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Analysis

Assessing the opportunity costs of Chinese herder compliance with a payment for environmental services scheme

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ABSTRACT

Addressing serious grassland degradation without exacerbating already low herder incomes is a major challenge for the Chinese government. In response, the Grassland Ecosystem Subsidy and Award Scheme (GESAS) was introduced in 2011 where herders receive payments if they comply with specified stocking rates set at more sustainable levels. However, compliance with GESAS, as well as low herder incomes in some years, is an ongoing issue. Using a stochastic, dynamic bioeconomic model of representative herder households in the desert steppe grasslands of Inner Mongolia Autonomous Region, the opportunity costs for herders in meeting specified stocking rates under different states of nature are identified and compared with GESAS payments. In addition, the impacts on productivity and environmental services provided by herders operating within or outside of GESAS are identified. The results highlight states of nature under which no incentivising payments are needed for compliance or when the opportunity costs greatly exceed the GESAS payments, thereby increasing the risk of non-compliance. The study highlights the need to unbundle the environmental incentive and welfare components of GESAS if the twin objectives are to be achieved, and the need to define and understand the distribution of possible outcomes in designing grassland and ecocompensation policies.

1. Introduction

Grasslands cover 42% of China's national territory (400 million hectares) and stretches from the north-eastern plains to the south-western Tibetan Plateau (Kemp et al., 2018). Various studies have highlighted the scope and severity of grassland degradation in China and the significant ecological and socioeconomic consequences at both regional and national scales (Kemp et al., 2018; Lang et al., 2020; Liu et al., 2018; Yang et al., 2016). The Grassland Ecosystem Subsidy and Award Scheme (GESAS) is part of a package of policy instruments of the Chinese government to deal with grassland degradation. GESAS is the key policy scheme for ecological rehabilitation of grasslands in pastoral areas of China, and the central government invested CNY77.4 billion during the 5 years of the 12th Five Year Plan in its first round of implementation. In the Inner Mongolia Autonomous Region (IMAR), which is one of the main pastoral areas in China and where the analysis of the paper is focussed, all 54 pastoral or semi-pastoral counties are involved in GESAS, including 26.93 million ha (1 ha equals 15mu) under grazing ban and 41 million ha under grassland-livestock balance. GESAS itself followed on from other grazing restriction and associated payment programs introduced across China following implementation of a revised version of the Grassland Law in 2002. However, these programs were more ad hoc in nature and are described in detail in Brown et al. (2008) and Addison et al. (2020a).

The annual compensation payment from central government to herders under GESAS was distributed in four ways: a subsidy for grazing ban (CNY90/ha/year); an award for forage-livestock balance (CNY22.5/ha/year); a subsidy for pastoralist's production materials (CNY500/household/year); and a grass seed subsidy (respectively, CNY450, 450 and 150/ha for the first three years) (AAHDIMAR, 2011). Under the forage-livestock balance part of GESAS, introduced in the 12th Five Year Plan in 2011, herders receive a payment if they comply with stocking rates specified in their grazing use rights contracts and which are set on the basis of being a sustainable rate for healthy grasslands. The stocking rates and payments do vary by ecosystem type (such as typical steppe, desert steppe and sandy steppe) but otherwise are uniform across

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herders and seasons. Although restoring degraded grasslands and improving ecological condition is a major goal of GESAS, for the Chinese government it also has to achieve this within the context of low incomes among herders while concurrently assisting herders to adopt more sustainable structures of production that can sustain their livelihoods.

In rolling the essence of the GESAS program over for a further five years in the 13th Five Year Plan (2016 to 2020), the Chinese government signalled its positive assessment of the overall direction and outcomes of the project. Nevertheless, both officials and academics have identified various issues and concerns associated with the scheme that may need to be addressed into the future (Pan et al., 2017). First, there is concern about herder compliance with the stocking rates as average stocking rates are still well above GESAS rates. For instance, in the desert steppe in IMAR, the average stocking rate of around 0.74 sheep equivalents/ha (SE/ha) is almost 50% higher than the GESAS/Land contract stocking rate of 0.5 SE/Ha. Second, herders perceive the payment as an entitlement or welfare payment rather than as an eco-compensation payment for looking after their grasslands (Li et al., 2014b; Zhang et al., 2019). Third, the uniform nature and size of the payment means that it may bear little relationship with the opportunity costs of herders to comply with the stocking rate given the heterogeneity among herders (Byrne et al., 2020) and the variation in opportunity costs across different market conditions, seasons and landscapes (Addison and Greiner, 2016), and so have minimal impact on herders' incentive to comply with the program stocking rates.

The main objective of the paper is to examine the opportunity costs for herders in meeting the stocking rates specified in GESAS under different states of nature and to compare these with the GESAS payments in order to better understand herder compliance with this eco-compensation scheme. In this study, the potential states of nature are defined by all the possible combinations of the prices for outputs (e.g. meat and wool) and climatic conditions which determine grassland growth and subsequent livestock performance. Further to this, the paper also seeks to uniquely determine the impacts on livestock and pasture productivity (such as growth rates and basal cover) as well as on the environment (such as dust and greenhouse gas emissions) of herders operating within or outside of GESAS. Such studies that integrate the complex and dynamic interactions of household economics, production and environmental outcomes in response to ecocompensation schemes are scarce and needed (Addison and Greiner, 2016; Yin and Zhao, 2012). The opportunity costs are estimated using a stochastic, dynamic bio-economic model of a representative herder households in the desert steppe grasslands of the IMAR, China, and based on detailed survey information of herder households (Zhang et al., 2019). The intent of the analysis is to provide a framework and information of use to Chinese grassland officials in future revisions to GESAS and associated programs in meeting the twin objectives of grassland condition and herder livelihoods.

2. Background and literature

The increasing attention the Chinese government has paid to grasslands along with the scope of the GESAS program have been accompanied by an increasing number of studies investigating different aspects of GESAS. A key theme relevant to this study are the reasons for a lack of compliance by herders to the requirements of the GESAS program, which is purported to be primarily linked to the mis-alignment between the level of eco-compensation payment offered by the policy and the opportunities costs of herders complying. This is supported through a contingent valuation study by Zhen et al. (2014) who found that herders' income from farm cultivation and animal grazing decreased under the GESAS program. They argued that too-low payments may lead some herders to expand grazing into restricted grassland or increase their number of animals particularly if either payment program ends. However, in contrast Gao et al. (2016) found that the subsidy increased herders' income and decreased grazing intensity, although the effects on the change in number of livestock kept by herders was found to be both positive and negative across different grassland biomes in Inner Mongolia. However, the decisions that herders make are influenced by a variety of interacting social, economic and environmental pressures, which in turn will influence both changes in environmental outcomes and herder livelihoods (Addison et al., 2020b). Zhang et al. (2019) indicated that for most herders in Inner Mongolia that the compensation offered under GESAS did not meet their expectations for satisficing livelihoods. This is supported by an earlier study using social-ecological systems framework applied to a dryland ecocompensation schemes in IMAR, that suggested non-compliance and opportunity costs were closely aligned, and that variable payments should be linked to climatic conditions to avoid non-compliance (Addison and Greiner, 2016). Their study also suggested that the applied framework could be enhanced through the inclusion of factors that determine net farm economic benefit, in particular commodity prices.

More recently and close to the objectives of this study, Byrne et al. (2020) used a simplistic factor-income approach to calculate the shadow prices for herders complying with payments for ecosystems services in Inner Mongolia. Their study indicated that in the desert steppe, the majority of herders received insufficient financial compensation to reduce their grazing intensity by removing all grazing animals. However, the study is constrained to the states of nature defined by 2012 and 2014, and do not represent, in the medium to long term, how the shadow price for compliance will dynamically vary from year to year under expected variations in exogenous factors such as price and climate. Similarly, Hu et al. (2016) investigated the change in average net incomes required to comply with GESAS rules and compared them against the subsidy payments based on a survey of herders in the program in IMAR. However, the main limitation of this analysis was that it did not account for different production or market conditions in determining the opportunity costs. In an environment where both production and market conditions can change dramatically, the need to account for these conditions in estimating the opportunity costs is paramount and a major objective of the paper.

The issue of uniform payments, incentive compatibility and land heterogeneity is not unique to China or to grasslands. Rygnestad and Fraser (1996) and Fraser (2009) highlight how uniform payments associated with land set-asides under the Common Agricultural Policy of the European Union resulted in different impacts across farmers, incentive incompatibility and the under or over provision of environmental goods or services given land heterogeneity. Recent work in assessing the acceptability and impact of agri-environmental schemes have focused on increasing the spatial and process resolution of simulation models and emphasise the importance of analysing farmer's decision making under the influence of stochastic institutional and natural conditions (Langhammer et al., 2019; Rosenstock et al., 2014). The desire to have incentives that are more compatible and that have more equitable impacts across farmers is also behind the Chinese government's considerations of refinements to the program.

3. Conceptual analysis

Herder incomes and grazing strategies will vary from year to year as ruminant livestock and livestock product prices vary, and as weather, production and market conditions change. In a hypothetical illustration in Fig. 1, the cumulative probability of reaching a particular level of income over all states of nature is displayed. Two cumulative distribution functions (CDFs) are presented in Fig. 1: one for the case of a herder stocking at the GESAS reward balance rate and receiving the reward balance payment (curve RB); and one for a herder who does not stock at the GESAS reward balance rate and does not receive the reward balance payment (curve NRB). Herders with lower stocking rates under GESAS will achieve higher productivity per head of livestock as more, and potentially better quality, feed will be available to the livestock (Jones and Sandland, 1974; Kemp et al., 2018). However, this positive

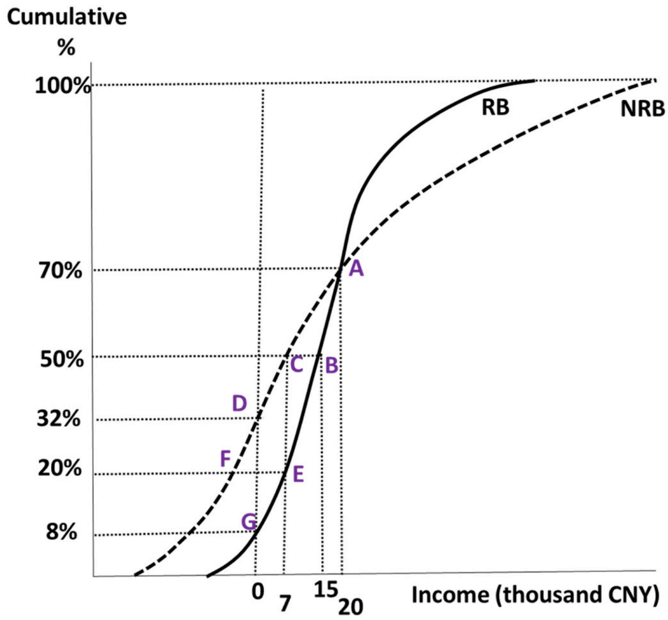

Fig. 1. Hypothetical cumulative distribution functions of herder income with (RB: Reward balance stocking rate and payment, –) or without (NRB: No reward balance, —) GESAS participation.

productivity effect may be more than offset by the fewer livestock under GESAS when looking at from an area basis. The ecocompensation payments under GESAS may be more or less than the reduction in incomes associated with the lower livestock numbers.

In Fig. 1, the distance between the RB and NRB curves represents the increase or decrease in payments that would be needed for the payments to exactly compensate for the lower stocking rates. In this hypothetical figure, the herder would be indifferent between RB and NRB at point A. In other words, in the hypothetical case in Fig. 1, in 30% of years involving good prices, production conditions or both, GESAS payments would need to be increased in order for the herder to be better off under the program. Thus under the current payments, herders would have little incentive to comply with GESAS stocking rates and indeed have a significant disincentive to reduce their stocking rates.

Conversely in the 70% of years below point A, the reward balance payments could be reduced and the herder still elect to be in the program or have the incentive to comply with the stocking rates in the program. On average (50th percentile) for this figure, herders will be better off by BC under GESAS. Point E indicates the point at which the herder would be indifferent between the RB and NRB stocking rates even without the RB payment (that is, the RB payment is equal to EF). Thus for the particular case presented in Fig. 1, in 20% of poor or low income years, herders would need no incentive payments to reduce their stocking rates to the GESAS levels. In essence, the poor market and or production conditions result in a negative gross margin for the livestock and so they would have incentives to reduce their stocking rates independent of the GESAS.

The income effects of GESAS are also revealed by the CDFs in Fig. 1. While the potential for higher incomes exists in the NRB case, the GESAS does mitigate against some low incomes with negative incomes under RB in Fig. 1 occurring in 8% of years compared with 32% of years under NRB (compare points D and G). In effect, the reward balance payments act as a buffer against low incomes in poor seasons and this is another reason why herders have tended to link GESAS payments with welfare payments or entitlements rather than as an eco-compensation payment.

This also raises the conundrum between the environmental and income objectives of GESAS. The greatest risk of non-compliance and need to shore up the incentive payments occurs in good years at a time when herders also receive their highest incomes. Conversely in poor years, herders need less incentive (and payments) to reduce their stocking rates but have a higher risk of negative incomes placing pressure on increasing the size of the payments to offset the low incomes. Reconciling this conundrum is a focus of the discussion later in the paper.

The precise CDFs are an empirical matter and will vary by type of herder and grassland biome. Thus, the relative magnitude of the impacts and critical points discussed above will depend on the specific functions. Section 5 presents the CDFs for representative herders derived from a stochastic, dynamic bioeconomic model which has been calibrated with data collected as described in Section 4.

Fig. 1 highlights the distribution of income effects and opportunity costs across the states of nature. However, stocking rates in GESAS will not only impact incomes but also livestock productivity as well as other jointly produced environmental goods impacted by grassland condition such as dust emissions. Assessments of the merits of GESAS will also be based on these non-income impacts. The model described in Section 4 can also reveal the productivity and environmental outcomes associated with the different stocking rates under different states of nature and these are presented in Section 5.

4. Method

4.1. The case study

The focus of the analysis is the grasslands of Inner Mongolia Autonomous Region (IMAR) and on one of the main grassland biomes, the desert steppe (Fig. 2). The 87 million ha of natural grassland in IMAR account for more than a fifth of China's grassland and represent a significant part of the Eurasian Steppe (Wu and Loucks, 1992). GESAS operates in grassland areas across China while use rights for grassland were contracted out to households for most grasslands in China in the 1990s (Addison et al., 2020a; Brown et al., 2008). However, unlike some of the more transhumant grazing systems and in other biomes elsewhere in China, where forms of communal grazing are practised on the grasslands, there is a more direct relationship between herder household stocking rates and livestock and grassland productivity in the area under study. Sheep, goats, cattle, and camels are grazed on summer and winter grasslands. In this grassland biome, the summer grazing areas are often communally managed areas with an aggregation of livestock around watering points, while the winter areas are allocated to individual households.

The case study area located in Siziwang Banner, IMAR, is north of the yellow river and borders Mongolia (Fig. 2), and is at 1400 m asl within a low rainfall environment which receives around 305 mm precipitation

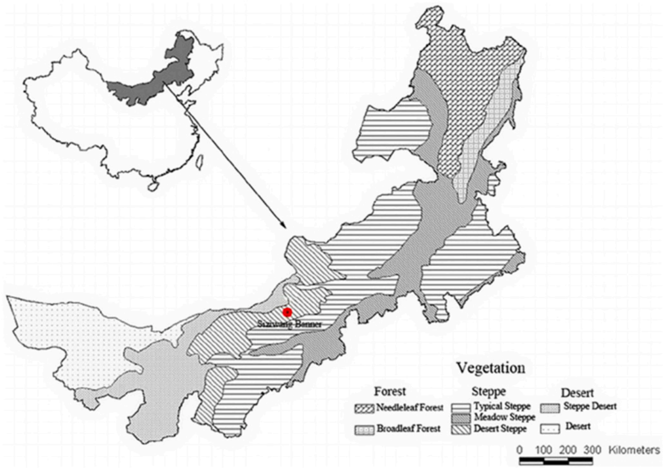

Fig. 2. Vegetation and location of the Inner Mongolia Autonomous Region case study.
Source: (Li et al., 2015).

per annum (Fig. 3). The rainfall is predominantly distributed during the summer months and average daily maximum and minimum temperatures range from 29 °C to −20 °C.

Research has shown that the IMAR is a primary source of dust storms for the populated areas of eastern China, including Beijing (Liu et al., 2004; Shao and Dong, 2006; Zhang et al., 2008). In its interaction with drought, overgrazing has been a primary factor in driving grassland degradation (Kemp et al., 2018; Kemp et al., 2013). Grassland degradation and gradual desertification is contributing to the increased incidence of dust storms and reduced air quality both locally and in populated urban areas (Liu et al., 2004).

4.2. *The modelling framework*

The framework for deriving herder opportunity costs includes two stages: 1) the use of a bioeconomic simulation model to predict probabilistic distributions of herder annual cash flows in response to alternative actions (i.e. operating within (RB) or outside (NRB) of GESAS), and 2) to calculate the herder's opportunity costs of entering into GESAS under the discrete states of nature defined by the simulation modelling.

The CDFs for herders within and outside of GESAS are estimated using a stochastic, dynamic bioeconomic model of representative herder households. A unique feature of this model, the *StageTHREE* Sustainable Grasslands Model (SGM), is that it allows for distributions of input parameters, or states of nature, to be simulated and inter-temporal trade-offs and interactions to be considered (Behrendt et al., 2020a; Behrendt et al., 2020b). The bioeconomic framework considers the impact of embedded climate and price risk, technology application and management on the state of the soil and grassland resources (including botanical composition) over time, which, in turn, impacts on the economics of herder households and the environmental outcomes from different strategies. The SGM has been designed for research environments which often have limited access to complex data. It integrates both established and published empirical and mechanistic/process based sub-models, some of which are parsimonious in approach (Fig. 4). The developed components of the model (e.g. grassland growth and composition sub-models) have been previously published in Behrendt et al. (2013a), Behrendt et al. (2016) and Behrendt et al. (2013b). The SGM has previously been applied to several other case studies in China and which includes the case study site (Behrendt et al., 2020a; Behrendt et al., 2020c; Liu et al., 2020). The SGM operates as a simulation model that is executed for each nominated grazing area (field or paddock level) on a daily time step and contains biophysical sub-models accounting for:

- grassland dry matter digestibility (DMD) and selective grazing (modified from Freer et al. (1997)) and its impact on grassland composition;
- herd/flock structure, size and culling policies;
- supplementary feeding policies;
- growth, production and daily state variables for each age cohort of females, male progeny and breeding males (based on the models of Freer et al. (2007) and Freer et al. (1997));
- growth indices and grassland growth (adapted from Behrendt et al. (2013a), Cacho (1993) and Fitzpatrick and Nix (1975));
- deep soil water drainage and rainfall run-off (adapted from Johnson (2013));
- soil erosion from wind and water run-off (developed from Lu and Shao (2001) and Littleboy et al. (1999)); and
- methane emissions (based on the IPCC guidelines from Hiraishi et al. (2014), Dong et al. (2006) and De Klein et al. (2006)) and expressed as global warming potential (GWP_{100} based on IPCC (2014)).

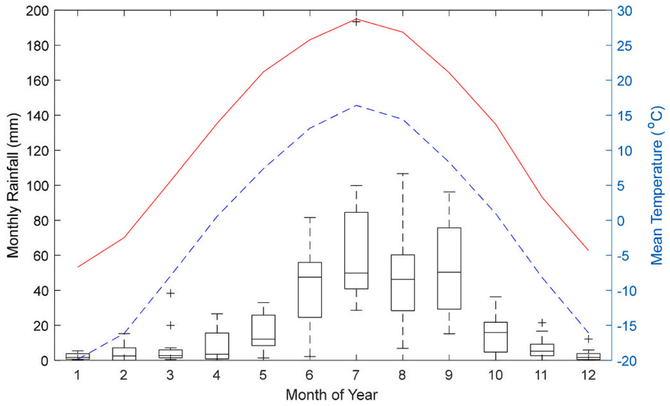

Fig. 3. Desert steppe climatology: 2006–2019.
Note: data for Darhan Muminggan Banner weather station (closest station to Siziwang Banner) in IMAR, indicating monthly rainfall distribution (boxplots, + outliers), average maximum (—) and average minimum (- -) monthly temperatures.
Adapted from Reliable-Prognosis (2020).

The grassland composition (adapted from Behrendt et al. (2013b) and Behrendt et al. (2016)) and soil depth/fertility (adapted from Sharpley (1985) and Wakatsuki and Rasyidin (1992)) sub-models predict changes at an annual time step. Livestock production and system externalities are aggregated to determine the environmental, economic and financial performance of the system at the enterprise and whole farm/household level.

The *StageTHREE* SGM has been developed using Matlab (Mathworks, 2019) and some specialised additional tools. A runtime version is available that can be used independent of the specialised software and full model specifications and functionality are detailed in Behrendt et al. (2020b).

Two key random input variables are considered, namely climate and output prices. Monte Carlo simulation procedures draw upon uniformly distributed annual sequences of daily climate data (2006–2019) and normally distributed prices for outputs (2012–2018) over a 10-year simulation period. A simulation horizon of 10 years was used as it defines the time frame of interest under the GESAS, which is based on two sequential 5-year plans (or program rounds).

The model was calibrated using local farm surveys and measurements of grassland and animal productivity (Han et al., 2011; Li et al., 2015; Wang et al., 2011). The grassland data, including grassland composition change, was based on experimental data from the long-term Siziwang Experimental farm (in IMAR, Fig. 2) which has been running since 2004 (Han et al., 2011; Wang et al., 2011). In this case study application of the model, the desirable species is based on perennial grasses (e.g. *Stipa spp*) and the less-desirable group is based on perennial shrubs (e.g. *Artemisa spp*). For an explanation of functional grouping and its interaction with grassland quality and quantity readers are referred to Kemp et al. (2013).

Based on the findings of the desert steppe herder survey reported by Zhang et al. (2019), herders in the IMAR desert steppe typically run around 386 Sheep equivalents (SE) on a grassland area of 503.4 ha, and so at a stocking rate of 1.36 ha/SE (0.74SE/ha). Typically, herders in the desert steppe grassland biome maintain 303 ha winter grazing and 200 ha of effective summer grazing land, which in the model are assumed to have a single soil type. Winter grazing starts on the 28th October and continues for 185 days, and summer grazing starts on the 1st May for 180 days.

Under GESAS, the required stocking rate in the desert steppe region was set at 2 ha/SE (or ~ 0.51 SE/ha). This required a stocking rate reduction of 0.23SE/ha and a new total flock size of 257SEs. Herders participating in the GESAS receive a Reward Balance (RB) payment of CNY25.5/ha in the desert steppe of IMAR (CNY12857 per annum).

Animal numbers and selling policies are automatically adjusted within the SGM to maintain a specified level of target females. As such two flock sizes were tested: 1) a typical herder starting with and maintaining 416 females (~0.74 SE/ha), representing those herders that

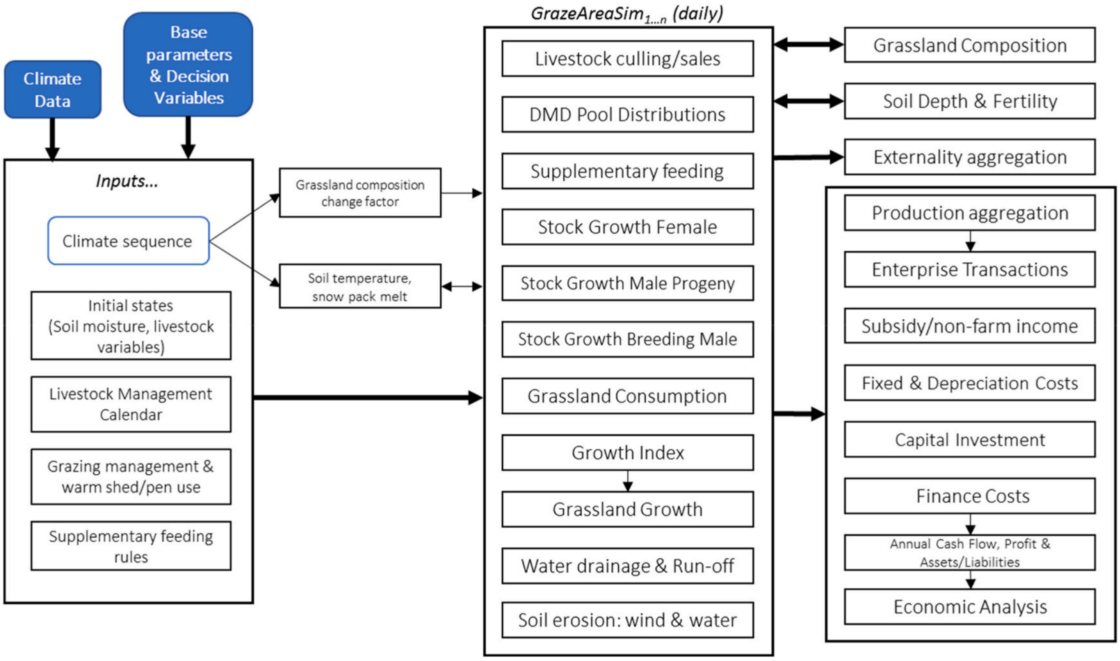

Fig. 4. *StageTHREE* Sustainable Grasslands Model framework.
Adapted from Behrendt et al. (2020a).

remain outside of GESAS; and 2) adjusting the flock size to a new level through either a voluntary reduction in stocking rate or with participation in the GESAS at 260 females (~0.51 SE/ha), which is then maintained for the remainder of the 10-year simulated period. The model financially (e.g. Annual Cash flow, Equity) and economically (i.e. Net Present Value) accounts for the reduction in livestock numbers, and the farming systems are modelled as typical desert steppe Mongolian sheep enterprises. In this study, only herder household annual cash flows, which represents the net herder household income after taking into account all variable, fixed and finance costs (Behrendt et al., 2020b), is reported as this metric best relates to herder decision making and as the actors of change. This is supported through studies that indicate herders in IMAR are substantially more income orientated than considering the long-term consequences of their actions (Addison et al., 2020b; Gao et al., 2016; Li et al., 2014a). Table 1 shows the model input parameters for the typical herder system in the desert steppe of IMAR.

The typical herder system is defined as the prevailing farm system with typical farm features that describe the production system, technology used, size and combination of labour, land and capital. This is determined through the use of a combination of surveys, herder, advisor and researcher consultation (Deblitz, 2010; Righi et al., 2011). This approach to designing a representative herder system provides more realistic and meaningful representations of existing farming systems than using averages of aggregated data or a selected individual herder (Kostrowicki, 1977; Mądry et al., 2013; Nuthall, 2011). The approach enables more broadly applicable evaluations of new technologies, management systems and the effect of government policies (Kostrowicki, 1977; Mądry et al., 2013; Nuthall, 2011; Righi et al., 2011). The approach avoids the sampling bias issues with surveys (Kostrowicki, 1977; Nuthall, 2011) and is more easily applicable in countries without, or with limited, statistics and accounting data (Deblitz, 2010; Righi et al., 2011).

Using regional historical price data for sheepmeat over the period of 2012–2018, stochastic output prices for sheepmeat were normally distributed around a mean of CNY41/kg cwt with a standard deviation of CNY3.50. For wool there is limited historical data, however, based on expert opinion a mean coarse wool price of CNY17.50/kg clean with a standard deviation of CNY3.5 was assumed. It is assumed there exists no significant correlations between climate, sheepmeat and wool prices given the spatially integrated nature of sheepmeat and wool markets in China (Brown et al., 2020).

Using the typical system over a 10 year simulation period for each iteration, a sample of test simulation output data for Annual Cash Flow were normalized through a Box Cox transformation and an iterative process was applied to calculate the minimum required number of Monte Carlo iterations (Osborne, 2010; Quinn and Keough, 2002). As the random sequence for both prices and climate risk were seeded, each modelled flock size scenario used identical random sets. This allowed for a significant reduction in the number of iterations required and facilitated calculation of opportunity costs under discrete states of nature. The convergence in sampling intensity occurred with at least 250 iterations to achieve a 95% confidence interval and an allowable error of no more than ±2.5% of the estimated mean Annual Cash Flow. This is the number of iterations used to generate the output from the model for each system.

To estimate the opportunity costs at discrete states of nature, in this instance combinations of Livestock Prices (LP), Wool Prices (WP) and Growing Season condition (GS), a discrete state of nature is firstly defined as a ratio of the mean price or growing season. The GS ratio is based on the ratio of each year's total annual rainfall to the mean long-term annual rainfall for the biome being simulated. As there will be variation in herder cash flows in both the short and medium/long term that may influence herder decision making, the SGM is capable of comparing and reporting both the outcomes for the entire simulation period and the final year, which is analogous with a steady state system (i.e. in terms of flock demographics and herder income stability). The difference between the resulting annual household cash flows for herders outside of GESAS (no reduction in stocking rate and no payment) and herders who voluntarily reduced their stocking rate (without GESAS payment) are then calculated for each combination of LP, WP and GS ratio. This is done separately for each year over the entire simulation period. The framework then uses the LP, WP and GS ratios as predictors to produce one-dimensional contours of the multidimensional opportunity cost response surface using fitted linear models within the interactive response surface modelling tool in Matlab (Mathworks, 2019). Additionally, other environmental services provided by herders

Table 1
IMAR desert steppe parameters for the Sustainable Grasslands Model.

Inputs	Units	Value
Geographic information		
Latitude of case study region	°	41
Altitude above sea level for case study area	m	1400
Case study general information		
Slope of grazing areas in degrees	°	5
Grazing areas	ha	Winter – 303; Summer – 200
Soil Information		
Starting available soil water on first day of simulation	gravimetric	0.44
Proportion sand content in soil	0–1	0.65
Proportion clay content in soil	0–1	0.11
Rooting depth	mm	400
Management calendar		
Time spent in each paddock	day	Winter – 185; Summer – 180
Selling assumptions for females	0–1	0.15 for sheep <1 yr old; minimum of 0.01 for sheep >1 yr old
Animal sale date	DOY	280
Purchase date for replacement breeding males	DOY	240
Lambing date	DOY	40
Lactation duration - Days post-partum	day	120
Wool or hair harvesting day (shearing)	DOY	150
Starting day for supplementary feeding rules	DOY	345
Ending day for supplementary feeding rules	DOY	300
Grassland information		
Proportion of legumes in the grasslands	0–1	0.1
Starting biomass of desirables in each grazing area	kg DM/ha	Summer & Winter grazing areas – 900
Starting biomass of undesirables in each grazing	kg DM/ha	Summer & Winter grazing areas - 900
Starting area proportion of desirables in each grazing area	0–1	Summer & Winter grazing areas – 0.5
Starting area proportion of undesirables in each grazing area	0–1	Summer & Winter grazing areas – 0.5
Soil Temperature Threshold	°C	8.0
Min, Optimal & Max Temperatures for plant growth	°C	5 / 19 / 35
Maximum leaf canopy height of grassland	m	0.3
Leaf Area Index at half maximum canopy height	m^2 leaf/m^2 ground	1.5
Canopy extinction coefficient	0–1	0.5
Mean monthly desirable Dry Matter Digestibility (DMD) – Jan to Dec	0.3–0.8	0.48 0.48 0.48 0.33 0.68 0.63 0.58 0.58 0.63 0.53 0.48 0.48
Mean Monthly less-desirable DMD – Jan to Dec	0.3–0.8	0.48 0.48 0.48 0.48 0.72 0.67 0.63 0.63 0.53 0.53 0.48 0.48
Grassland growth curve - alpha	0–1	Desirable & Less-Desirable: 0.065
Grassland growth curve – gamma	1–2	Desirable – 1.05; Less-Desirable – 1.04
Grassland Growth curve – Ymax	Kg DM/ha	Desirable – 6000; Less-Desirable – 5000
Maximum Biomass Decay Rate	0–1	Desirable & Less-Desirable: 0.995
Change in the proportion of space occupied by desirables over time under no grazing	0–1	Annually adjusted through stochastic multipliers – 30 yrs. for recovery from 0.3 to 0.9
Livestock Impact on Desirable group	0–1	0.272
Animal information		
Animal type		Wool type sheep[a]
Standard reference weight (SRW)	kg	55
The normal expected birth weight of an animal	kg	3.5
Opening numbers of females and male progeny	head	425 ewes, 40 wethers
Joining rate	0–1	0.03
Basal mortality rate	0–1	0.0202
Standard greasy fleece weight	kg/head	1.5
Mean fibre diameter	µm	24
Standard fleece length	cm	6
Clean:Greasy ratio for wool/fibre	0–1	0.6
Supplementary feeding		
DMD of supplement feed	0.3–0.9	0.66
Ether extract value for supplement	g/kg	25.84
DM:Wet weight ratio for supplements	0–1	0.88
Ration offered per head (adult @ SRW)	kg wet /hd/d	1.5
Relative condition for initiating supplementary feeding	0–1	<1 yr old – 1.0; 1-2 yr old – 0.85; >2 yr old – 0.7
Minimum grassland biomass threshold for initiating supplementary feeding	kg DM/ha	200
Economic inputs		
Carcass: Liveweight Ratio	0–1	<1 yr old – 0.465; > 1 yr old – 0.45
Meat Sale Prices	CNY/kg Cwt	Mean: 41; StDev: 3.5
Skin Price	CNY/hd	50
Wool/Fibre Price	CNY/kg clean wool	Mean: 17.5; StDev: 3.5
Enterprise Variable Costs	CNY/hd	12.25
Herder Family Costs (including opportunity costs of labour)	CNY/yr	35,000
Herder Fixed costs	CNY/yr	30,000
Herder equipment replacement value & expected life	CNY & yrs	CNY327600 & 10–70 yr effective life
Interest Rate for any borrowed money	%	7.0
Interest Rate for any saved money	%	0.5

[a] Based on Freer et al. (1997) breed types for defining reproductive parameters.

and the externalities of production are predicted by the SGM and reported in this study for both the entire simulation period and the final year of the simulation horizon.

5. Results

Cumulative distribution functions of herders' annual household cash flow under stocking rates within GESAS and outside GESAS appear in Fig. 5. The results highlight that in up to 10% of years over the 10-year simulation period (Fig. 5a) that no additional payment is needed to ensure compliance. This is primarily due to the sale of livestock capital as herders comply with the GESAS program (*Reduced stocking rate* in Fig. 5a), but also due to higher production under low stocking rates. For the majority of years, herder cash flows of operating outside of the GESAS program greatly exceed the cash flows of operating within GESAS (88% of the time), increasing the risk of non-compliance. Similar differences exist between the options in the final year annual cash flow data (Fig. 5b), which indicates that in just over 90% of years, that under longer-term steady state conditions, herder household cash flow exceeds the cash flow inclusive of payments being offered within GESAS (CNY25.5/ha for the desert steppe). Fig. 5b also indicates that only in around 1.5% of years are there no cash flow disadvantages from the herder reducing their stocking rate, which represents the small gains made from improvements in per animal production under lower

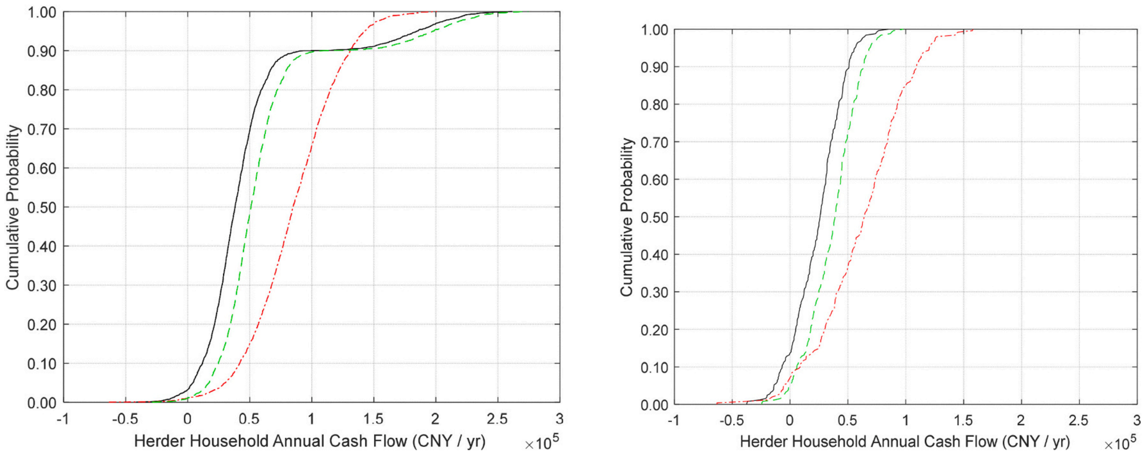

Fig. 5. Cumulative Distribution Functions for herder's annual cash flows under reduced stocking rates with no subsidy (—), within GESAS (- -) and outside of GESAS (-·) in: a) all individual years of the 10 year simulation period; and b) only the final year of the simulation period (Year 10).

stocking rates. This is also expressed through the slope and spread of the *Reduced Stocking Rate* CDF, which is steeper with a reduced range of outcomes, hence a more resilient system with less risk, albeit with lower overall cash flows. Theoretically, the difference between the *Reduced stocking rate* CDF and *Outside GESAS* CDF of Annual Cash Flows at different discrete states of nature represents the herder's household opportunity cost for a reduced stocking rate, or in equivalence, the minimum payment required for herders to comply with GESAS under these states of nature.

Using elemental wise pairing of LP, WP and GS ratio, the opportunity costs under all modelled discrete states of nature is calculated. Fig. 6 shows the cumulative distribution function for all calculations of opportunity cost for both the final year of the simulation horizon and for all years of the simulation period. Corresponding to the findings in Fig. 5, Fig. 6 indicates that for all years simulated, around 10% of years herders incur no opportunity costs, and in around 89% of years the opportunity cost exceeds the current level of GESAS reward balance payment. If only the final year of the simulation period is considered then in only 1.5% of years are there no opportunity costs for herders (and so where they would benefit from reducing stocking rates) while for 92% of years the opportunity costs greatly exceed the GESAS reward balance payment offered.

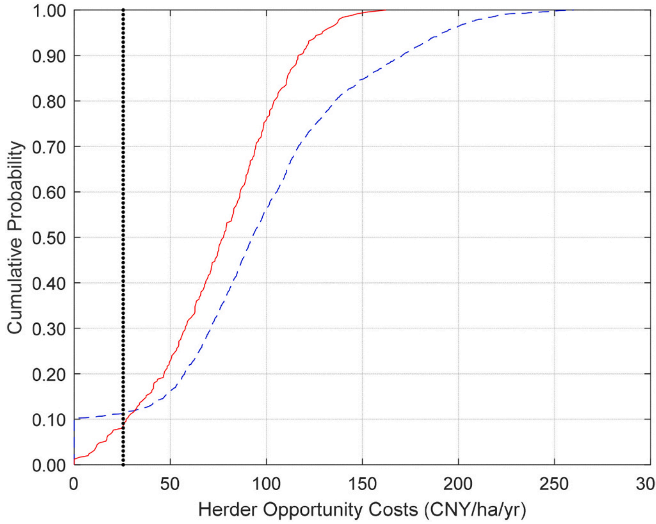

Fig. 6. Cumulative Distribution Functions for herder's annual opportunity costs of a stocking rate reduction over the entire 10-year simulation period (- -) and under more steady state conditions (—) (final year of simulation period). GESAS payment level is indicated (⋯).

To more easily visualise and interrogate the relationships between opportunity cost and the LP, WP and GS ratios as predictors, one-dimensional contours of the multidimensional response surface are fitted using linear models (Fig. 7) using interactive response surface modelling in Matlab (Mathworks, 2019). At median factor values for LP (0.999), WP (1.020) and GS (0.891), the expected opportunity cost for GESAS compliance in the final year of the simulation period is CNY75.71 (+/− CNY6.05)/ha/year. The results indicate that the opportunity costs are more sensitive to variations in livestock price than they are to wool price and climate variability. In response to livestock prices, when growing season and wool price is held at median factor values, the opportunity costs are shown to vary between CNY33 and CNY115/ha/year. Correspondingly, in response to wool prices, when livestock price and growing season is held at the median factor value, the opportunity costs vary between CNY71 and CNY80/ha/year. Similarly, opportunity costs vary between CNY74 and CNY79/ha/year in response to growing season condition. At extremes for each factor, under both maximum and minimum factor values for LP, WP and GS, the expected opportunity cost ranges from around CNY27 to CNY124/ha/year. The results indicate that under low sheepmeat prices (LP index values of ~0.84), minimum wool prices and the poorest seasonal conditions, the opportunity costs of compliance are less than current GESAS payments for the desert steppe.

The economic, production and environmental outcomes are presented in Table 2. The simulation results indicate that herders within GESAS have reduced meat production per hectare with 3.4 kg Cwt per hectare less being produced, although meat production per SE is 0.77 kg Cwt/SE higher within GESAS. Herders operating within GESAS are also expected to have improved grassland composition and ground cover, with the final year proportion of Desirable species being around 0.57 within GESAS and 0.49 outside GESAS, which indicates some recovery of degraded grasslands within GESAS over the medium to long term, and maintenance of the current degraded state outside of GESAS. Grassland biomass is expected to be around 68 kg DM/ha higher within GESAS, with a notable larger positive difference in summer grazing areas, which are found to be much more susceptible to both grassland degradation and soil erosion.

A major benefit, or positive externality, from herders complying with GESAS is reduced soil erosion from both water and wind, and reduced GHG emission intensity per unit of sheepmeat production. For herders within GESAS, cumulative soil erosion over the 10-year simulation period is expected to be around 4.41 t/ha lower. GHG emission intensity was estimated to be 16.17 kg CO_2e GWP_{100} / kg Cwt sold, and 16.92 kg for herders outside of GESAS, which overall represents a reduction in total emissions of 33.6 t CO_2e GWP_{100} / year for herders within GESAS. There is also a tendency for variability, or risk of production and most

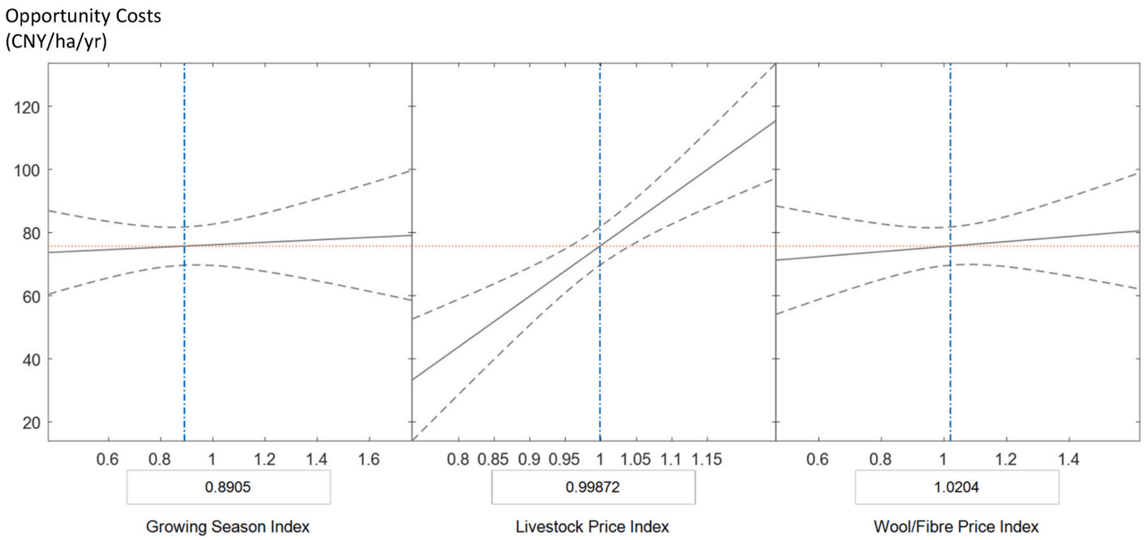

Fig. 7. Prediction plots of linear models for the final simulation year opportunity costs of herders complying with GESAS under different states of nature (—) with 95% simultaneous confidence bands for fitted responses (— —). Median opportunity cost (····) at median factor values for growing season, livestock and wool price index (—·—) are highlighted.

Table 2

Mean annual values and coefficient of variation (in parentheses) for a selection of economic, production and environmental outcomes.

Biophysical and gross margin outcomes	RB (within GESAS)[a]	NRB (outside GESAS)
Cumulative net soil erosion (t/ha)[b]	29.23 (0.53)	33.62 (0.54)
Final year grassland biomass (Kg DM/ha)[c]	1177 (0.32)	1109 (0.32)
Final year grassland height[c] (cm)	12.0 (0.30)	11.4 (0.30)
Final year fractional ground cover[c]	0.44 (0.24)	0.42 (0.25)
Final year proportion of Desirable species[d]	0.57 (0.15)	0.49 (0.25)
Meat production (kg cwt/ha)	8.6 (0.29)	12.0 (0.09)
Supplementary feeding (Kg DM/SE)	136 (0.19)	153 (0.19)
Gross Margin per Head (CNY/head)[e]	251 (0.22)	243 (0.25)
Gross Margin per Hectare (CNY/Ha)[e]	217 (0.22)	359 (0.26)
Total Greenhouse Gas Emissions (t CO_2e)[f]	67.96 (0.13)	101.51 (0.04)
Emission Intensity (Kg CO_2e/kg meat produced)[f]	16.17 (0.10)	16.92 (0.07)

[a] Includes the scenario whereby herders voluntarily reduce stocking rates without subsidy payment

[b] Total cumulative net soil erosion over the 10-year simulation period (net of soil formation)

[c] Extracted for July period only, which represents peak period for livestock production and grassland tourism.

[d] Starting proportion of Desirable species was 0.5. Desirable species is based on perennial grasses (e.g. *Stipa spp*) and less-desirable group is based on perennial shrubs (e.g. *Artemisa spp*). See Kemp et al. (2013) for explanation of functional grouping and its interaction with grassland quality and quantity.

[e] Gross Margin is a measure of enterprise profitability and is the difference between livestock trading income and enterprise variable costs (Behrendt et al., 2020b).

[f] Equivalents calculated using GWP_{100} based on IPCC (2014).

externalities, to be reduced for herders within GESAS, which also leads to more resilient and favourable grassland and environmental outcomes.

6. Discussion

Due to the significant variation in these key output variables of importance to policy makers, it is critical for policy and livestock and grazing strategy design to define and understand the distribution of outcomes rather than rely on average expected or deterministic outcomes. This includes understanding the distribution of environmental outcomes associated with the different stocking rates across spatially explicit parts of the landscape and how these link with the aims of grassland policy. The framework applied here indicates that there is a proportion of years under different states of nature in which no incentive is required for herders to voluntarily adjust stocking rates. In the short-term, these are predominantly the result of herders selling surplus animals to meet requirements for stocking rate adjustments, but also due to improved per animal performance under reduced stocking rates in the long-term (as a result of subtly improved grassland condition and nutrition) (Jones and Sandland, 1974; Kemp et al., 2018; Kemp et al., 2013).

Additionally, there are a significant proportion of years, or states of nature, where a much larger incentive (RB payment) would be needed to offset opportunity costs of herders for reducing stocking rates and meeting GESAS requirements. This is somewhat consistent with the findings of Byrne et al. (2020) who suggested a mean shadow price of CNY196 for herders participating in a complete destocking scheme in IMAR. The constraint with this factor-income study, however, is the limited states of nature upon which it is based. Thus, there should be scope to adjust the level of reward balance payment in response to different states of nature. However, in contrast to the conclusion drawn by Addison and Greiner (2016) in regards to the importance of climatic conditions on policy compliance and opportunity costs, this study indicates that market prices for outputs, in particular sheepmeat in this case, far outweighs the importance of climatic conditions in determining opportunity costs and GESAS compliance. This is consistent with the empirical study of Hu et al. (2019) in IMAR that suggested that herders predominantly made their livestock production and grazing decisions in response to market prices.

In states of nature where no incentive is required (low prices and below average growing seasons), herder incomes are likely to be very low, whereas states of nature with high opportunity costs (requiring greater incentives for compliance) are associated with periods of much higher incomes. These findings highlight the need to unbundle the environmental incentive and welfare components of GESAS if the twin objectives of reversing ongoing grassland degradation and improving herders household incomes are to be achieved (Li et al., 2014b). The unbundling would also serve the purpose of herders perceiving the payment as an ecocompensation payment for an environmental service rather than as a welfare entitlement (Zhang et al., 2019).

This study clearly shows the need to shift away from constant across states of nature payments and towards differentiated payments based on different states of nature. It could be hypothesised that such an approach to setting ecocompensation payments would best be achieved through an *ex post* analysis of states of nature, with different states of nature defined by well-known indicators for weather (e.g. county rainfall) and market price (e.g. county sheepmeat price). With the benefits fully explained to herders, a differentiated payment approach could be incorporated into the GESAS scheme, as such precedents exist in agricultural and weather index insurance schemes. However, from all the potential ways of implementing such a scheme, the best approach would be dependent upon the transaction costs.

The biophysical outcomes of the model here are consistent with those of stocking rate experiments and herder surveys, in that although per animal performance improves with reduced stocking rates, total meat production per hectare declines to reduce overall income for herders (Li and Behrendt, 2019; Müller et al., 2014). Gains in per animal performance partly compensate for reduced stocking rate, as indicated by the change in the range of outcomes and slope of the steady state (final year) CDF (Fig. 5b), but are limited in this case due to the marginal difference in the nutritional value of desirable and less-desirable species (Table 1). Additionally, in this analysis it is assumed that surplus cash flows received by herders as part of reducing stocking rates under GESAS are not re-invested into further improving system performance, nor is there any assumed gain in flock phenotypic performance from the culling of surplus animals, both of which have been shown to increase the long-term profitability of herders in China (Kemp et al., 2018; Kemp et al., 2013; Takahashi et al., 2015). These relationships are also indicated by the lower final year cash flows than the values shown for all 10 years of data (Fig. 5). However, for outside of GESAS, herder cash flows would be expected to decline due to the slow degradation of grassland condition (Table 2).

It is also likely that at 10 years post-stocking rate adjustment, the ecological system may not be completely at a steady state as grassland condition may still be transitioning towards a condition that will further improve livestock production and reduce environmental externalities. This may occur due to continued changes in both botanical composition of the grassland and the quantity of higher quality dry matter available (Kemp et al., 2018). In a desert steppe biome, this may take well in excess of 20–30 years (Han et al., 2011; Zhao et al., 2018) and there is no data available to adequately indicate an historically ideal state of grassland condition (Kemp et al., 2020). Similarly, the small marginal gains found from reduced stocking rates, in terms of grassland condition and externalities shown in Table 2, would be expected due to the predominant influence of abiotic factors in any year in combination with the gradual changes in grassland condition (Jamiyansharav et al., 2018; von Wehrden et al., 2012).

The asymmetry between herders planning horizons (which may well be 1 year or shorter) and those of policy makers is a considered compromise within the modelling framework. The GESAS programs are integrally tied to multiple five-year plans and the targets and incentives for all levels of officials, particularly the local level officials, relate to these five-year plans. As discussed, the impacts of GESAS are not likely to be realised within five years and policy makers planning horizons should be at least 10 years, but this is not consistent with the reality of Chinese decision making as evidenced in previous policy decisions and processes. Thus, the frameworks 10-year horizon, which can be modified for different applications, is a considered compromise between the normative (what should be) and positive (what time frames policy makers are actually working against).

The developed framework and findings from this study suggest that it should be possible to design more efficient programs and policies more closely aligned with weather and market states. This could lead to the more targeted use of limited program payments to improve herder compliance and environmental outcomes, which is consistent with the propositions of Addison and Greiner (2016). Additionally, it provides policy analysts and researchers with better information on the importance of ecocompensation payments to herder household incomes. It also provides insight into the expected gains in environmental services provided by herders which comply with policies, and thus understand the benefits and costs of the ecocompensation policies at farm and societal levels (Addison and Greiner, 2016; Yin and Zhao, 2012).

The framework developed for assessing opportunity costs, which integrates the use of dynamic stochastic bioeconomic grasslands model, is broadly applicable to the majority of grasslands and rangelands across the Eurasian steppe and many other parts of the world. The merits of using this approach is that it defines the probabilistic outcomes that decision making units (in this case herders as the actors of change), are faced with when comparing whether or not to adopt and comply with policy offerings. The limitation of the approach is that to more accurately replicate the range of herder systems, responses, soil types and biomes across a landscape that may be affected by a policy, it would require a more agent-based modelling approach with a network of typical herder systems. It would also require the necessary data to inform both the definition of robust farm types, but also the parametrisation of the bioeconomic model.

A challenge in implementing more dynamic payments for environmental services policy is in relating thresholds to objectives and widely understood weather and market states. In addition, as this modelling study relates only to a single type of desert steppe household, there is a need to identify, define and model an appropriate number of representative herder households given the heterogeneity of herders and biomes across the grasslands of IMAR. There is also the additional policy challenge in delivering such a program consistently over a number of years to ensure its revenue neutrality, especially in situations where policy makers will be under pressure to change the policy (increase the payments) when conditions are in poor states of nature.

Declaration of Competing Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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