
2018	1.267	0.524	2.651
2019	1.022	1.869	0.606
2020	1.113	1.028	1.125
2021	1.093	1.366	0.861

5.1 Overall Analysis

The changes in MFIs' outreach productivity (GML) exhibit two significant inflection points over the average trend. The first occurred in 2014 during an economic transition, resulting in a slowdown in economic growth and a subsequent decline in MFIs' productivity. However, MFIs quickly adapted to mitigate this decline, benefiting from favourable conditions for small businesses and increased demands for microfinance. Subsequently, their productivity steadily recovered since 2015 and remained consistently above 1 since 2017. The second inflection point, observed in 2018-2019 due to financial deleveraging policies, profoundly affected MFIs. Despite policy shocks, MFIs remained productive, surpassing a productivity threshold of 1, indicating their efficiency in producing loans for financial inclusion.

5.2 Analysis of Technical Efficiency Change

The annual technical efficiency change (GEFFCH) showed a continuous drop in technical efficiency from 2015 to 2016, impacting management and scale efficiency. The diminished technical efficiency during this period appears to be a key factor contributing to the decline in the productivity index during economic transition. Although there was a slight improvement in 2017, a significant downturn occurred in 2018. This can be attributed to the weak recovery of small businesses in sustaining the capital chain amid drastic supply-side deleveraging, leading to failure in timely repayments (Zhao, 2022). Subsequent to the enforcement of new capital regulations, more rigorous standards pertaining to capital leverage and comprehensive risk disclosure were introduced, superimposed upon the extant reservoir of non-performing loans inherited from prior periods. Consequently, this compounded the diminished resolve and capacity of MFIs to extend microcredit for the purpose of facilitating financial inclusion (Zhang & Jiang, 2018). Subsequent to the alleviation of constraints and recalibration in managerial and scale efficiency, technical efficiency witnessed a pronounced resurgence in 2019. However, a substantial decline in technical efficiency became apparent in 2020, attributable to the disruptive impact of the Covid-19 pandemic. Across the entire trajectory, variations in technical efficiency exert a pivotal influence on alterations in financial outreach productivity.

5.3 Analysis of Technological Change

Regarding technological change (GTECH), it appears that advancements in technology serve as the primary catalyst in sustaining a relatively stable level of productivity, thereby mitigating steep declines in outreach productivity commensurate with fluctuations in technical efficiency. This underscores the adeptness of MFIs in adapting to shifts in policies and market dynamics to seize the frontier of best practices through technological innovations, including advancements in business models and product offerings.

6. Empirical Results and Discussion

6.1 Estimation results of direct effect in Model 1

The initial model employed in this study utilizes the system GMM estimation technique to account for dynamic interrelationships among variables while addressing concerns related to persistence and endogeneity. As indicated in Table 5, a preliminary examination through Arellano-Bond (AR) tests and Hansen's test effectively rules out the existence of second-order autocorrelation and overidentification of instruments in the system GMM estimations (Blundell & Bond, 1998; Windmeijer, 2005). The outcomes derived from the application of robust two-step system GMM estimators affirm the consistency and efficiency of all estimates.

Table 5 reveals a noteworthy observation: the lag terms of financial outreach productivity (L.GML), technical efficiency change (L.GEFFCH), and technological change (L.GTECH) exhibit unexpected negative influences on their corresponding current terms. The emergence of these notably adverse effects in lag terms may be attributed to the non-parametric approach employed in measuring efficient DMUs. Under the productivity criterion of up to 1, designated DMUs are deemed efficient, facilitating their convergence with or advancement beyond the production frontier (Tone, 2001). Hence, if DMUs operate efficiently in the preceding period, the continuation of the initial production mode persists into the current period, notwithstanding the possibility of employing the super-efficiency approach, which enables the comparison of productivity beyond the conventional limit of 1 (Tone, 2002). In situations where DMUs exhibit inefficiency or experience a decline in efficiency in the previous period, adjustments to the production mode are made to enhance efficiency in the current period, aiming for closer alignment with the production frontier or a transition towards the best-practice frontier. The discernible trend in Table 4 underscores that outreach productivity can swiftly rebound positively in the current period following a substantial negative downturn in the preceding period. These adverse impacts elucidate that the productivity of the previous period serves as a substantial determinant for the alterations in productivity in the current period.

Additionally, column (1) presents a positive impact of deleveraging (DEL) on outreach productivity (GML) of MFIs at 1% significant level. As per Sinha & Ghosh (2022), deleveraging establishes a more stable and sustainable financial structure for MFIs. This reduction in debt burden enables MFIs to alleviate the challenges of expensive debt financing, freeing up cash flow for operational investments. Furthermore, deleveraging enhances an MFI's credit rating, facilitating easier and cheaper access to funds when needed in the future. This stable capital structure contributes to increased outreach productivity by reducing debt input and expanding the loan portfolio for financial inclusion outcomes. In the decomposition of outreach productivity coefficients, specifically in column (2), the implementation of deleveraging by MFIs demonstrates a significantly positive impact on technical efficiency change (GEFFCH) at a 10% significance level. This suggests that the deleveraging process optimizes technical progress in managerial efficiency and scale efficiency, leveraging economies of scale through a potential decrease in transaction costs with the inclusion of more clients in financial support (Awaworyi Churchill, 2020). In a simplified context, deleveraging aids Microfinance Institutions (MFIs) in effectively meeting the demands of microfinance, facilitating their convergence towards the production frontier. In the context of the regression analysis for technological change (GTECH), column (3) reveals a positive influence of deleveraging on technological change. This signifies that deleveraging fosters technological innovation, encompassing product and business innovations, thereby advancing the production frontier of

outreach towards financial inclusion. Notably, the impact of deleveraging on technical efficiency change is more elastic and substantial than its effect on technological change. In essence, the favourable impact of deleveraging on outreach productivity is predominantly driven by its facilitation of technical progress. In other words, deleveraging is responsive to MFIs catching up with efficient outreach for financial inclusion through the accrual of scale economies.

Table 5: Dynamic Regression Results for Direct Effects of Deleveraging of Mfis.

Variables	(1) GML	(2) $GEFFCH$	(3) $GTECH$
$L.GML$	-0.069*		
	(-1.79)		
$L.GEFFCH$		-0.359**	
		(-2.53)	
$L.GTECH$			-0.112***
			(-2.69)
DEL	0.208***	11.926*	0.189***
	(2.90)	(1.82)	(2.83)
CPI	0.077***	0.380***	-0.263***
	(2.67)	(2.90)	(-4.65)
PPI	0.017***	0.037**	0.012
	(2.96)	(2.53)	(1.64)
RPI	0.008**	-0.030***	0.066***
	(2.31)	(-2.92)	(11.44)
EC	2.667	69.133***	-2.171***
	(0.95)	(3.89)	(-2.75)
GOV	1.551	23.570***	-0.766***
	(0.93)	(2.76)	(-2.95)
Covid-year effect	YES	YES	YES
AR (1)	0.000	0.000	0.000
AR (2)	0.206	0.132	0.256
Hansen test	0.116	0.196	0.163
Obs.	1632	1632	1632

Note: ***, ** and * indicate significance at 1%, 5% and 10% respectively. Figure in () are t-values of coefficients. All tests report p-value. The GMM estimators are obtained using Stata module xtabond2.

6.2 Robustness Tests

In prior empirical studies, the substantial direct effects of deleveraging on outreach productivity were identified across the entire sample of MFIs. To ensure the robustness of these findings across diverse types of MFIs, the analysis is replicated for subsamples, specifically deposit-taking and profit-making MFIs. Table 6 presents the robustness results for the corresponding estimations. The empirical outcomes align closely with the findings of the overall sample; however, varying degrees of impact are observed across different subsamples. Notably, evidence indicates that deleveraging in both types of MFIs is positively correlated with their outreach productivity and decompositions. Hence, the estimation of the direct effect of deleveraging on outreach productivity in the overall MFI sample is deemed robust.

Table 6: Dynamic Regression Results for Direct Effects of Deleveraging in Different Subsamples of Mfis.

	Deposit-taking MFIs			Profit-making MFIs		
Variable	(1) GML	(2) $GEFFCH$	(3) $GTECH$	(4) GML	(5) $GEFFCH$	(6) $GTECH$
$L.GML$	-0.133**			-0.119**		
	(-2.17)			(0.234)		
$L.GEFFCH$		-0.696***			-0.372**	
		(-8.11)			(-2.13)	
$L.GTECH$			-0.181***			-0.263**
			(-3.52)			(-2.03)
DEL	0.289**	4.944**	0.193*	0.190*	13.628**	0.114***
	(2.53)	(2.22)	(1.74)	(2.02)	(2.17)	(3.65)
CPI	0.108***	0.209**	-0.198***	0.003	0.519***	-0.293***
	(4.34)	(2.17)	(-2.68)	(0.06)	(3.25)	(-2.86)
PPI	0.020***	0.011	0.013	0.023***	0.061*	0.013
	(3.17)	(0.92)	(1.53)	(4.91)	(1.98)	(1.26)
RPI	0.009*	-0.046***	0.066***	-0.005	-0.082***	0.040***
	(1.99)	(-7.95)	(9.68)	(-0.12)	(-4.27)	(3.31)
EC	2.734	29.560*	-2.032	1.353*	80.426**	-1.900
	(0.94)	(1.83)	(-1.62)	(1.87)	(2.15)	(-1.43)
GOV	1.755	8.972*	-0.388	0.424	15.471*	-1.084***
	(1.02)	(1.68)	(-0.68)	(0.79)	(1.90)	(-3.18)
Covid-year effect	YES	YES	YES	YES	YES	YES
AR (1)	0.000	0.000	0.000	0.006	0.002	0.000
AR (2)	0.142	0.137	0.144	0.272	0.281	0.203
Hansen test	0.207	0.109	0.288	0.102	0.228	0.244
Obs.	1272	1272	1272	360	360	360

Note: ***, ** and * indicate significance at 1%, 5% and 10% respectively. Figure in () are t-values of coefficients. All tests report p-value. The GMM estimators are obtained using Stata module xtabond2.

6.3 Estimation Results for Model 2

As detailed in the methodology section, a bootstrap with 1000 iterations is employed to capture the gradual distribution of statistics for the threshold effect within 95% confidence intervals. Table 7 presents the threshold effects of GF for regressions involving outreach productivity, technical efficiency change, and technological change. It is important to note that the specific analysis in this study encompasses all regressions with the inclusion of control variables, as the threshold values for green finance did not exhibit significant variations with changes in the combinations of added control variables in prior tests. Based on the p-values and confidence intervals, the threshold effects of green finance in all dynamic threshold models are statistically significant, rejecting the null hypothesis of no threshold effect within non-crossing zero confidence intervals. Consequently, the nonlinear impacts of deleveraging on MFIs' productivity, attributed to changes in green finance, underscore the necessity of introducing dynamic threshold panel models.

Table 7: The Threshold Values of Green Finance and Its Confidence Intervals.

Explained variables	Threshold (GF) value	P-value	Bootstrap	95% confidence interval	
				Lower	Upper
GML	0.189	0.070	1000	0.177	0.194
$GEFFCH$	0.145	0.031	1000	0.143	0.147
$GTECH$	0.305	0.023	1000	0.300	0.319

To preserve more information in a finite sample while addressing endogeneity and individual effects, the preference for estimation in all dynamic models lies with the system GMM. Like the analysis of direct effects in Model 1, the introduction of Arellano-Bond (AR) tests and Hansen's tests is imperative. As delineated in Table 8, the outcomes of AR (1) and AR (2) tests indicate the absence of second-order autocorrelation in all regressions, even with the allowance of first-order autocorrelation. Moreover, the results of Hansen's tests do not warrant rejection at the 10% significance level, thus refuting the possibility of overidentification for the selected instrument variables. Additionally, the assessment of bootstrap-based Wald statistics is employed to ascertain whether deleveraging effects exhibit nonlinearity due to the inclusion of the threshold variable of green finance. The results of Wald statistics consistently support the hypothesis of threshold effects of green finance in all regressions, with significance levels of at least 5%.

As delineated in the results of dynamic threshold regressions presented in Table 8, column (1) reveals that variations in green finance exert divergent effects on the impact of deleveraging on outreach productivity. Specifically, when the level of green finance descends below the established threshold (0.190), the growth of green finance impedes the deleveraging effect on outreach productivity. Subsequently, upon surpassing the threshold, a positive impact of deleveraging on outreach productivity emerges, surpassing the preceding negative effect and exceeding the direct effect. Evidently, only substantial progress in green finance can facilitate the positive impact of deleveraging on outreach productivity; otherwise, it proves counterproductive. Drawing on the "financial accelerator" theory, any shock induces the reallocation of credit rationing (or capital allocation) between "loose" and "tight" by influencing additional agency costs arising from the asymmetric characteristics of information in the credit market, thereby influencing economic fluctuations through the financial accelerator effect (Bertomeu & Cheynel, 2013; Wang, 2020). In this context, given the surpassing of the threshold by the growth in green finance, there is potential for the reallocation of credit by MFIs toward small businesses, thereby fostering an accelerated pace of economic transition.

Upon thorough examination in column (2) following a comprehensive decomposition, it is evident that when the level of green finance descends below the threshold of 0.145, the positive impact of deleveraging on technical efficiency change surpasses that observed when the level of green finance exceeds the threshold, albeit significantly smaller than its direct effect. This indirectly validates Duqi's (2023) perspective that, despite deleveraging alleviating liquidity pressure for MFIs to lend, the limited scale of green credit for small businesses results in insufficient effective demand to achieve economies of scale. This is attributed to the challenge faced by small businesses in sustaining green project requirements over the long term.

In examining the effect on technological change, akin to the impact on outreach productivity, it is noteworthy that the threshold effect of green finance leads to a polarization of the deleveraging effect on technological progress between negative and positive. One potential explanation is that in the initial stages of green finance development, the high leverage ratio of green projects creates discord between the green finance landscape and the deleveraging initiatives of MFIs, resulting in idle capital (Zhou, Tang, & Zhang, 2020). As green finance matures, MFIs increasingly prioritize green innovation in financial inclusion. Consequently, once green finance reaches a certain level and exerts a herd effect (Gao, Li, & Wang, 2023), deleveraging stimulates an acceleration of technological innovation, propelling the production frontier from outreach to financial inclusion.

6.4 Estimation Results for Model 3

Building upon the examination of threshold effects of green finance in Model 2, this study extends its focus to the interplay between green finance and macroprudential initiatives. The analysis, as depicted in Table 9, preliminarily affirms the threshold effects of macroprudential green finance ($GF * MPI$) in all regressions, evident through p-values reaching significance levels and non-crossing zero confidence intervals. Consequently, it becomes imperative to employ dynamic threshold panel models to systematically explore the specific threshold effects associated with macroprudential green finance.

Table 8: Dynamic Regression Results with Green Finance as A Threshold Variable.

Variables	(1) GML	(2) $GEFFCH$	(3) $GTECH$
$L.GML$	-0.346***		
	(-6.86)		
$L.GEFFCH$		-0.305***	
		(-3.36)	
$L.GTECH$			-0.217***
			(-4.17)
$DEL * I(GF < \gamma)$	-0.498*	1.964**	-0.245**
	(-1.93)	(2.60)	(-2.33)
$DEL * I(GF \geq \gamma)$	0.248**	1.085*	1.099***
	(2.51)	(1.95)	(8.33)
CPI	0.119***	0.462***	-0.231***
	(3.61)	(6.42)	(-3.96)
PPI	0.016***	0.013	0.013*
	(2.67)	(0.88)	(1.73)
RPI	0.008*	-0.027*	0.061***
	(1.88)	(-1.66)	(10.33)
EC	3.470	54.713**	-4.774***
	(1.41)	(2.35)	(-5.12)
GOV	3.346*	9.385*	-0.784**
	(1.85)	(1.70)	(-2.04)
Covid-year effect	YES	YES	YES
Wald test	7.55***	6.53**	87.71***
AR (1)	0.001	0.047	0.000
AR (2)	0.182	0.155	0.341
Hansen test	0.165	0.280	0.157
Obs.	1632	1632	1632

Note: ***, ** and * indicate significance at 1%, 5% and 10% respectively. Figure in () are t-values of coefficients. All tests report p-value, except Wald test which is used to judge whether the threshold effect is significant by observing χ^2 statistics. The GMM estimators are obtained using Stata module xtabond2.

Table 9: The Threshold Values of Macroprudential Green Finance and Its Confidence Intervals.

Explained variables	Threshold $(GF * MPI)$ value	P-value	Bootstrap	95% confidence interval	
				Lower	Upper
GML	0.107	0.083	1000	0.104	0.276
$GEFFCH$	0.181	0.007	1000	0.168	0.186
$GTECH$	0.299	0.040	1000	0.184	0.327

Similarly, as indicated in Table 10, the noteworthy outcomes of Wald tests illustrate that the impact of macroprudential green finance introduces nonlinearity in dynamic regressions encompassing outreach productivity, technical efficiency change, and technological change. The application of system GMM estimators, passing both AR tests and Hansen's tests, ensures the reliability and efficiency of estimates. Specifically, the results in column (1) reveal that deleveraging exerts a significant and positive impact on outreach productivity only when macroprudential green finance remains below the threshold of 0.107, losing significance above this threshold. This observation underscores the pivotal role of macroprudential intervention in the early stages of green finance development, where such intervention is conducive to counteracting the negative effects of deleveraging in the segment of green finance levels below the threshold (refer to Table 8) and alleviating the incongruity between the deleveraging efforts of MFIs and highly-leveraged green projects in microfinance (Gortsos, 2020). Surprisingly, in column (2), the results indicate that deleveraging has a consistently negative impact on technical efficiency change, regardless of whether macroprudential green finance is below or above the threshold (0.181). This may be attributed to heightened macroprudential regulation imposing stringent conditions on green lending, particularly for financially vulnerable small businesses committing to green requirements (Kedward, Ryan-Collins, & Chenet, 2020). Consequently, the insufficient effective demand for green lending hinders the achievement of scale efficiency, preventing the catching up to the optimal frontier in the context of reduced external funds under deleveraging.

Table 10: Dynamic Regression Results with Macroprudential Green Finance As A Threshold Variable.

Variables	(1) GML	(2) $GEFFCH$	(3) $GTECH$
$L.GML$	-0.119***		
	(-2.77)		
$L.GEFFCH$		-0.539***	
		(-5.14)	
$L.GTECH$			-1.139***
			(-4.08)
$DEL * I(GF * MPI < \gamma)$	0.263***	-0.218*	1.765***
	(2.83)	(-1.85)	(3.11)
$DEL * I(GF * MPI \geq \gamma)$	0.015	-0.246**	-1.239*
	(0.09)	(-2.17)	(-1.84)
CPI	0.071**	0.131	1.369***
	(2.25)	(1.62)	(3.63)
PPI	0.011*	0.004	-0.175***
	(1.80)	(0.35)	(-3.13)
RPI	0.016***	-0.063***	0.275***
	(3.47)	(-4.97)	(5.04)
EC	1.595	1.635	25.666
	(0.32)	(1.53)	(0.42)
GOV	1.083	0.892*	11.195
	(0.37)	(1.82)	(0.41)
Covid-year effect	YES	YES	YES
Wald test	5.78**	15.33***	21.06***
AR (1)	0.000	0.000	0.000
AR (2)	0.162	0.206	0.230
Hansen test	0.130	0.293	0.241
Obs.	1632	1632	1632

Note: ***, ** and * indicate significance at 1%, 5% and 10% respectively. Figure in () are t-values of coefficients. All tests report p-value, except Wald test which is used to judge whether the threshold effect is significant by observing χ^2 statistics. The GMM estimators are obtained using Stata module xtabond2.

Regarding the effect on technological change, macroprudential green finance below the threshold (0.299) enhances the

positive impact of deleveraging on technological innovation, while this effect turns negative as macroprudential green finance exceeds the threshold. In contrast to the singular threshold effect of green finance, macroprudential regulation appears to facilitate the green innovation of MFIs, reinforcing the deleveraging effect on the combination of capital efficiency and technological innovation. However, as the development of green finance matures, the intervention of macroprudential regulation may counterproductively affect the deleveraging effect. Hence, the strength of macroprudential regulation should be judiciously adjusted in response to the growth of green finance.

7. Conclusion

This study utilizes the GML method to assess the outreach productivity of 204 MFIs in China from 2012 to 2021, focusing on financial inclusion. Employing dynamic panel regressions and a dynamic threshold panel model, we analyse the direct effects of MFIs' deleveraging on outreach productivity, including technical efficiency change and technological change. We further explore the role of green finance, developed through the entropy method, and its interaction with macroprudential index, employing dynamic threshold panel models. Results, estimated through the system GMM method, reveal that MFIs' deleveraging positively impacts outreach productivity, primarily through enhanced scale and management efficiency, with limited contributions from technological innovation. Additionally, the threshold effect of green finance introduces nonlinearity in the deleveraging effect on outreach productivity, turning from negative to positive with increasing green finance up to a threshold. Green finance also influences the nonlinear relationship between deleveraging and technological innovation. Despite the positive role of green finance in enhancing technical efficiency change through deleveraging, this effect diminishes beyond a certain threshold. Moreover, the threshold effect of macroprudential green finance introduces a nonlinear association between deleveraging and outreach productivity. However, this relationship is only found to be significant and positive within a specific range of green finance values below the threshold. In terms of decomposition, whether green finance is above or below the threshold, deleveraging hampers technical efficiency progress. Meanwhile, the effects of deleveraging on technological change vary in direction depending on the interval in which green finance falls relative to the threshold.

Hence, the outcomes suggest clear policy implications. Primarily, the deleveraging efforts of MFIs are pivotal in enhancing access to financial inclusion for small businesses and fostering economic transition. This is achieved by mitigating "funds idling" within financial and fiscal systems. Notably, the deleveraging of MFIs is especially effective in promoting technical efficiency progress, underscoring its role in bolstering financial sustainability. This is achieved by curbing risk-taking activities related to external debts and fortifying financial stability (Dai et al., 2023). Therefore, regulatory authorities should carefully consider the deleveraging efforts of MFIs and regional leverage levels when evaluating their capital structure. MFIs with robust balance sheets should be given preferential access to multiple financing opportunities and encouraged to operate across regions, leveraging their management efficiency for scale economies in serving small businesses. While deleveraging assists in technological advancements, fostering innovation in loan products and decentralized mechanisms, caution must be exercised, as financial innovation may amplify vulnerabilities, potentially resulting in negative consequences like an unreasonable financing structure and increased costs for economic entities (Ajello et al., 2022). Regulatory authorities should enhance mechanisms addressing risk insensitivity in capital regulation for MFIs, aligning incentives and constraints in microfinance operations. This includes incentivizing MFIs for expanding financial inclusion and improving credit allocation efficiency to small businesses through technological innovation. Simultaneously, constraints should be imposed to prevent excessive use of financial innovations, especially off-balance sheet practices, for leveraging. Additionally, the observed threshold effect of green finance underscores the importance of collaborative efforts by regulatory authorities to incentivize long-term commitments to green projects. This can facilitate green finance development and enable MFIs to effectively implement environmentally sustainable credit services, contributing to economic transition. In regions where green finance is nascent, regulatory authorities may consider easing leverage restrictions on MFI green credit activities. This initiative encourages MFIs to align with green finance, addressing challenges in expanding outreach productivity during deleveraging pressures. In practical terms, macroprudential intervention mitigates the adverse effects of deleveraging on MFIs' outreach productivity in the early stages of green financial development, demonstrating the effectiveness of macroprudential assessment. However, as green finance matures, a uniform macroprudential approach hampers effectiveness, impeding technical efficiency progress and technological innovation. Hence, dynamic refinement of macroprudential assessment for green finance is essential, aligning closely with microfinance development. Simultaneously, it should flexibly adjust regulations on MFIs' financial leverage based on the nature of green finance transactions, addressing regulatory gaps and loopholes.

While this paper presents a pioneering quantitative exploration of the nonlinear impact of deleveraging on the outreach productivity of MFIs in China, it is essential to acknowledge certain limitations and identify avenues for future research. Notably, the focus of this study is on empirical investigations, yet understanding the mechanisms underlying the nonlinear relationship between deleveraging and MFIs' outreach productivity is equally crucial. Therefore, future research is encouraged to delve into establishing comprehensive theoretical frameworks to elucidate the empirical findings.

Moreover, the outreach productivity constructed in this study

predominantly reflects the financial performance of MFIs in the realm of financial inclusion. However, the study falls short in capturing the social well-being contributions of MFIs in practicing outreach to financial inclusion. Subsequent research endeavours by Hudon & Périlleux (2014) are advised to augment this understanding by exploring the relationship between deleveraging and the outreach productivity of MFIs within the social dimension, employing analytical methods akin to productivity surplus distribution.

Declaration

Availability of data and material

Data sharing is not applicable to this article as no new data were created in this study.

Competing Interests

The authors declared that they have no competing interests.

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Author Contributions

YL: conceptualization, project administration, data curation, formal analysis, and writing (original draft, review and editing). ZMA: investigation, methodology, writing (original draft) and supervision. WNS: software and writing (review and editing). NHAR: writing (review and editing) and validation. All authors read and approved the final manuscript.

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Appendices

Table A1: List of Control Variables.

Variable	Symbol	Description
Consumer Price	CPI	Annual change in local consumer price based on previous year's level of 100
Producer Price	PPI	Annual change in local producer price based on previous year's level of 100
Real Estate Price	RPI	Annual change in local real estate price based on previous year's level of 100
Economic Contribution	EC	Local GDP / national GDP
Government Fiscal Expenditure	GOV	Local fiscal expenditure / local GDP

Table A2: Characteristics of main types of MFIs in China
(Luo & Rahman, 2010; Tang, 2009; Zhao & Han, 2020)

Type	Nature	Since	Regions	Target clients	Traditional collateral	Annual interest rate
Deposit-taking	Urban Commercial Banks	2005	Urban Areas	Low-income citizens & laid-off workers	Guarantee companies	Zero or low interest rate
Deposit-taking	Rural commercial banks (Village banks)	2006	Rural Areas	Farming households & micro/small enterprises	Uncertainty	0.9-2.3 times basic rate
Profit-making	Microloan / Micro-guarantee Companies	2008	Local	Citizens & micro/small enterprises	Uncertainty	14-28% but 21% on average

Abbreviations

AR	Arellano-Bond
DEA	Data envelopment analysis
DMU	Decision-making unit
GDDF	Global-directional distance function
GDP	Gross domestic product
GF	Green finance
GML	Global Malmquist-Luenberger
GMM	Generalized method of moments
MFI	Microfinance Institution
MPI	Macroprudential index
SBM	Slack-based measure