ENVIRONMENTAL RESEARCH
LETTERS

Financial inclusion may limit sustainable development under economic globalization and climate change

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Abstract

Financial inclusion is a key policy for achieving the UN Sustainable Development Goals worldwide. However, emerging evidence has challenged the universal effectiveness of this policy. Combining a cross-sectional socio-economic and ecological survey with regional macro-economic and climatic data, we undertook an integrated causal analysis of the impact of financial inclusion policy on the Inner Mongolian herder social-ecological system. Exposure to economic globalization and climate change threatened herder livelihoods via increased feed costs and reduced livestock sales prices. Financial inclusion loans were beneficial for herders with large grassland plot size who used their traditional ecological knowledge to adapt via seasonal herd mobility. However, most herders were sedentary, constrained by small plot size, and used financial inclusion loans to reserve livestock and maintain high stocking densities. This strategy exposed them to inflated feed costs, increased their debt, and led to widespread grassland degradation. The results illustrate the limitations of financial inclusion policy in achieving sustainable development when people are trapped in poverty, subject to novel social-ecological contexts, and their ability to adapt is compromised. Transformative adaptations based on community cooperation, traditional knowledge and institutions, complementary public policies, and technological innovation are crucial to support financial inclusion policy and enhance sustainable development.

1. Introduction

Financial inclusion is a key policy for achieving multiple Sustainable Development Goals (SDGs) and implementing the pledge of 'leaving no one behind' under the United Nations' Agenda 2030 (Arun and Kamath 2015, United Nations 2015, Corrado and Corrado 2017, UNSGSA *et al* 2018). Policy mechanisms include improving poor people's access to financial services and providing credit at affordable interest rates (Arun and Kamath 2015, Corrado and Corrado 2017). Financial inclusion policy (previously known as microfinance) has been widely used to help rural people increase productivity and profits, thereby contributing to the achievement of several SDGs, most prominently: SDG 1 No poverty, SDG 2 Zero hunger, SDG 8 Decent work and economic growth, and SDG 15 Life on Land (United Nations 2015, Corrado and Corrado 2017, UNSGSA *et al* 2018).

However, the combined impacts of economic globalization and climate change (O'Brien and Leichenko 2000) may aggravate local social-ecological system crises (Olsson *et al* 2004, Bryan 2013, Chaffin and Gunderson 2016) and pose a novel threat to

smallholders and the environment (Lamichhane *et al* 2020). Smallholders have limited access to global markets (Amare *et al* 2019) and may lose access to local markets when faced with competition from imports. For instance, smallholders in several Chinese agricultural sectors (e.g. soybean, cotton) have lost their competitive advantage following exposure to global markets (Huang *et al* 2009). In addition, extreme climatic events such as El Niño-induced droughts have become more frequent and severe (Cai *et al* 2018), affecting smallholders' livelihoods in developing countries. Under global change, complex interactions between these social-ecological system components can affect the ability of rural people to maintain incomes and livelihoods from smallholder agriculture and animal husbandry (Eakin 2005, Guido *et al* 2020). Hence, exposure to climate change and globalization can put the benefits of financial inclusion policy for smallholders' livelihoods and environment at risk (Chaffin and Gunderson 2016). Undesirable outcomes of financial inclusion policy have occurred in several regions, including the rural areas of India (Taylor 2011, Mader 2013) and the Mongolian Plateau (Murphy 2018, Zhang *et al* 2018, Li and Li 2021).

Financial inclusion underpins rural development and environmental conservation in China's grasslands which cover around 40% of its land area. Historically, the exclusion of herders from financial services forced them to take out usurious (i.e. high interest) loans and exacerbated poverty and grassland degradation (Li and Huntsinger 2011). Introduced in Inner Mongolia in 1998 (Zhang *et al* 2018) and Tibet in 2001 (Gongbuzeren 2016), financial inclusion policy met with some initial success but over time lost its effectiveness. The policy lacked flexibility in repayment arrangements, with herders having to sell livestock at low prices (Zhang *et al* 2018) or take out usurious loans (Gongbuzeren 2016, Gongbuzeren *et al* 2020) in years of extreme climatic events (i.e. drought and snow) to meet annual financial inclusion loan repayments. After 2015, subsequent reforms better-adapted the policy to dynamic grassland environments by increasing credit, loosening guarantee demands, and providing longer-term loans, debt extension, and refinancing mechanisms (State Council PRC 2015). However, these policy reforms did not achieve the desired outcomes, suggesting more complex causal mechanisms at play.

In addition to economic globalization and climate change, the effects of financial inclusion policy are also compounded by local grassland property tenure. Introduced in 1979, the Rural Household Responsibility System (China's major rural land reform program) gradually divided most of Inner Mongolia's vast public grasslands into fragmented, family-owned plots (Li *et al* 2007, Li and Huntsinger 2011).

Allocated only a small area of grassland, most herders were forced to abandon traditional seasonal livestock movements and community cooperation, and became dependent upon hay from external markets as a supplemental feed source (Robinson *et al* 2017). As a result, herders lost their capacity to adapt to volatile markets and climate change via traditional ecological knowledge, and became trapped in a vicious cycle of debt and environmental degradation (supplementary note 1 (available online at stacks.iop.org/ERL/16/054049/mmedia)).

In this study, we undertook an integrated causal analysis of the effects of financial inclusion policy on the sustainable development of the Inner Mongolian grasslands social-ecological system, where herders faced novel challenges of economic globalization and climate change characterized by volatile markets and extreme climatic events. We first assessed the drivers of changes in herders' profits and costs by collecting and analyzing regional scale macroeconomic and climatic data. We then assessed the influence of financial inclusion loan availability on livestock selling ratio and grazing intensity based on a cross-sectional socio-economic survey of 98 households from 2015 to 2018 (figures 1(A) and (B)) and assessed the ecological effects of herd management on the grassland environment via an ecological survey of each household's grassland. We integrated the social-ecological data at both regional and local scale, and used novel causal inference methods to assess the effects of financial inclusion policy in the Inner Mongolian grasslands. We analyzed the multiple sources of macroeconomic, microeconomic, and environmental data following the four-point approach (i.e. establishing covariation, verifying temporal precedence, ruling out alternatives, and providing an explanatory mechanism, Spector 2019) for causal inference to establish the complex links among financial inclusion loans, herder adaptation, grassland resource availability, and social-ecological consequences. This new understanding of the context-sensitive interactions between financial inclusion policy and other multi-scale social-ecological processes is essential for enabling progress towards the SDGs and promoting sustainable development globally.

2. Methods

Financial inclusion policy aims to provide more accessible credit for herders to increase production and economic returns. However, many other factors influence the economic returns to herders' in rangelands, in particular livestock sale price and the cost of hay. We undertook an integrated causal analysis of the effects financial inclusion policy on herd management, herder livelihoods, and the environmental health of grassland ecosystems relative to other influential factors. In this section, we provide
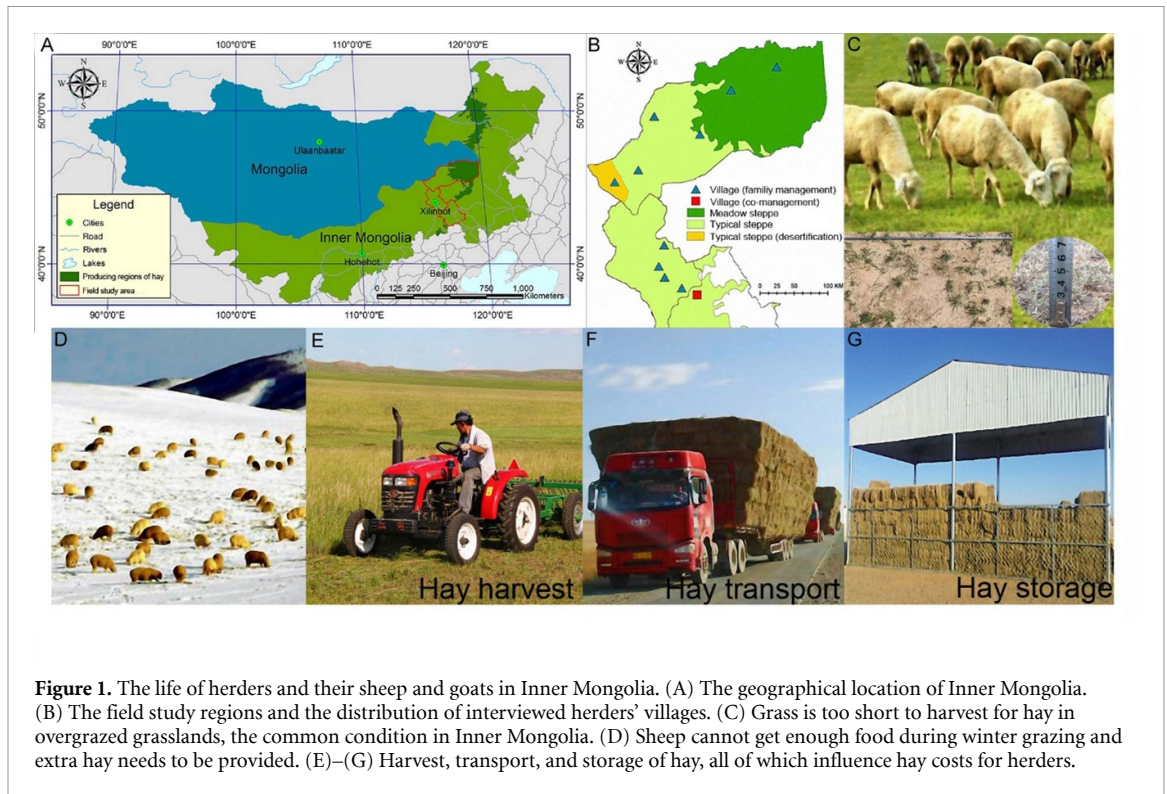
Figure 1. The life of herders and their sheep and goats in Inner Mongolia. (A) The geographical location of Inner Mongolia. (B) The field study regions and the distribution of interviewed herders' villages. (C) Grass is too short to harvest for hay in overgrazed grasslands, the common condition in Inner Mongolia. (D) Sheep cannot get enough food during winter grazing and extra hay needs to be provided. (E)–(G) Harvest, transport, and storage of hay, all of which influence hay costs for herders.

some background to the study area and describe the collection of provincial level macroeconomic and climatic data. We then describe the socio-economic and ecological survey of herder households and grasslands. Last, we describe the causal inference and statistical methodologies used to quantify the impacts of financial inclusion.

2.1. Study area and background
Our field study area was located in the Xilingol grassland in central Inner Mongolia (figures 1(A) and (B)). The cold, continental, semi-arid climate has become drier and more variable, with more frequent extreme drought and snow events (supplementary note 2). During winter and drought periods, livestock typically require supplemental fodder in Inner Mongolia (figures 1(A), (C), and (D)). Over the past decade, most herders have been forced to purchase hay at market prices due to limited grassland area, overgrazed pastures, and grassland degradation exacerbated by droughts (figures 1(E)–(G)).

Before the 2015 financial inclusion policy reforms, the initial standard credit line for each household was 100 000 Yuan (~15 000 USD) with an interest rate of 9.6% p.a. The reforms increased the standard credit line to 300 000 Yuan (~45 000 USD). Around 90% of herders obtained a loan via the financial inclusion policy (Xilingol Central Branch of the People's Bank of China 2017), but lending behavior varied among herders, with around 30% of herders also taking out supplementary usurious loans at a higher interest rate (at least 30% p.a.).

2.2. Climatic and economic data at provincial level
We established a long-term provincial dataset consisting of climatic data and economic data about household livestock husbandry, to assess the changes in the social-ecological system of Inner Mongolia resulting from economic globalization and climate change from 2001 to 2019. We used two global climate events to characterize the climate dynamics of Inner Mongolia, namely the El Niño-Southern Oscillation (supplementary table S1, Rayner *et al* 2003) and the East Asian summer monsoon (EASM, supplementary figure S1, Wang *et al* 2008), which correlate with droughts in Inner Mongolia (Huang *et al* 2015, Liu *et al* 2016). We obtained records of extreme snow events from Inner Mongolia's annual environmental reports (supplementary table S2).

We assembled economic data from diverse sources to describe changes in household livestock husbandry from 2001 to 2019 in Inner Mongolia, including domestic market and import prices of sheep and goat meat, the cost of household livestock husbandry, and stocking rates (supplementary note 2). We obtained data on China's KOF Globalization Index (2001–2016, Gygli *et al* 2019), the consumer price index (CPI), and a money supply index (M2, the sum of cash, checking deposits, and near money) to quantify the extent of China's exposure to economic globalization (supplementary note 2).

2.3. Experimental design of field survey
To evaluate the effects of financial inclusion policy on livestock management and grassland health, we conducted an extensive, field-based, cross-sectional

social-ecological survey in the Xilingol grassland from October 2015 to December 2018 (figure 1(B)). We randomly selected 11 villages in the study region. We obtained loan information from bank managers and village leaders and used stratified random sampling to randomly select around 10% of families from each village. We surveyed 98 families from 11 villages spanning the full range of available grassland area (plot size), climate, and biophysical environment (see supplementary table S3, figure S2). Herders were allocated to two groups with distinct management styles based on their livestock mobility: a Sedentary group and a Mobile group. Overall, the 44 (out of 98) families surveyed managed their herds with traditional seasonal rotations, and these were allocated to the Mobile group. The other 54 families who had abandoned traditional seasonal herd movements due to limitations in grassland area were allocated to the Sedentary group (see supplementary notes 1 and 2).

We conducted semi-structured interviews to collect a range of socio-economic information about the herder households, including borrowing behavior, grassland area, herd management, and livelihoods. We asked herders specifically about their livestock selling ratio (the proportion of the herd sold) and grazing intensity (sheep units per hectare of grassland)—two key indicators of livestock and grassland management which are strongly linked to economic and environmental sustainability (supplementary table S4). We also asked herders to assess the effects of financial inclusion policy on their livestock businesses. During the survey, we invited them to identify key problems and constraints affecting their livelihoods. We recorded their local adaptations and their requirements for public services. We also collected information from other stakeholders such as bank clerks and local government officers. We asked bank clerks about herders' borrowing behavior and repayment conditions to cross-check the survey responses. We also enquired about the assessment process for financial inclusion policy from the bank's perspective. We interviewed local government officers from different agencies about their understanding of local livestock business, hay resources, financial inclusion policy, and the level of coordination among agencies. We also asked about other types of policy interventions implemented by local governments to alleviate the effects of drought and unfavorable market conditions.

In parallel, we carried out a comprehensive vegetation and soil survey in each household's grassland plot from August 5th to 20th (i.e. during peak annual standing biomass) of 2016 and 2018. We measured a number of fast ecological variables that are sensitive to changes in rainfall and grazing during the year including aboveground biomass, community height, species richness, root biomass, and soil organic carbon (SOC) and total nitrogen (TN) in the topsoil layer (see supplementary note 2).
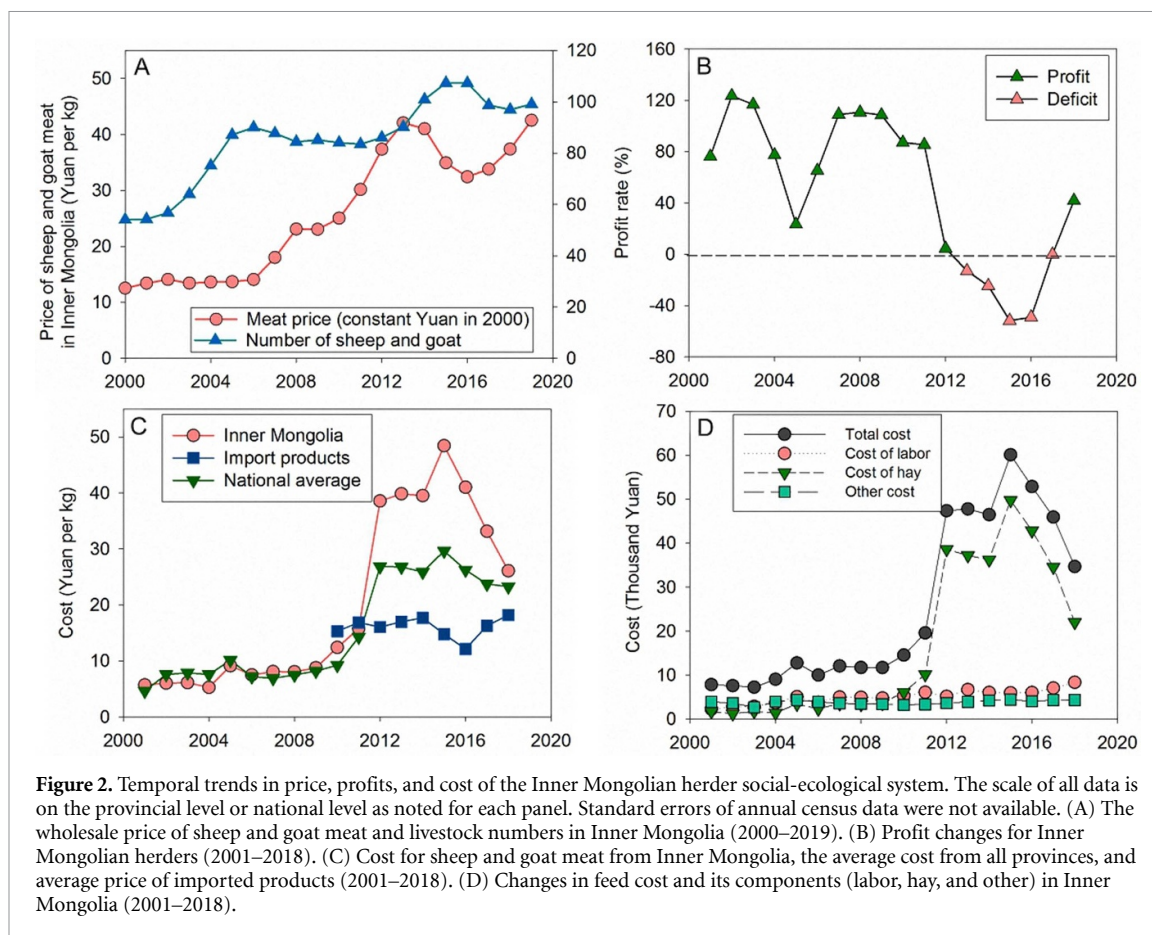
2.4. Data pre-processing

We first adjusted all price and cost values for inflation, converting them to constant values for the year 2000 via the CPI (Mankiw 2010); visualized trends in prices and costs over time; and plotted the correlations between hay cost, climate, and macro-economic factors. We standardized all field survey data by the *z*-score method, checked the cross-correlations among variables, and excluded the amount of ecological subsidies (Bryan *et al* 2018) from the stepwise regression (supplementary figure S3).

2.5. Statistical analysis and causal inference

We aimed to established reliable covariation and rule out alternative explanations following Spector's four-point approach to causal inference to determine the impacts of financial inclusion loans on livestock management. We used stepwise multiple linear mixed regression to determine the optimal models representing the relationships between livestock management and the explanatory factors including financial inclusion loans, first for the whole dataset, then for the Mobile and Sedentary households separately. Explanatory variables included financial inclusion loan amount and other field survey information (i.e. family grassland area, incomes and expenditures, family size, dependency ratio of family, market price and subsidies, and rainfall). Livestock mobility was defined as a categorical explanatory factor for the whole dataset analysis. The dependent factors were the two key indicators of livestock management, i.e. livestock selling ratio and grazing intensity. Village was set as a random variable in the mixed model because original grassland condition, climate, and vegetation were relatively homogeneous within each village but varied between villages. The optimal model was selected as the one with the smallest Akaike information criterion value. To distinguish the effects of financial inclusion loans on livestock management from the effects of other potential explanatory factors, we calculated a parsimonious model which included financial inclusion loan amount as the only independent variable. To avoid the overly aggressive ruling out of alternative explanatory factors, we also included these explanatory factors (originally excluded from the optimal models) in the new model, and calculated *p*-values for these variables (supplementary table S5).

We quantified the effects of financial inclusion loans on grassland ecological responses via the mediating influence on grazing intensity. The effect of grazing intensity on each ecological variable was determined from stepwise regression and compared between the Mobile and Sedentary groups in which rainfall and soil nitrogen were set as control variables because of their impacts on arid grassland ecosystems (supplementary table S6). Second, we implemented a path analysis using a structural equation model

Figure 2. Temporal trends in price, profits, and cost of the Inner Mongolian herder social-ecological system. The scale of all data is on the provincial level or national level as noted for each panel. Standard errors of annual census data were not available. (A) The wholesale price of sheep and goat meat and livestock numbers in Inner Mongolia (2000–2019). (B) Profit changes for Inner Mongolian herders (2001–2018). (C) Cost for sheep and goat meat from Inner Mongolia, the average cost from all provinces, and average price of imported products (2001–2018). (D) Changes in feed cost and its components (labor, hay, and other) in Inner Mongolia (2001–2018).

(SEM) to explore potential relationships between financial inclusion policy and the ecological condition of grasslands in the two groups considering the complex interactions within the social-ecological system. All statistical analysis was conducted in R version 3.6.1 (R Core Team 2018) with stepwise regressions implemented using the lme4 (Bates *et al* 2015) and lmerTest (Næs *et al* 2010) package and the SEM implemented using the sem package (Fox *et al* 2017).
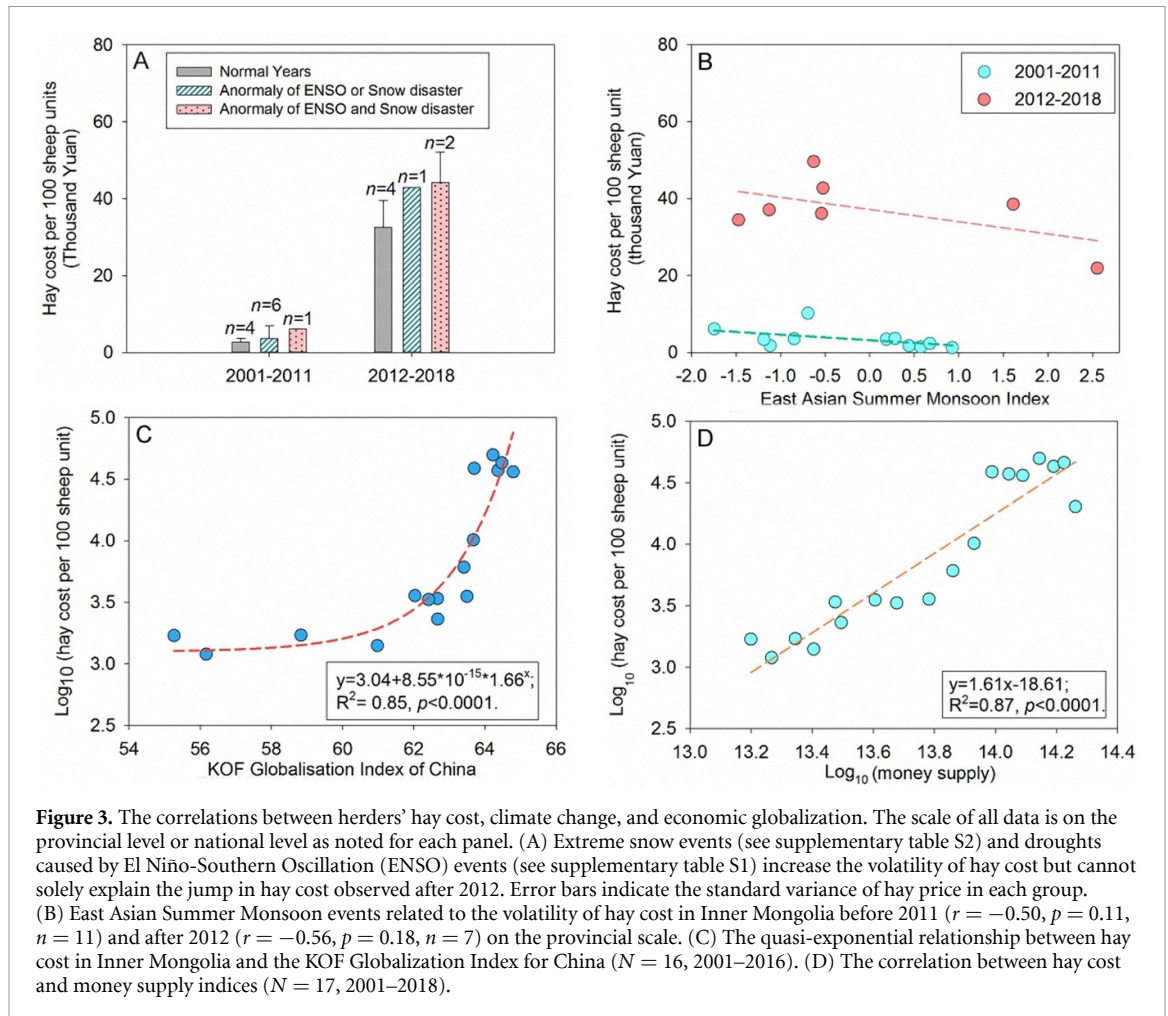
3. Results

This section first describes the fluctuations in livestock market prices and feed costs (section 3.1) in Inner Mongolia driven by climate change and economic globalization, which strongly influenced herders' profits. Then, we present the impact of financial inclusion policy on livestock production and management (section 3.2). Next, we analyzed the effects of financial inclusion policy on herders' profits and economic returns (section 3.3) and grassland health (section 3.4). Last, we discuss herder innovation and adaptation (section 3.5) and local government responses (section 3.6) to the financial inclusion policy in the dynamic social-ecological system.

3.1. Volatile markets for livestock and feed
Inflation-adjusted price information, which was converted to constant values for the year 2000, showed

abrupt changes in herders' costs, livestock sale price, and profit. Imports of sheep and goat meat in China increased nearly five-fold between 2010 and 2014. The lower price of imports shifted expectations in China's domestic market. As a result, long-term price increases for sheep and goat meat stopped after 2014 (figure 2(A)). Because of more intensive competition and unfair trade practices (supplementary note 3), the sale price of sheep and goats in Inner Mongolia fell to 75% of the long-term average price across the three agricultural provinces of western China after 2012 (Sichuan, Gansu, and Ningxia, figure S4). Thereby, Inner Mongolian herders suffered ongoing annual deficits, with net profits ($+89\% \pm 29\%$) in the period 2001–2011 turning into losses ($-35\% \pm 19\%$) from 2012 to 2017 (figure 2(B)), while herd sizes remained constant (figure 2(A)).

Inner Mongolian herders suddenly lost their cost advantage after 2011 (figure 2(C)). During the period from 2012 to 2017, the cost of meat from Inner Mongolian herders was 1.51 times higher than the national average level and 2.66 times higher than imported products. Even in 2018 (the wettest year in the past 20 years), the cost of meat from Inner Mongolian herders was still 1.39 times higher than imported products. High hay cost was the main contributor, which jumped more than four-fold after 2011 (figures 2(C) and (D)) and exceeded 80% of herders' total costs (figure 2(D)). Hence, herders with limited

Figure 3. The correlations between herders' hay cost, climate change, and economic globalization. The scale of all data is on the provincial level or national level as noted for each panel. (A) Extreme snow events (see supplementary table S2) and droughts caused by El Niño-Southern Oscillation (ENSO) events (see supplementary table S1) increase the volatility of hay cost but cannot solely explain the jump in hay cost observed after 2012. Error bars indicate the standard variance of hay price in each group. (B) East Asian Summer Monsoon events related to the volatility of hay cost in Inner Mongolia before 2011 ($r = -0.50$, $p = 0.11$, $n = 11$) and after 2012 ($r = -0.56$, $p = 0.18$, $n = 7$) on the provincial scale. (C) The quasi-exponential relationship between hay cost in Inner Mongolia and the KOF Globalization Index for China ($N = 16$, 2001–2016). (D) The correlation between hay cost and money supply indices ($N = 17$, 2001–2018).

family-owned grassland areas who were reliant upon external hay as supplementary feed (supplementary note 1) could not control their feed costs.

Both climate and macro-economic conditions drove hay cost dynamics in Inner Mongolia. However, while climatic variability caused herders' costs to fluctuate, it did not explain the distinct jump after 2011 (figures 3(A) and (B)). Economic globalization and climate change indirectly contributed to the jump in hay cost via multiple complex effects. We observed a significant quasi-exponential relationship between the KOF Globalization Index for China and hay costs after 2001 (figure 3(C)). During this period, China's money supply increased as the country continued to open its economy, raising costs in all aspects of the hay supply chain in Inner Mongolia, including grassland rental, labor, and transport (figures 1(E)–(G)). We also observed a strong correlation between China's money supply and the rise in hay costs ($r = 0.87$, $p < 0.0001$, figure 3(D)). The total amount loaned by herders in Inner Mongolia increased from 1.83 billion US dollars in 2010 to 5.23 billion US dollars in 2014 (i.e. a 160% increase) and continued to increase by around 10% p.a. since 2014. The increasing availability of financial inclusion loans in Inner Mongolia was one of the vehicles by which the rapid increase in money supply was implemented in China.

In 2018 however, climate and economic conditions enabled herder profits to return. Hay cost dropped around 50% from its peak because of plentiful rainfall in the region (figure 2(D)) brought on by the strongest EASM in the past 20 years (figure S1). At the same time, African Swine Fever (an epidemic disease affecting pigs) reduced China's pork supply, increasing demand for (and hence the price of) sheep and goat meat (figure 2(A)). With these favorable conditions, the rebound of profits to 42% in 2018 (figure 2(B)) illustrated that Inner Mongolian herders were now subject to exaggerated variability in economic returns driven by the interacting effects of global climate and demand.

3.2. Effects of financial inclusion on livestock management

The optimal models calculated based on the whole dataset suggested significant mediating effects of livestock mobility on the influence of financial inclusion on selling ratio and grazing intensity (table 1). Further analyses disentangled the effects of financial inclusion policy from the interactions with livestock mobility. Access to financial inclusion loans impacted livestock management decisions with different effects for the Sedentary and Mobile groups. Livestock selling ratio was negatively associated with

Table 1. The result of stepwise multiple regression for the selling ratio of livestock (number sold: total herd size) and grazing intensity (sheep units/ha) in the whole survey sample in the Xilingol grassland, Inner Mongolia. Boldface indicates statistical significance at $\alpha = 0.05$. Standard errors of estimates are in brackets. M denotes livestock mobility conditions of herders, which is a categorical variable. M(0): Sedentary status, M(1): Mobile status. Note that the ten families in a village that co-managed and shared their grassland with others were kept in the regression for selling ratio ($n = 98$), but were excluded from the regression for grazing intensity ($n = 88$).

Dependent variable	Explanatory variables	Coefficient estimate	*p*-value	R^2
Selling ratio ($n = 98$)	Financial inclusion loan amount: M(0)	-0.0003 (0.0001)	**0.0285**	0.45
	Financial inclusion loan amount: M(1)	0.0004 (0.0001)	**0.0152**	
	Usurious loan amount	-0.0006 (0.0002)	**0.0278**	
Grazing intensity ($n = 88$)	Financial inclusion loan amount: M(0)	0.0067 (0.0010)	**<0.0001**	0.82
	Financial inclusion loan amount: M(1)	-0.0013 (0.0014)	0.3668	
	Growing season rainfall $_{t-1\ \text{year}}$	0.0359 (0.0119)	**0.0060**	

Table 2. The results of optimal model selected by stepwise multiple regression and a parsimonious model only including financial inclusion policy for the selling ratio of livestock (sold: herd size) and grazing intensity (sheep unit/ha) for Sedentary and Mobile herders in the Xilingol grassland, Inner Mongolia. Boldface indicates statistical significance at $\alpha = 0.05$. Standard errors of estimates are in brackets. Results for the regressions about dropped explanatory variables are presented in table S5.

Optimal model selected by stepwise multiple regression

Dependent variable	Sub-dataset	Explanatory variables	Coefficient estimate	*p*-value	R^2
Selling ratio	Sedentary group ($n = 54$)	Financial inclusion loan amount	-0.2575 (0.1947)	**0.0168**	0.45
		Usurious loan amount	-0.2209 (0.0953)	**0.0245**	
	Mobile group ($n = 44$)	Financial inclusion loan amount	0.4464 (0.1456)	**0.0038**	0.41
Grazing intensity	Sedentary group ($n = 44$)	Financial inclusion loan amount	0.3583 (0.0610)	**<0.0001**	0.81
		Area of rented grassland	-1.9701 (0.5635)	**0.0013**	
		Hay expenditure	0.3402 (0.1114)	**0.0043**	
		Growing season rainfall $_{t-1\ \text{year}}$	0.4199 (0.1248)	**0.0076**	
	Mobile group ($n = 44$)	Total interest of all family loans	0.1405 (0.0531)	**0.0120**	0.38
		Area of family-owned grassland	-0.1010 (0.0339)	**0.0052**	
		Dependency ratio of family	0.0750 (0.0341)	**0.0344**	

Parsimonious model only including financial inclusion policy

Dependent variable	Sub-dataset	Target variable	Coefficient estimate	*p*-value	R^2
Selling ratio	Sedentary group ($n = 54$)	Financial inclusion loan amount	-0.3191 (0.1033)	**0.0034**	0.42
	Mobile group ($n = 44$)		0.4464 (0.1456)	**0.0038**	0.41
Grazing intensity	Sedentary group ($n = 44$)		0.3987 (0.0754)	**<0.0001**	0.68
	Mobile group ($n = 44$)		-000076 (0.0599)	0.8992	0.04

financial inclusion loan amount in the Sedentary group, but positively associated with financial inclusion loan amount in the Mobile group. Grazing intensity in the Sedentary group was positively associated with financial inclusion loan amount but was not significantly related to financial inclusion loan amount in the Mobile group (table 2, S5). Although

the model selection results also detected the effects of other explanatory factors on livestock management decisions (especially rainfall and the area of family-owned grassland), the parsimonious model which only included financial inclusion loan amount suggested strong impacts of the policy on livestock management decisions in the Sedentary group (table 2).

Table 3. Correlations, fitted by univariate regressions, between financial inclusion loan amount and ecological indicators in two groups. Boldface indicates statistical significance at $\alpha = 0.05$. SOC: soil organic carbon. TN: total nitrogen.

Ecological indicators	Sedentary group ($n = 44$)			Mobile group ($n = 44$)		
	Estimate	*p*-value	R^2	Estimate	*p*-value	R^2
Aboveground biomass	−0.1049	**<0.0001**	0.55	0.0198	0.7942	0.06
Root biomass (0–30 cm)	−0.1126	**<0.0006**	0.31	−0.0519	0.3630	0.16
Community height	−0.1282	**<0.0001**	0.62	−0.0153	0.8400	0.08
Dominant plant species richness	−0.0747	**0.0172**	0.24	0.0393	0.5050	0.13
SOC (0–10 cm)	−0.1427	**0.0061**	0.27	0.0491	0.5365	0.12
SOC (10–30 cm)	−0.0415	0.3120	0.18	0.1112	0.4543	0.07
TN (0–10 cm)	−0.1086	**0.0256**	0.30	0.0605	0.4643	0.07
TN (10–30 cm)	−0.0089	0.8110	0.01	0.0861	0.5434	0.04

3.3. Herders' profit and perceptions

All survey respondents reported that the reformed financial inclusion policy provided them with flexible, low-interest loans. During droughts, loans enabled herders to reserve large herds and wait for the expected recovery of livestock prices and profits. This response was supported by our statistical findings. Respondents reported that before the financial inclusion policy reforms, only the wealthiest herders could reserve livestock by migrating herds and providing extra forage, and then recover profits when livestock prices rebounded following extreme climatic events, a finding consistent with previous studies (Zhang *et al* 2018). Following the 2015 reforms, flexible repayment rules and increased loan amounts made this reserve and wait strategy available to all. This strongly affirms that the changes in livestock management and selling behaviors of herders occurred after implementation of the financial inclusion policy and established the temporal precedence required in the four-point causal inference approach with cross-sectional study design (Spector 2019) from local governments. Almost all herders in the Sedentary group reported that the financial inclusion policy failed to improve their overall income but rather increased their debt during droughts. Only in 2018 did profits return due to the higher market livestock price and low hay cost, which was consistent with the provincial census data. Therefore, the effectiveness of financial inclusion policy on alleviating financial hardship for herders was mediated by volatility in livestock price and hay cost.

3.4. Effects on grassland environmental health

Grazing intensity was significantly related to almost all environmental variables in both the Sedentary and Mobile groups (table S6), mediating the impact of financial inclusion loans on grassland health. In the Sedentary group, financial inclusion loan amount showed significant negative correlations with fast ecological variables such as aboveground biomass, root biomass, perennial plant species richness, community height, SOC, and TN in the topsoil (0–10 cm depth; table 3). In the Mobile group, financial inclusion loan amount was not related to grazing intensity nor any environmental indicator (table 3, figure S5). The environmental impacts of financial inclusion policy were also confirmed by SEM (figure 4).

To synthesize, the results suggest that when adaptive capacity via traditional ecological knowledge (maintaining seasonal grazing mobility) was eroded by limited family-owned grassland area as in the Sedentary group, increased financial inclusion loans enabled herders to reserve livestock, this exposed them to higher hay costs which, along with reduced livestock prices, led to financial losses and debt. Maintaining high grazing intensities also caused widespread grassland degradation. Conversely, when herders were able to access a larger area of family-owned grassland, access to financial inclusion loans did not lead to higher grazing intensities and grassland degradation.

3.5. Herder innovation and adaptation

Some signs of herder innovation and adaptation, however, did emerge. Supported by financial inclusion loans and recognizing that changes in economic and climatic conditions were occurring, some herders changed their management practices. Some diversified their business interests by producing horse milk and other traditional foods, trading or transporting hay, and using advanced technologies to breed improved livestock varieties (see supplementary note 4). To foster fairer prices, one community collectively invested their financial inclusion loans to establish a local livestock market and developed self-managed market rules from traditional institutions. Herders received ∼10% more income in this market (see supplementary note 4).

3.6. Local governance

Local governments and banks did implement several emergency measures to prevent the situation from worsening after the drought in 2016. Once again, banks raised the credit lines of herders and extended the maturities of loans. Local governments successfully banned usurers from using violence when collecting debts. While agriculture officers did notice the depletion of hay resources and rising feed costs, they did not share this information with policy makers in
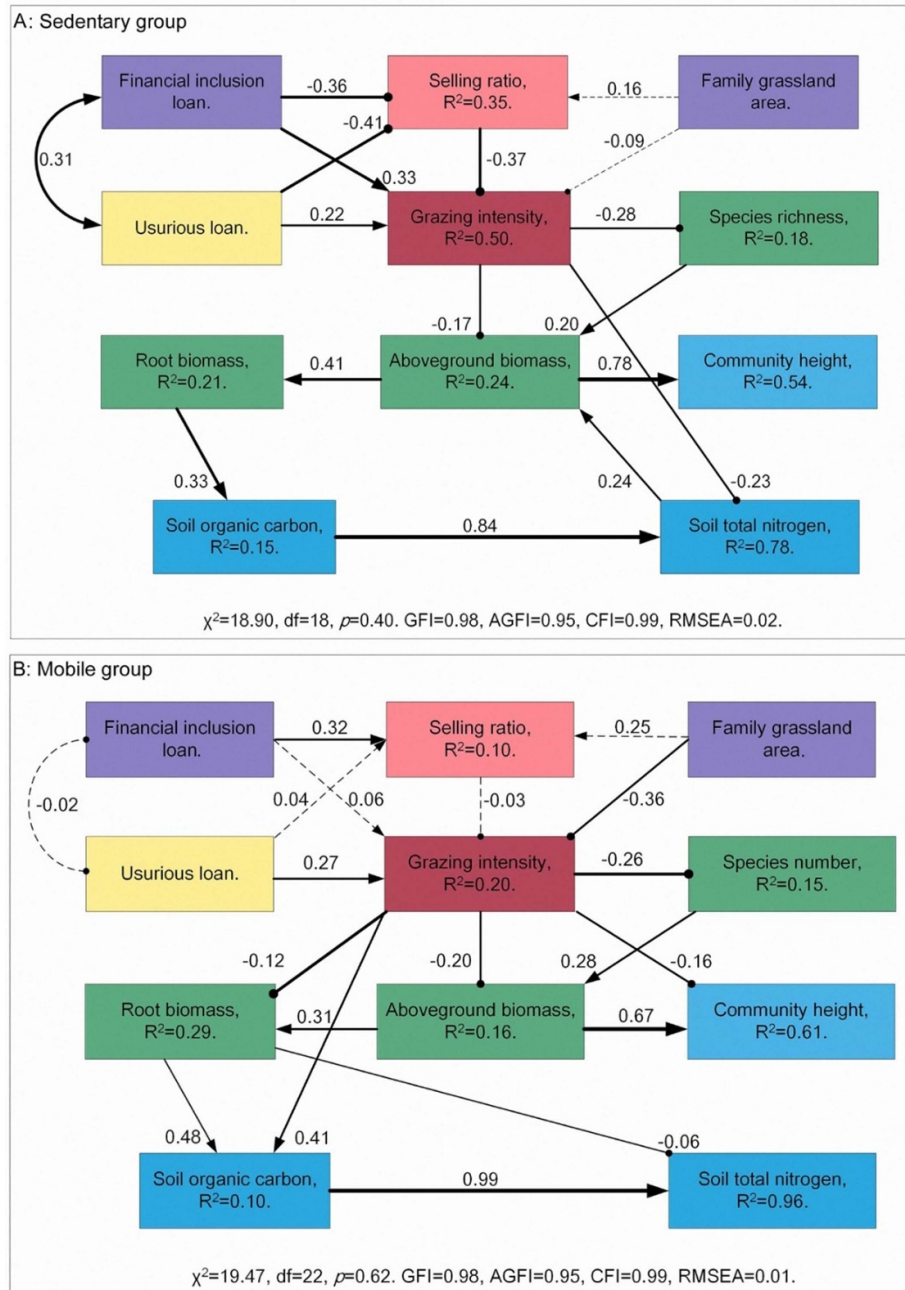
Figure 4. Financial inclusion loans directly influenced the selling ratio of livestock and grazing intensity, then indirectly impacted grassland ecosystems in the Sedentary group (A) but did not affect grazing intensity and grassland health in the Mobile group (B). Paths shown using the solid line are statistically significant ($p < 0.05$), while paths represented by dotted lines indicate insignificant relationships in the structural equation models. Standardized partial regression coefficients of single paths are presented near arrows. Positive numbers and pointed arrows stand for positive effects while negative numbers and rounded arrows denote negative effects. Arrow thickness indicates effect strength. Partial variances (R^2) explained by each variable are shown by their names. GFI: goodness of fit. AGFI: adjusted goodness of fit. CFI: comparative fit index. RMSEA: root mean squared error of approximation.

the financial agencies. Thus, policy-makers did not realize the impacts of constraints imposed by small grassland plots and the implications of increased hay cost.

4. Discussion

4.1. A poisoned chalice for smallholders
Maladaptive risks of financial inclusion policy is not an isolated issue confined to China's grasslands, but rather a global challenge for all smallholders and rural environments in developing countries. To improve livelihoods, smallholders must turn loan-supported increased productive capacity into profit by selling their primary commodities in competitive markets (Hermes *et al* 2011). However, profits were uncertain when facing grassland area constraints to adaptation (Gongbuzeren 2016), high feed costs (Gongbuzeren *et al* 2020), complex financial markets, volatile market (Murphy 2018), and unstable climate (Li and Li

2021). Our study further confirmed the effects of more accessible credit on herders' income were highly variable under China's reformed financial inclusion policy and dependent upon feed and livestock markets made increasingly volatile under climate change and economic globalization. Moreover, production was boosted via increased grazing intensity which, in turn, increased environmental degradation and vulnerability to extreme climatic events. Local community and traditional ecological knowledge had been eroded by constraints of fragmented land tenure (Li and Li 2012) and did not serve herders when participating in the global economy, and making adaptation more difficult. These processes have formed a maladaptive trap and impeded the ability of financial inclusion policy to promote sustainable development in China's vast grasslands. Smallholder producers are the mainstay of agriculture in developing countries and are vulnerable to economic globalization and climate change (Lowder *et al* 2016). To avoid the maladapive outcomes when implementing financial inclusion policy, policy-makers need to be alert to abrupt changes in social-ecological systems and be prepared to rapidly adapt policy mechanisms.

4.2. More open and inclusive governance
Although China's top-down, state-directed model can be efficient in granting loans, this implementation mode may also impede rural sustainability when novel cross-scale interactions emerge in complex social-ecological systems (Chaffin and Gunderson 2016, Bodin 2017). Even after the reforms in 2015, financial inclusion policy institutions lacked proper channels for providing and receiving critical feedback about policy impacts on the ground. Feedback about policy performance came almost exclusively from local government financial agencies rather than the multiple stakeholders (including herders) involved, which is a common problem around the world (Mader 2017). Uncompromising policy implementation and repeated positive feedback ensure that local financial agencies are rewarded by higher levels of government, while critical negative feedback about the real conditions and policy impacts is unlikely to generate the same result. Under this incentive-incompatible mechanism, positive feedback from local financial agencies reinforced central government policy-makers' (misguided) confidence in the effectiveness of financial inclusion policy. Policy-makers overestimated the effectiveness of financial inclusion loans in rural development, and ignored the constraints to sustainable development and the innovation of herders. Further, the generous fiscal spending by the central government produced an interest group, reinforcing the top-down policy mode (Mader 2017), impeding the learning of policy-makers (Kraker 2017), and locking the system into a maladaptive trap (Lade *et al* 2017). Although herder profits rebounded in 2018 due to good rainfall

and increased demand resulting from a reduction in supply of pig meat, there is a risk that this may continue to inflate the perceived effectiveness of financial inclusion and further delay the fundamental reform urgently needed in China's grassland governance.

To fix these issues, policy-makers must adjust the top-down governance and state-directed investment mode by establishing a coordination mechanism in financial inclusion policy implementation (Mader 2018). The benefits from natural resources are constrained not only by financial exclusion, but also by access to information, technology, markets, and autonomy within changing social-ecological systems (Ribot and Peluso 2003). Some local constraints, such as the fragmented grassland areas in Inner Mongolia and collapse of local community may seriously aggravate and trap smallholders in poverty when exposed to economic globalization and climate change. Our study suggests that incremental reforms (DeFries and Nagendra 2017), such as increasing the loan amount and easing loan repayments in Inner Mongolia, cannot eradicate the root causes of poverty nor contribute to other environmental SDGs such as reducing land degradation. Rather, transformational adaptation is required to realize the potential of financial inclusion policy for sustainable development.

4.3. Transformational adaptation
Policy-makers need to improve their knowledge about novel social-ecological system processes and dynamics through co-ordination and communication between multiple stakeholder groups. Via this mechanism, people need to share information about changes and the emergence of novel system behaviors (Berkes and Turner 2006, Kates *et al* 2012). Policy-makers can integrate herders' traditional knowledge (Gomez-Baggethun *et al* 2013) and innovation, community co-operation and autonomy into future policy design (Kraker 2017). The most urgent co-ordination role is to manage the impact of impending changes involving grassland-use rights, which form the collateral for financial inclusion loans. China's Central Government is currently implementing a new rural land reform to allow the trade of grassland-use rights (Li *et al* 2018). However, indebted herders risk losing their grassland use rights to banks and other creditors legally under this land property reform. Careful policy design is required by government policy-makers and banks in carrying out this reform to prevent indebted herders from losing their grasslands permanently.

In addition, policy-makers should avoid the over-reliance on financial inclusion policy to address all social-economic problems (Murphy 2018). Financial inclusion policy cannot replace other public policies in achieving sustainable rural development. In our study, many herders used financial inclusion loans to cover higher education and health care expenses, and

this suggests a broader gap in the social security of rural households. Policies for climate mitigation and adaptation depend upon financial inclusion loans in grassland regions, while emergency drought subsidies and agricultural insurance (Di Falco *et al* 2014) have developed slowly and covered very few herders. Other public policies are needed to complement financial inclusion policy in promoting social security and sustainable development more broadly (Mader 2018).

Policy-makers should also help local communities develop fair-trade mechanisms (Raynolds 2012). Herders considered exploitation by middle merchants in the livestock trade and low prices to be the main reasons for the decline in their profits. Governments could use financial inclusion policy and other supporting policies to help smallholders develop their trade capability, which had been weakened by the emergence of cheaper imported livestock products. Several herders had used financial inclusion loans to establish a co-management market that was important for community vitality (Dale *et al* 2010) and improving their trade capability, highlights this potential. Financial inclusion policy may fund herders' efforts in developing their negotiation skills, building infrastructure for providing more competitive products, and establishing community-based fair-trade institutions. Working with the community (Li and Huntsinger 2011) would complement the top-down governance of financial inclusion policy in achieving sustainable development.

5. Conclusion

The benefits of financial inclusion in helping the world's rural poor have been widely demonstrated (Arun and Kamath 2015, Corrado and Corrado 2017). However, our results showed that many factors impeded the ability of financial inclusion policy to achieve positive outcomes for smallholders and the environment under complex changes in the social-ecological system of Inner Mongolian herders. Globally, the unintended consequences of the widely used financial inclusion policy need to be anticipated and mitigated to support progress towards achieving the SDGs. Responses to financial inclusion policies in local social-ecological systems need to be assessed from an interdisciplinary perspective. Future studies should also assess the adaptive capacity and ability of local people to use financial inclusion loans to cope with the challenges of climate change and economic globalization. Governments must be aware of the limitations of incremental adaptation when implementing financial inclusion policy. Instead, governments should develop the capacity for adaptive management by integrating financial inclusion with community co-operation, traditional knowledge and institutions, complementary public policies, and technological innovation to ensure that 'no one is left behind'

in the era of economic globalization and climate change.

Data availability statement

Acknowledgments

Ethical statement

The authors declare that no humans or animals were harmed during the study.

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