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A factor-income approach to estimating grassland protection subsidy payments to livestock herders in Inner Mongolia, China

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ABSTRACT

This paper contributes to the growing literature on land use policies designed to prevent livestock overgrazing. It offers a straightforward factor-income approach to calculating payments for ecosystem services (PES) to livestock producers who reduce or suspend grazing for the purpose of grassland restoration. Our approach requires only cross-sectional farm-level accounting data and is thus feasible where policies have either not yet been applied or specialized data is sparse, as is common in many developing regions. We apply and validate this approach with empirical analysis of sheep and goat herders in the Ulanqab prefecture in Inner Mongolia, China where herders currently receive payments in exchange for reduced grazing intensity on vulnerable land. However, observed stocking rates are still commonly higher than recommended. Our results suggest payments are currently insufficient to offset the financial loss incurred by herders who reduce their grazing intensity, a finding consistent with previous studies. Using an approach we refer to as the factor-income method, we estimate and validate new levels of recommended payments. This demonstrates how future payments could be tailored to meet the financial needs of individual herding communities using basic farm-level data.

1. Introduction

The tradeoffs between food production and environmental conservation have received an increasing amount of attention, with particular concerns raised about how livestock production contributes to desertification, water contamination, erosion, climate change, and other environmental externalities. Incentive-based mechanisms have gained hold as a way to incentivize land use behavior and management activities that have a public benefit but might come at a private cost. Payment for ecosystem service (PES) programs, one particular variety of these policy mechanisms, aim to address environmental externalities. However, the success of such programs hinges on setting payments appropriately: they must be high enough for land managers to participate but should not be so high as to overspend public funds. Thus, a key issue in developing these programs is how to set the level of payment.

PES programs are only socially *and* privately beneficial if the payment is set correctly. Land managers targeted for PES programs can expect to lose profit by changing their practices, with the PES is intended to offset such profit loss. For example, a livestock herder who reduces his herd size to lessen pressure on grassland loses the revenue from the animals he no longer produces and sells. This is the *cost to the producer*. However, reducing his herd allows the grassland ecosystem to rehabilitate, which is a *benefit to society*. If the cost to the producer is less than the benefit to society, then a successful transfer from society to the producer leads to an improvement for both. The challenge of landing in this “sweet spot” of compensation (i.e. ensuring additionality) has long been recognized as difficult (e.g. Engel et al., 2008) but, still, practical approaches to estimating payment levels are lacking. The question of how much to pay has been well-explored in the literature, but most peer-reviewed studies that determine prices involve detailed data not often available to most designers of a PES program (Ferraro, 2008; Kaczan et al., 2013; Layton and Siikamäki, 2009; Wünscher et al., 2008). The method proposed in this study and applied to a PES subsidy program in Inner Mongolia, China uses household data that is often at hand or more easily obtained in developing regions.

The most basic challenge is estimating the distribution of recipients’ opportunity costs for avoiding a land use activity. This distribution is required in order to determine what proportion of land users are likely

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to accept a payment and thus how much of the landscape may be impacted by the PES program. Ideally, such information would be known before the implementation of a costly policy. This paper uses a simple "factor-income" approach that can be applied in a multitude of contexts to evaluate, develop, and improve policies designed to manage livestock production on vulnerable grassland. The method's details and efficacy are demonstrated in a study site in Inner Mongolia, China.

PES programs are widely used in China, where agricultural producers are often land managers tasked with the simultaneous objectives of producing food for the nation while sustainably managing arable land. Rapid urbanization has transformed China and directly impacted agricultural producers through land conversions, in-country migration, and changes in food demand, often coupled with environmental costs (Liu, 2018). In particular, significant attention has been focused on grassland restoration after several decades of increased livestock production have led to reductions in grassland health and vegetation (Steffens et al., 2008; Waldron et al., 2010; Wu et al., 2015; Zhao et al., 2005). Policies have targeted Chinese herders and offered a variety of incentives for them to change their land use including a form of PES, sometimes referred to as "ecological compensation" or simply "eco-compensation," in exchange for reduced grazing (Hua and Squires, 2015; A. Li et al., 2018; Yang and Lu, 2018; Yin et al., 2019).

We use the factor-income approach to assess a PES program in Inner Mongolia, China. Inner Mongolia is an important region for livestock production and is characterized by a diversity of grassland ecologies, ranging from lush meadows to dry desert steppe (Chuluun and Ojima, 2002; Hua and Squires, 2015; Wu et al., 2015). Economically, Inner Mongolia (and Western China, more generally) has higher rural poverty rates than elsewhere in the country (Long et al., 2010). Further, much of Inner Mongolia has suffered from land degradation as a result of livestock activity. In an effort to restore grasslands and provide economic support, the Chinese government has funded programs for Inner Mongolian herders to change their grazing practices and restore grassland health (Kemp et al., 2013), including the recent "Ecological Subsidy and Award System"(ESAS) which offers direct payments in return for reduced grazing (Gao et al., 2016). However, this payment program has been more effective in some regions than in others, with herders in the desert steppe of Ulanqab showing low levels of participation and satisfaction (Gao et al., 2016; Hu et al., 2019; Zhang et al., 2019). This demonstrates the need for policy analysis that (1) easily and accurately estimates the appropriate payment level in Ulanqab and (2) can be easily be modified for different regions so that payment levels can be more targeted and, thus, more effective.

Our findings show that current payment rates in our study area are too low to fully offset most herder's financial losses when grazing is reduced, a minimum condition for the subsidy program to be effective. We provide estimates of payments that could achieve varying levels of compliance. Each herder has a minimum necessary payment level, so as payment levels increase so too does the number of herders made whole. For example, we find that an increased subsidy of ¥250 RMB/ha annually for land removed from grazing would lead to an estimated 80% compliance rate. The subsidy rates we find are substantially higher than current rates. This is expected given previous studies have reported low participation and satisfaction with the program in the same study location (Gao et al., 2016; Hu et al., 2015b; Zhang et al., 2019). While some of those previous studies claim that "throwing money at the problem is not the answer to improved policy effectiveness," (Gao et al., 2016) such analysis examines small increases in subsidy rates at the margins; our analysis finds that the changes necessary would in fact be much larger. To that end, for the program to operate efficiently, it would likely require a much larger budget or a smaller set of target recipients.

In the section that follows, we describe the context of grassland management in Inner Mongolia and how a PES approach might compare to other policy alternatives in this context. Section 3 then describes the theoretical approach for the factor income method, followed by a Section 4 which describes our data and the empirical model used for estimation. Results are presented in Section 5, detailing the minimum subsidy payment levels within our sample and expected rates of participation in the PES program in the region of study as a function of the subsidy payment level. These estimates are then discussed and validated with findings from previous literature in in Section 6. We conclude with implications for future research and policy design.

2. Managing grassland and livestock in Inner Mongolia

2.1. Recent changes in land use and livestock

Over 41.7% of China's land area is classified as grassland. Changes in agricultural practices and large increases in livestock production have resulted in reports that 90% of Chinese grasslands are degraded (Han et al., 2008b; Li and Huntsinger, 2011). This has been driven partly by dramatic increases in human activity; developed land increased from 1.4% to 12.7% in Inner Mongolia between 1988 and 2011 (Z. Li et al., 2017). Simultaneously, the livestock population has grown dramatically, increasing by a factor of five over the past six decades (Robinson et al., 2017), a result of increases in meat and animal product demand and population pressure (Kemp et al., 2008; Liu et al., 2019a). These changes reflect a national trend whereby rapid urbanization has transformed land use in China, dramatically shifting the balance of land use. In response, a large branch of recent Chinese land use policies have focused on arable land loss and land-related livelihoods, which are strategically grounded in both ecological protection and food security (Liu et al., 2014).

Grassland degradation poses multiple threats, including species loss, desertification, and decreased productivity (Jiang et al., 2006; Kemp et al., 2013; Li and Huntsinger, 2011; Meyer, 2006). Nationally, unsustainable grazing practices have consistently been linked to grassland degradation (Wang and Wesche, 2016; Yan et al., 2013), which in turn makes it difficult and costly for herders to raise livestock on grassland pasture due to limited nutritional availability and decreased grassland productivity (J. G. Han et al., 2008). Studies in Inner Mongolia's desert steppe have shown the extent to which overgrazing causes degradation, and how it can be reduced or even reversed through grazing management strategies (Schönbach et al., 2011; Steffens et al., 2008; Wang et al., 2014; Zhang et al., 2015; Zhao et al., 2005). Within the larger context of Chinese land use changes, degraded grassland and associated losses in rural farm households are examples of the negative impacts of Chinese urbanization on rural communities; policies to alleviate such impacts are necessary to efforts of rural revitalization (Liu, 2018).

To reduce overgrazing and mitigate its negative impacts, China developed several grassland management policies over the past two decades, including those that govern China's grasslands (A. Li et al., 2018; Li and Huntsinger, 2011; Liu et al., 2008, 2019a; Yang and Lu, 2018). In addition to other large grassland policies, the Ecological Subsidy and Award System (ESAS) represents a major initiative. The ESAS, also referred to as an "eco-compensation" subsidy program, is the focus of this study and includes two subsidy levels for reduced grazing: a higher (¥90 RMB/ha) annual subsidy for full grazing withdrawal and a more modest (¥22.5 RMB/ha) annual subsidy for a forage-livestock balance. Subsidy payments are given with the intent to keep producers financially stable while achieving the goals of livestock production and grassland restoration, serving as a form of "payments for ecosystem services" (PES). Yet fragmentation and overuse of grazing land parcels has continued across time (Liu et al., 2019a; Robinson et al., 2017; Waldron et al., 2010; Williams, 1996). Additional payments for improved husbandry and production practices are included in the ESAS program but are beyond the scope of this study.

2.2. The Ecological Subsidy and Award System (ESAS) in Inner Mongolia

The ESAS is a large national initiative, though a substantial portion

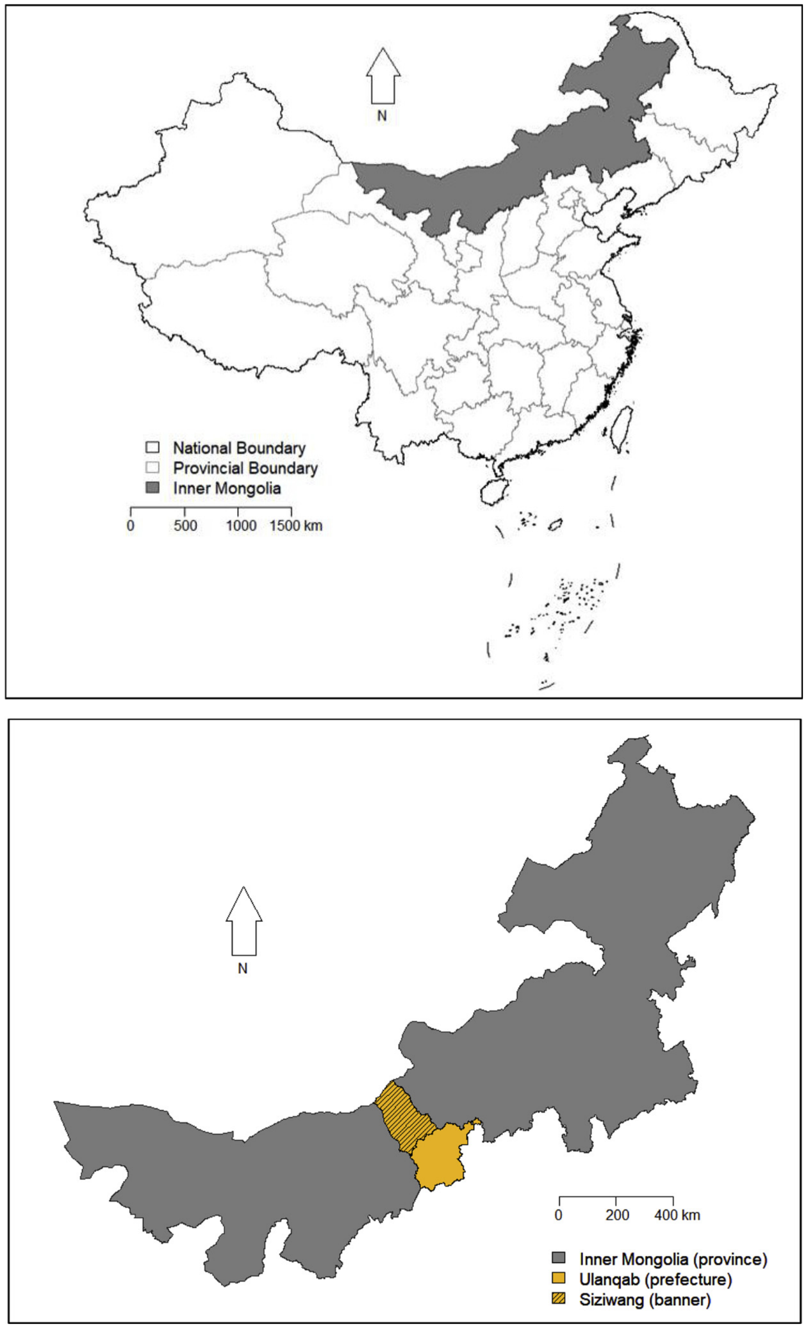

Fig. 1. Location of Inner Mongolia province and Ulanqab prefecture (study area).

has been directed to Inner Mongolia. The entire program reported annual expenditures of ¥14.9 billion RMB (~$2.1 billion USD) in 2011, exceeding the originally budgeted ¥13.6 billion RMB (Shao et al., 2017), of which about 30% has been directed to Inner Mongolia (Gao et al., 2016). The regions it covers within Inner Mongolia vary tremendously, with previous studies showing variation in ecological resilience (Hao et al., 2014), differences road access and associated grassland health (Deng et al., 2011), and livestock herd composition and density (Yu et al., 2004). Despite this diversity, the ESAS eco-compensation subsidy program is relatively rigid, with herders in and across Inner Mongolia given the same program options despite tangible and important differences in circumstance.

Several studies demonstrate the subsidy program has not had its intended impact on herders in Inner Mongolia (Dai and Tan, 2018; Hu et al., 2015a; Yin et al., 2019; Zhang et al., 2019). Notably, the program's shortcomings have been observed in Ulanqab prefecture (see Fig. 1), which is the location of interest in this study and is described in more detail in Section 4. Some studies report broad ecological benefits of the program (Chen et al., 2017; Kemp et al., 2013; Yang et al., 2015; Zhang et al., 2018). But recent work also shows that herders have low levels of satisfaction with the program and respond weakly to payments (Gao et al., 2016; Hu et al., 2015b; Liu and Zhang, 2018), small farms are particularly prone to overgrazing (Hu et al., 2019; Jin and Hu, 2013), high meat prices have increased herder incentives to overgraze (Liu et al., 2019b), and subsidies are not sufficiently differentiated across location and landscape characteristics (Hu et al., 2015a; Liu and Zhang, 2018). Such reports of low satisfaction and participation beg the question: is there a problem with the subsidy payment level or is the use of subsidies altogether inappropriate? In the remainder of this section, we examine how payments can be calculated in a manner that will

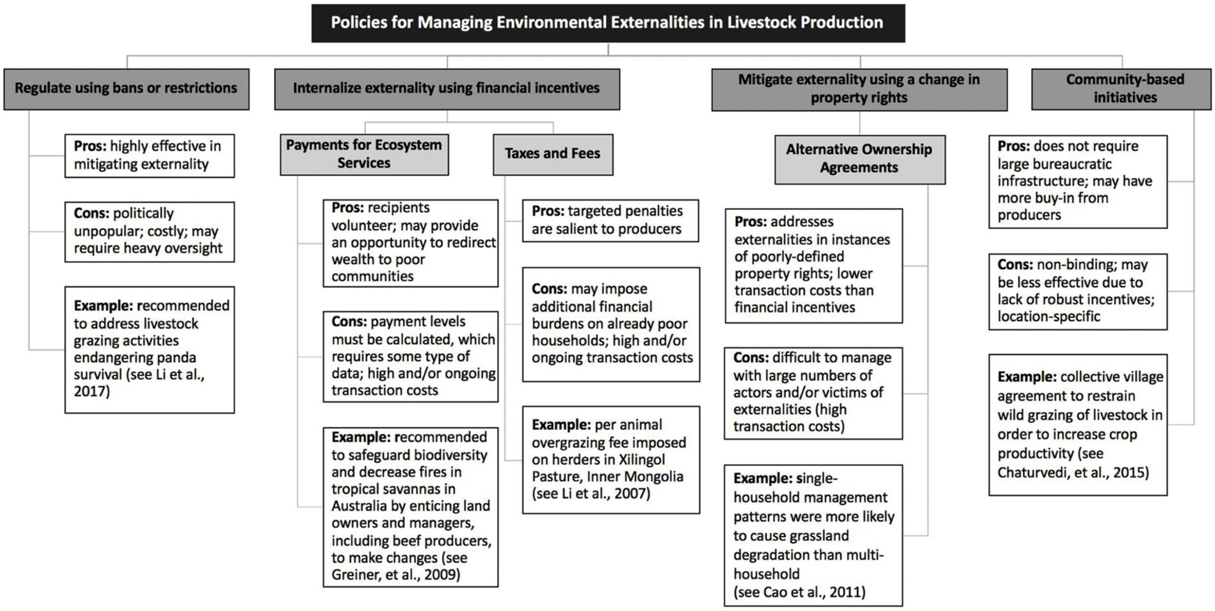

Fig. 2. Framework for categorizing policies to address externalities in livestock production (Cao et al., 2011; Chaturvedi et al., 2015; Greiner et al., 2009; B.V. Li et al., 2017; Li et al., 2007).

improve its efficacy.

2.3. Payments for ecosystem services (PES) to manage Inner Mongolian grassland

PES programs are one of several policy options for managing externalities. There is a long literature on examining and managing environmental externalities beginning with early work on internalizing externalities (Pigou, 1920) and institutional or contractual changes to eliminate externalities (Coase, 1960). We limit this discussion to those policies which have been suggested or implemented for managing externalities created by livestock production.

We broadly categorize policies for managing externalities created by livestock production as follows: bans, policies that internalize externalities, policies that mitigate externalities through contracts, and community-based initiatives (see Fig. 2). PES programs, including the ESAS, fall in the second category, policies that internalize externalities, by internalizing the cost of ecosystem management.

While alternative policy approaches are used in other contexts, they would likely be infeasible for grassland management in Inner Mongolia. Outright land use bans can have high financial and livelihood costs for landholders, and political costs for policymakers. In Inner Mongolia, complete bans would leave many herders with no livelihood, especially considering the limited mobility imposed by the Hukou system which restricts migration within China (Mullan et al., 2011). Policies that shift the overall incentive structure to make it less appealing to generate an externality in the first place are classified as those that mitigate externalities. In Inner Mongolia, property rights undergone dramatic changes since the 1970's yet overgrazing is still and ongoing problem (Li and Huntsinger, 2011), showing this alone has been is insufficient in this context (Robinson et al., 2017). Finally, community-based initiatives may include education or capital improvement initiatives. There have been policy suggestions from this category that could offer economic improvements, including recommendations for supply chain improvements (e.g. improves processing and storage) that connect Inner Mongolian herders with more lucrative markets so that the effective price per head is increased (Briske et al., 2015). While these recommendations should also be considered in the interest of alleviating poverty among Inner Mongolian herders, specific proposed policies that open access to new markets would likely intensify incentives to overgraze in the absence of additional regulations. Furthermore, it would be difficult to tie such investments to specific behaviors (e.g. reduced grazing). Thus, a PES approach seems well-suited for grassland restoration in Ulanqab, and across Inner Mongolia.

PES encompasses a broad set of policies; given the wide array of ecosystem services, there is a large assortment of PES schemes (and accompanying literature).[1] This is in part due to the specific components of a given ecosystem service's total economic value, which is the sum of all value derived from a natural resource (Greiner et al., 2009). Any PES program must consider the specific components of the ecosystem service's total economic value. In the case of grasslands in Ulanqab, the primary components of the total economic value are the consumptive use value of grazing land for livestock and the indirect use value of grassland cover that prevents desertification, mitigates climate change and provides other useful ecosystem services (Chen et al., 2017; Y. Li et al., 2017; Zhao et al., 2009). Secondary components include its recreational and aesthetic value, which is demonstrated in the growing grassland tourism industry (Wang et al., 2017). Given the sources of economic value in Inner Mongolia's grasslands, direct payments in exchange grazing reductions are indeed appropriate.

PES programs have several qualities that would benefit Inner Mongolia's herders, despite current failings in the ESAS program. These programs are amenable to direct monitoring and regulation, as required to meet ecological recommendations for reductions in grazing intensity (G. Han et al., 2008a; J. G. Han et al., 2008; Steffens et al., 2008). They are often cost-effective when compared to long-terms costs associated with lost ecosystem services (e.g. desertification of grasslands). Direct costs for transactions and payments can be kept low while creating long-term environments that are conducive to innovation by simultaneously imposing a necessary environmental constraint while infusing cash into production operations (Jack et al., 2008). Furthermore, they are demonstrably effective in poverty alleviation (Bulte et al., 2008; Jack et al., 2008), which is of particular importance in Ulanqab where incomes are lower than elsewhere in Inner Mongolia (Gao et al., 2016). Contextualized with the full range of policy options, we see that eco-compensation subsidy payments used to mitigate externalities are indeed best suited to effectively manage overgrazing in Inner Mongolia,

[1] See (Gómez-Baggethun et al., 2010) for an overview of the history of PES.

and likely elsewhere.

However, such programs require proper design and implementation. As previously mentioned, the ESAS subsidies have not resulted in the broad success for which policymakers had hoped. Common concerns with PES programs are oversight and its costs, “leakage” whereby land managers shift environmentally damaging activities to different locations, and market effects whereby the payment shifts market conditions which shift incentives such that the objective is not fully met. The issue of oversight in Ulanqab is modest because compliance can be easily observed. Leakage is not a major concern due to the nature of allocated land leases and restrictions on migration. Market effects have been shown to change herder behavior (Hu et al., 2019); however such effects would be mitigated with higher rates. Thus, we conclude that the major failing of the policy is rooted in the rates themselves.

2.4. Challenges in Inner Mongolia’s ESAS subsidy design

The subsidy levels for ESAS, ¥90 RMB/ha and ¥22.5 RMB/ha annually for grazing withdrawal (no grazing) and moderated grazing, respectively, were set at the start of the program with little regional differentiation. If a community was identified for a withdrawal from grazing, the payment level was set at ¥90 RMB/ha, regardless of location. Given the heterogeneities in ecology, production practices, and household incomes across Inner Mongolia, a uniform payment level was bound to have one of two outcomes: either payments would be set so high that some herders would be compensated more than necessary (resulting in overspending of government funds) or payments would be set low such that some herders would not have incentive to participate. Evidence from previous literature suggests the latter has happened (Gao et al., 2016; Hu et al., 2019; Wei and Qi, 2017), all the while many have noted that payments should be differentiated due to the heterogeneity in ecology, markets, and other conditions impacting the value of the grassland to herders (Hu et al., 2015a; Zhang et al., 2019).

Most of this previous analysis has been diagnostic, evaluating the program’s efficacy without offering estimates of payment rates that could remedy the program’s shortcomings. One exception is a study that estimates payments for the neighboring Xilingol League of Inner Mongolia using a contingent valuation approach (Zhen et al., 2014). However, in addition to their estimates being specific to Xilingol, policy makers are often suspicious of contingent valuation studies due to well-known issues with hypothetical bias from self-reported willingness to accept estimates from herders. Further, a contingent valuation approach applied broadly across the whole of Inner Mongolia would be prohibitively costly to replicate and values from Xilingol are hardly representative of Inner Mongolia broadly.

For a large program, such as the subsidy payments in Inner Mongolia distributed through the ESAS, policymakers need to accurately and cheaply estimate differentiated payments. Methods for estimating payment levels for PES programs are numerous and varied. They include travel cost, contingent valuation and stated preference approaches, hedonic modeling, cost-based approaches, and factor-income approaches (Swinton et al., 2007). Table 1 presents a brief overview of these methods and the varying contexts in which they could be applied. For the subsidy program in Inner Mongolia, a factor-income approach is most suitable. A factor-income approach is one where farm income is estimated with and without externality management; the difference is the minimum necessary payment. Our factor-income approach uses the shadow price of land as estimated from herder household budgets, to determine the difference in income with and without an additional hectare of land used in production.

The benefits of the factor-income approach, as presented here, are clearly offset by its limitations, primarily measurement error in determining land prices. Hedonic approaches, which use land sale values provide an alternative to factor-income method and directly measure land values; however, because the market for land in Inner Mongolia is closed and leases are allocated to herders at no cost, such an approach

Table 1
Methods for estimating payment levels for payment for ecosystem services (PES) policies.

Method	Description	Economic value captured	Accuracy	Data availability
Travel cost	Relates the cost to travel to a site with the its value to users	Recreational and other non-consumptive values	May not capture all costs associated with travel or may require assumptions about whether a trip had multiple purposes	Limited, often available for tourism or recreational activities that require permitting
Contingent valuation & stated preferences	Survey individuals to determine how much they would pay or accept in exchange for a service	Often used for passive and indirect use values, though these methods can be expanded and should capture total economic value	Relies on stated, not revealed, preferences, which may be inaccurate especially if respondents expect payments	Requires specific surveys or interviews
Hedonic modeling	Use land parcel prices and determine value associated with individual characteristics	Anything linked to property value, which may include consumptive use value, or indirect use value.	Calculated accurate values for components of property value	Requires open markets for land to obtain prices, and sufficient variability in characteristics
Cost-based approaches	Estimates the cost of expected damages and translates this into payment levels	Appropriate for indirect use value	Requires estimation of expected costs	Often intended to avoid a specific damage with a known cost, so survey work can be avoided
Factor-income approaches	Examines farm income with and without externality management; compensates producers for the difference	Appropriate for consumptive use value and possibly other forms of direct use value	Calculates accurate consumptive use value of land	Requires farm income data, which is often collected for other purposes

would be impossible in this context. Furthermore, the factor-income approach proposed here can be applied using basic farm accounting data that includes input and output prices and quantities. Such data is collected regularly in our study location and elsewhere throughout Inner Mongolia and, as such, could feasibly be applied by local officials with minimal additional data collection and still result in location-specific policy targeting. Furthermore, this approach is adaptable and can be modified to target only certain types of farms, a desired quality given the evidence that overgrazing is a greater problem in smaller farms and that targeting smaller farms may be more effective (Hu et al., 2015a; Zhang et al., 2019).

3. Theoretical framework for the factor-income method using shadow prices

The factor-income method estimates a minimum subsidy payment level for a community of herders using farm-level data. It does this by estimating the shadow price of the land, which is the value an additional unit of land would add to the overall profit of an operation. It assumes that land quality across parcels is homogenous and that payment rates will be equal across all households in the target community.

The factor-income method identifies the subsidy amount necessary to compensate producers for land that is completely restricted, or its equivalent in stocking rate reductions.[2] The remainder of this section is used to demonstrate how the shadow price is calculated and why it is reasonable to expect that this level of compensation would be salient. The land shadow price refers to the marginal increase in overall farm profit that a herder could expect to receive given a one-unit (one hectare) increase in land. It is calculated as follows):

1 Identify an appropriate production function, $f(\boldsymbol{x})$, where $\boldsymbol{x}$ is a vector of inputs which includes land, x_1.
2 Estimate the coefficients of the production function using farm-level accounting data.
3 Use the estimated production function in the profit equation: $\pi(\boldsymbol{x}) = p \cdot f(\boldsymbol{x}) - \boldsymbol{w} \cdot \boldsymbol{x}$, where π is profit, p is the price of the good produced, and $\boldsymbol{w}$ is a vector of input prices.
4 Take the derivative of the profit function with respect to land and evaluate it at the constrained level determined by the policy, $\boldsymbol{x}^{\boldsymbol{C}}$: $\frac{\partial\pi}{\partial x_1}(\boldsymbol{x}^{\boldsymbol{C}})=$ shadow price. Note, x_1^C is strictly less than the optimal value of x_1.

The shadow price is the estimated value of the land to the producer and, thus, represents the maximum amount the producer would be willing to spend to make use of an additional unit of land. Their profit with an additional unit ("high profit," π_H) would be: $\pi_H(\boldsymbol{x}^{\boldsymbol{C}}) = p \cdot f(\boldsymbol{x}^{\boldsymbol{C}}) - \boldsymbol{w} \cdot \boldsymbol{x}^{\boldsymbol{C}} + \left(\frac{\partial\pi}{\partial x_1}(\boldsymbol{x}^{\boldsymbol{C}}) - w_1\right)$ and their profit without the additional unit ("low profit," π_L) would be: $\pi_L(\boldsymbol{x}^{\boldsymbol{C}}) = p \cdot f(\boldsymbol{x}^{\boldsymbol{C}}) - \boldsymbol{w} \cdot \boldsymbol{x}^{\boldsymbol{C}}$. The difference between the two represents an estimate of the marginal product of land value. By similar logic, the profit lost to the herder from a unit of land removed from production is equal to the shadow price less the cost of land: $\frac{\partial\pi}{\partial x_1}(\boldsymbol{x}^{\boldsymbol{C}}) - w_1$. This value provides an adequate subsidy payment to compensate the producer for profits lost due to the land constraint and can be paid on a per-unit basis. Typically, the marginal value of land diminishes as the overall plot size increases, so the estimated shadow price represents the marginal value of land given the current land holding. Using this price as constant over large changes in land, or strict bans of grassland use, may not appropriately reflect diminishing (increasing) marginal returns as land size increases (decreases). It may be that herders would accept lower payments for the second, third, etc. units, but since most payments are set as a standard price, the shadow price (less the cost of land) for the first unit should be used.

4. Data and empirical model

4.1. Study location: Siziwang banner, Ulanqab prefecture

The data for this study comes from the Siziwang banner in the Ulanqab prefecture of Inner Mongolia (shown in Fig. 1). This area has a desert steppe ecology characterized by resilient but sparse vegetation that cannot support as much livestock per unit area as other grassland ecologies and an arid climate with annual precipitation between 150 and 250 mm (Kang et al., 2007; C Li et al., 2008; Yu et al., 2004). The Siziwang banner represents the largest portion of pastoral land in Ulanqab prefecture and has been a target region for the eco-compensation subsidy policy, among other government initiatives for grassland restoration (Chen et al., 2017). The Siziwang banner covers an area of 2,401,696 ha in Ulanqab prefecture and lies 150 km north of Hohhot, the capitol of Inner Mongolia (G. Han et al., 2008b). Desert steppe is considered particularly vulnerable to degradation from livestock grazing (Hao et al., 2014; Kang et al., 2007; C Li et al., 2008). Herders in this area have been hit particularly hard by natural shocks; from 2009 to 2014, the herders in the area reported numerous external shocks including locusts, drought, and snowstorms (Jin et al., 2014; P. Li et al., 2018). Furthermore, studies have shown that herders in Ulanqab (including in the Siziwang banner) actually increased stocking rates over the period where the eco-compensation subsidy was introduced (Gao et al., 2016; P. Li et al., 2018). However, these increased stocking rates were not associated with higher overall earnings (P. Li et al., 2018).

Herders in this study already received subsidy payments at the time of data collection, but household survey data used in this study reveals that overgrazing has continued. Using this factor-income approach, we find that the continued overgrazing likely reflects the fact that the subsidy payments- currently ¥90/ha annually to eliminate grazing on a parcel[3] - are too low to sufficiently make up for the profit losses experienced from removing that land from use. In the sections that follow, we demonstrate that a factor-income approach based on shadow price calculations can be used to estimate necessary subsidy payment levels to restore herder incomes and, thus, deter herders from overgrazing. We find that herders in our sample from Ulanqab would require at least double the payments they are currently being offered in order to compensate for their foregone production losses.

Herders in our sample produce mixed herd of sheep and goats. The herd composition and typical farm budget for the 187 farms surveyed between 2012 and 2014 are reported in Tables 2 and 3, respectively. To provide comparisons across herds, we standardize the livestock composition using animal units (AU) as presented in Table 2. One AU is equivalent to one adult sheep in terms of average costs and requirements for feed, land, veterinary and medical resources, etc.

Sheep (specifically lamb) sales generate their greatest source of revenue for herders in our sample, who earn just over $16,000 USD per year (including subsidy payments). Table 3 provides average input use and costs for the typical herder's budget. We observe that selling prices for sheep are higher than goats, while sheep's wool prices is substantially lower than goat's cashmere prices, making the revenue earned from a sheep or a goat roughly equal. The costs outline many of the key inputs for the operations included in our sample, except for land, over which herders have effective ownership (in the form of long-

[2] If a grazing reduction on X hectares effectively removes Y% of the land, then the per-ha subsidy would be Y% of the per-ha subsidy for full grazing withdrawal

[3] Maintaining a forage-livestock balance is treated as equivalent to a 0.25 ha reduction rather than a full 1 ha reduction, as is the case with grazing withdrawal. For example, if a herder is converts 100 ha to forage balance, he receives ¥2250 in subsidies, which is the same as he would receive for full grazing withdrawal on 25 ha of land.

Table 2
Farm characteristics (n = 187, surveys taken between 2012 and 2014).

	Head[a]	Weight (kg)[b]	Animal Units (AU) per head[c]	Total AU
Sheep				
Ewe	239	50	1	238.5
Lamb	200	35	0.7	140
Ram	3	50	1	3
Wether	10	50	1	10
Goats				
Doe	50	35	0.7	35
Kid	38	22.5	0.45	17.1
Ram	1	35	0.7	0.7
Wether	10	35	0.7	7
Total	551			451.3
Pasture (ha)	528			

[a] Herd characteristics are calculated using median values for the number of heads of each animal type (e.g. ewe, lamb, etc.).
[b] Weights are calculated using the median weights reported for each animal type.
[c] The term animal unit (AU) has be defined in a variety of ways to relate different breeds and species of grazing animals, including the number that represents equivalent grazing requirements as well as the live weight equivalent (Scarnecchia, 1985). We use the live weight equivalent, as is common in much of the literature.

Table 3
Typical farm budget (n = 187, surveys taken between 2012 and 2014).

Revenue	Price	Unit	Quantity	Unit	Total	
Lamb Sheep Sales	700.00	¥/head	180.00	head	126,000.00	¥
Adult Sheep Sales	800.00	¥/head	30.00	head	24,000.00	¥
Kid Goat Sales	520.00	¥/head	33.00	head	17,160.00	¥
Adult Goat Sales	700.00	¥/head	20.00	head	14,000.00	¥
Wool Sales	7.60	¥/kg	372.75	kg	2,832.90	¥
Cashmere Sales	320.00	¥/kg	27.00	kg	8,640.00	¥
GBP Subsidy					7,500.00	¥
Total Revenue					200,132.90	¥
Revenue per AU					443.46	¥
Variable Costs	**Price**	**Unit**	**Quantity**	**Unit**	**Total**	
Concentrate Feed	3.00	¥/kg	10,000.00	kg	30,000.00	¥
Hay	1.20	¥/kg	7,975.00	kg	9,570.00	¥
Corn	2.00	¥/kg	6,000.00	kg	12,000.00	¥
Veterinary and Medical Costs	3.00	¥/AU	451.30	AU	1,353.90	¥
Fuel					6,000.00	¥
Labor					19,000.00	¥
Total Variable Costs					77,923.90	¥
Variable Costs per AU					172.67	¥
Fixed Costs						
Machinery and Equipment					2,600.00	¥
Miscellaneous					1,000.00	¥
Total Fixed Costs					3,600.00	¥
Fixed Costs per AU					7.98	¥
Total Costs					81,523.90	¥
Net Profit					118,609.00	¥
Net Profit per AU					262.82	¥

term leases) at no cost. Labor cost represents less than a fourth of total costs because it only includes off-farm laborers (i.e. employees); within our sample, most labor is provided by the household, which is not reported in the household surveys as an additional input cost. Feed accounts for the greatest cost, demonstrating that grassland grazing must be supplemented. Machinery and equipment costs are typical for small farm operations. Data presented in Tables 2 and 3 summarize the data necessary to conduct analysis using the factor-income approach. Notably, such data is regularly collected in Inner Mongolia.

4.2. Parameterizing the model

We calculate the shadow price of land following the steps detailed in section 3. The first step is to identify the appropriate production function, $f(\boldsymbol{x})$, where $\boldsymbol{x}$ is a vector of inputs which includes land, x_1. Examining the survey responses, as summarized in the typical farm budget reported in Table 2, the primary inputs are land (x_1), supplemental feed (x_2), and capital (x_3). We use grassland area as our measure of land, supplemental feed expenditures as our measure of supplemental feed, and machinery and fuel expenditures as our measure of capital.[4] Since these are small family farms and the majority of labor is provided by the household (making it both inelastic and lacking in variation), labor is omitted from the production function estimation. Output ($y = f(x)$) is measured as the total animal units (AU) in the herd.

We select our functional form in order to satisfy the following properties:

i Essentiality of inputs: Producers cannot produce livestock without land or feed, so we assume all inputs are jointly essential, $f(0) = 0$.
ii Marginal products: We assume producers are in Stage II of production, so marginal products should be nonnegative. Additionally, we require diminishing marginal returns on land cultivation inputs. Mathematically, $\frac{\partial f}{\partial x_i} \geq 0$ for all i, and f is concave.
iii Homogeneity: We assume constant returns to scale as is common in agricultural production literature, $(\alpha x) = \alpha f(x)$. Note, we include results where this property is relaxed.
iv Substitutability of inputs: Land and feed are both sources of feed, so we require that they be substitutable, $\sigma_{1,2} > 0$ is the elasticity of substitution between land and feed.

We select an appropriate functional form based on contextual criteria (I) - (IV) (Griffin et al., 1987). In this case, a linearly homogenous Cobb-Douglas functional form is suitable:

$$y = f(x) = \alpha \sum_{i=1}^{3} x_i^{\beta_i} \tag{1}$$

Using this equation, we estimate α, β_1, β_2, β_3 assuming the CRS restriction (criteria III). We use a log-log form so that we can use OLS with the restriction:

$$\ln y = \ln\alpha + \beta_1 \ln x_1 + \beta_2 \ln x_2 + \beta_3 \ln x_3 \tag{2}$$

$$s.\ t.\ \beta_1 + \beta_2 + \beta_3 = 1$$

5. Results

5.1. Production function estimates

We obtain the coefficient estimates reported in Table 4. The first set are estimated without a vector of controls and the second set are estimated with a vector of household characteristics, including gender, ethnicity and household size. We see a slight difference in coefficient estimates when the controls are added, though the qualitative results from key inputs (feed and capital) remain unchanged. Note, some observations are lost because of missing data.

These estimates can be used in a standard profit function, $\pi(\boldsymbol{x}) = p \cdot f(\boldsymbol{x}) - \boldsymbol{w} \cdot \boldsymbol{x}$, where π is profit, p is output price (¥RMB/AU), and $\boldsymbol{w}$ is a vector of input prices. From this we can calculate the shadow price for land,

[4] Supplemental feed expenditures are the sum of expenditures on concentrate feed, corn and hay. In cases where one source of supplemental feed is missing, expenditures are the sum of the other two. Capital is the sum of fuel and machinery, except in cases where data is only reported for one in which case it is either fuel or capital.

Table 4
Production function coefficient estimates (estimation from Eq. 2).

	Without controls (Root MSE = 0.3831) N = 137			With controls (Root MSE = 0.3824) N = 135		
	Estimate	Standard Error	P-Value	Estimate	Standard Error	P-Value
Constant ($\ln\alpha$)	−2.8428	0.1928	0.0001	−2.6932	0.3056	0.0001
Land β_1	0.2960	0.0449	0.0001	0.3245	0.0498	0.0001
Supplemental Feed β_2	0.4612	0.0442	0.0001	0.4553	0.0475	0.0001
Capital β_3	0.2429	0.0381	0.0001	0.2202	0.0396	0.0001

$$\frac{\partial \pi}{\partial x_1} = p\cdot(\alpha\cdot\beta_1 x_1^{\beta_1-1}\cdot x_2^{\beta_2}\cdot x_3^{\beta_3}) - w_1 \quad (3)$$

5.2. Subsidy payment estimates

We find two estimates for the shadow price of land. The first approach is to apply the shadow price function in Eq. (3) to the median farm using the estimated coefficients.[5] In this case, we find that the land in the Siziwang banner has an average shadow price of ¥169.75 RMB/ha. The second approach is to apply the function in Eq. (3) to the farms with sufficient relevant data and identify the average shadow price across them. This approach yields an average shadow price of ¥196.40 RMB/ha. The distribution of shadow prices is presented in Fig. 3. Examining the shadow price distribution, we observe that while a few farms have particularly high shadow prices (over ¥400 RMB/ha), most are below ¥250 RMB/ha. This demonstrates the fact that almost all herders in the area have a higher value for their land than what the current subsidy payments offers, which is ¥90 RMB/ha for full grazing removal.

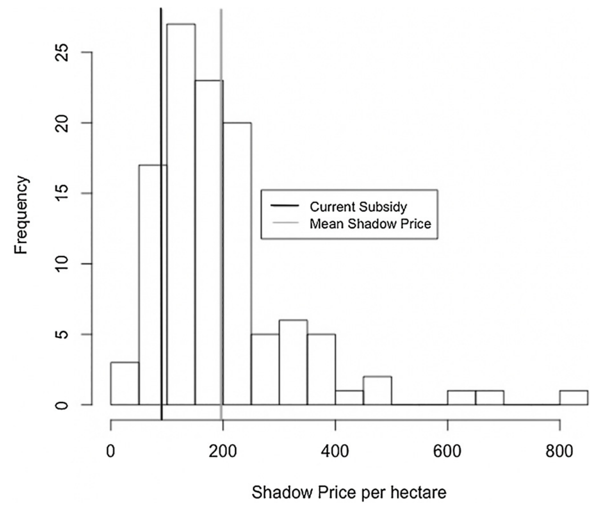

Fig. 3. Distribution of shadow prices* (¥/ha/year), estimated from Eq. (3). *Estimated shadow prices are the minimum necessary subsidy payment level required for participation

6. Discussion

The shadow prices estimated can be used to determine the number of farms that would benefit from compliance if the subsidy rate were increased. Fig. 4 presents a distribution of the number of farms who are expected to comply with a stocking rate and corresponding subsidy rate. For example, at the current level of ¥90 RMB/ha, we would predict only about 14% of the farms would financially benefit from participation. A subsidy payment of ¥250 RMB/ha is predicted to make 80% of the farms financially whole, and thus likely to participate. A subsidy greater than ¥650 RMB/ha is needed to ensure that 100% of herders are better off with the subsidy and corresponding grazing reduction. The rate necessary for all herder to be better off financially is likely higher than the desired budget. However, a ¥200 RMB/ha would leave over 60% of the herders better off and expected to comply. This additional cost may be worth it to increase participation by over three times. Alternatively, it may be more suitable for the program to reduce its scope and more heavily invest in a smaller number of farms and consider strategic consolidation for poverty alleviation (Wang and Li, 2019).

The participation prediction is validated by examining current stocking rates of the households in our dataset. Fig. 5 shows the smoothed distribution of stocking rates in our sample. Indeed, we find that only 28 of the 187 farms (14.97%) are stocked at rates considered to be "light" or "moderate" for this region (i.e. below 0.3 AU ha), while all others were operating at or above stocking rates considered "heavy" for this region at the time of the survey (Wang et al., 2014).

We can further validate our method by comparing our findings to those of previous study in the same region (Gao et al., 2016), which used a sample of herders from four locations across Inner Mongolia including 40 households in Ulanqab. They report average household subsidy payments of $1,102 USD (~¥7,520), which is equivalent to subsidy payments reported in the dataset used for this study where the median subsidy value is ¥7,500. Their sample from Ulanqab skews towards slightly smaller herds and, correspondingly, slightly smaller incomes. They use regression techniques to estimate the "subsidy elasticity" of the typical Ulanqab herder, which measures the percentage change in grazing intensity resulting from a 1% increase in subsidy payment levels. This elasticity can vary dramatically with location, culture, context and any number of other factors that influence willingness to participate in such a program. To that end, Gao et al. (2016) find that herders in other prefectures of Inner Mongolia have much larger subsidy elasticities than those in Ulanqab. The low elasticities of Ulanqab herders indicates they are less sensitive to changes in subsidy payment and thus require greater payment increases in order to comply. Specifically, Gao et al. (2016) find that in order to reduce grazing to ecologically sustainable levels, subsidy payments in Ulanqab would have to be increased 396%. In the context of our sample, this would be equivalent to payments of 356 ¥/ha; our model predicts that at such a level, 91% of herders in our sample would comply (Fig. 4). Though our study and the Gao et al. (2016) study differ in data and empirical approach, they agree that for uniform compliance in the target region of Ulanqab prefecture, subsidies would need to increase

[5] The median farm has an animal unit price of ¥610.39 RMB/AU, 528 ha of grassland, ¥52,890 in supplemental feed costs, and ¥9000 in capital costs.

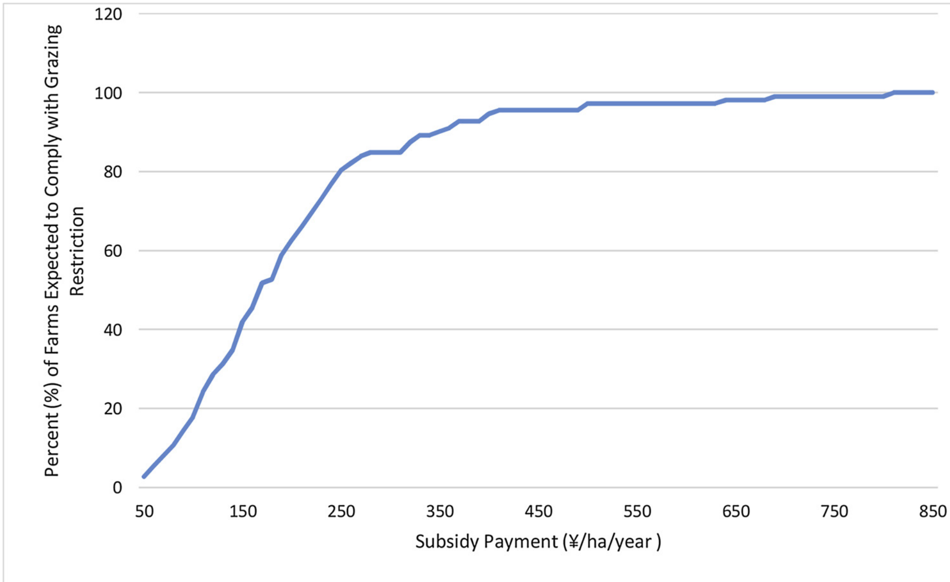

Fig. 4. Distribution of expected participation based on subsidy level.

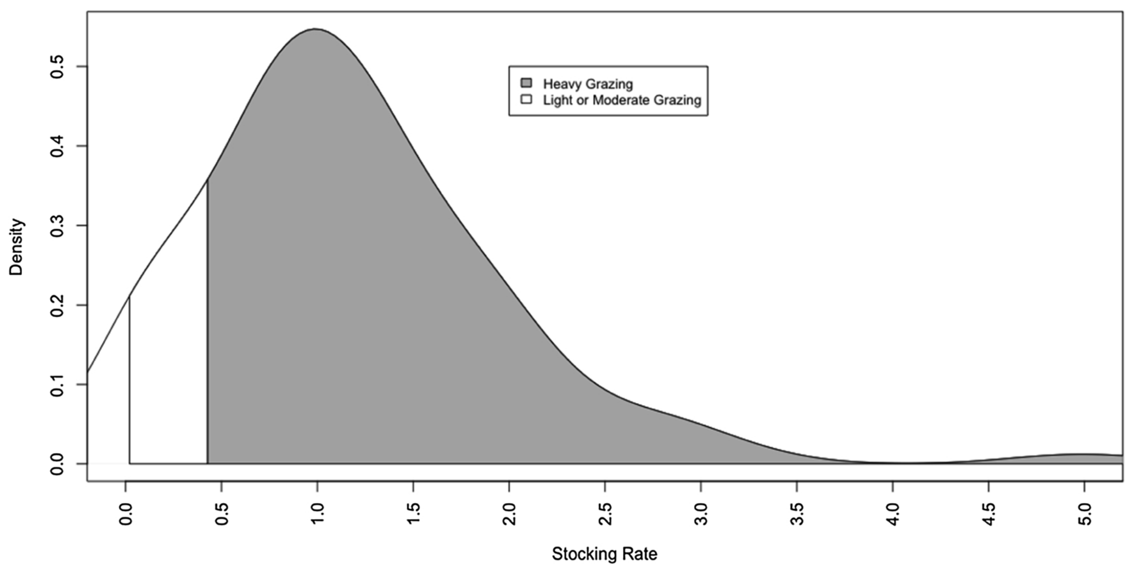

Fig. 5. Distribution of stocking rates from surveyed farms.

by three to four times their current levels.

There are notable assumptions made in our payment level calculations, which merit discussion. First, these calculations assume time invariant technology. The relatively high effect we found associated with feed indicates that these are feed-intensive operations, while the lower effects on capital indicates that these are not capital-intensive operations; if these input intensities were to shift, so too would the production function and shadow price estimates. For this reason, any subsidy payment level calculated using this method should be revisited periodically, especially if major technological shifts occur, such as large investments in capital. Second, the estimated payment levels assume that herders require full compensation for profit losses in order to comply with the program. This inherently assumes that money is the source of utility for herders. However, herders may have preferences in herd size beyond profit maximization and those who, for example, prefer a smaller herd may be willing to accept lower payment while those who prefer a larger herd may require a higher payment. Finally, these subsidies are allocated to the land contractors (i.e. the individual who owns the long-term lease); the grassland rental market has been severely denigrated and may require alternative policies (A. Li et al., 2018).

7. Conclusions

Our results demonstrate both the usefulness of the factor-income approach to estimating subsidy payments as well as the specific need to increase ESAS eco-compensation subsidy payments to herders in Ulanqab prefecture, Inner Mongolia. While the intention of the program is to compensate herders for reduced grazing in an effort to restore grassland health, recent studies have found it ineffective in this region (Gao et al., 2016; Hu et al., 2019; Zhang et al., 2019). We find that subsidy rates would need to be substantially higher to expect compliance from Ulanqab herders; at current rates, they are simply not being compensated for the losses the program imposes upon them.

In large-scale, high-budget PES programs such as the ESAS, it is essential that payment levels be set correctly and that levels be determined in the most cost-effective manner. With reports of low participation and satisfaction in the ESAS program, something must change.

However, prior studies have not presented concrete recommendations. This paper adds to the analysis of the ESAS subsidy program by identifying the subsidy payment levels that are necessary for participation to make financial sense for herders. Furthermore, it does so in a manner that could be easily replicated throughout Inner Mongolia.

The factor-income approach presented here is a low-cost, accurate method for setting such PES subsidy levels. It does not require specialized data and can thus be applied more widely. It is accurate to the extent that the market prices and accounting data are accurate. It relies solely on farm-level accounting data, which is often collected for more general use either in censuses or other large-scale data collection efforts. In many cases, it would not require additional data collection which makes it more cost-effective than many other proposed strategies; although it still requires self-reported data, the types of variables reported (e.g. number of animals, market selling price) are generally more accurate and reliable than variables like "stated willingness to accept."

It is essential that the literature on PES, and the broader body of literature on economic solutions to environmental management, provide practical solutions. While there is much to be gained from discussions of how to model and estimate true values of ecosystem services or understanding compensation levels for losses that ecosystem service managers might forego for protecting them, many of those proposed involve onerous data collection that is simply infeasible in many contexts; the data collection alone would outweigh the benefits of the policy.

As China continues its initiatives to coordinate urban and rural development, much of the actual change occurs through targeted policies, such as the subsidy payments paid to herders in exchange for reduced stocking rates discussed in this paper. As researchers have noted, attention must be paid to the future livelihoods of agricultural producers as the central Chinese government moves to "build a new countryside" (Long et al., 2010). Ensuring that payments such as these are sufficient to make producers financially whole is an important component of moving forward with this large-scale effort.

While we continue to study how producers respond to policies and thus build our understanding of what is effective, we similarly must evaluate the resources available to determine what is feasible. In many cases, the data necessary to inform a certain policy is simply not available. It is unlikely that policymakers can obtain the data necessary for complex contingent valuation analysis every time they wish to perform it. Furthermore, the contexts in which PES programs can lead to improvements are vast and varied. Thus, we must add to our policy arsenal simple and feasible approaches given the likely constraints in various areas. Ultimately, the array of tools available to policymakers balancing ecological management with agricultural production may be just a diverse as the contexts in which these policies are applied.

The tradeoffs between agricultural production and environmental conservation continue to be priorities for many policymakers around the world. With a growing global population, pressure is mounting on both the agricultural and ecological sides to find policies that are effective, equitable, and feasible. Furthermore, it has been noted that these grasslands are suffering additional damage from climate change, though such effects have sometimes been difficult to detect given the severity of overgrazing (Angerer et al., 2008; Mu et al., 2013); herders in the study region are aware of the extreme events brought on by climate change and will require pathways to adapt (Jin et al., 2014). This is likely the case in numerous other locations where climate change introduces additional uncertainty for herders; they urgently require numerous and varied approaches to maintain their livelihoods.

Declaration of interest

None.

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