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A multi-scaled analysis of the effect of climate, commodity prices and risk on the livelihoods of Mongolian pastoralists

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ABSTRACT

Studies of common pool resources tend to neglect how aspects of the resource system interact with the external social, physical and institutional environment. We test the hypothesis that select market and non-market based options available to Mongolian Gobi Desert pastoralists in the current instiutional setting are not sufficient to ameliorate the risks of resource gaps caused by climatic and commodity price variability. An empirical decision tree was used to model interactions between climatic variability, commodity price volatility and economic returns. Results from the model were then discussed in light of a critical, qualitative analysis of risk management strategies and capabilities of pastoralists. Returns to pastoralists were dependent upon climate and commodity prices, as expected, but pastoralist decision-making could influence these returns. Pastoralist decision-making was further influenced by multi-scaled social, economic and climatic factors. Existing market-based options available to Mongolian Gobi Desert pastoralists reduced price, but not production, risks in this largely subsistent system. A focus on improving market-based options for reducing risk is likely to provide more benefits to livelihoods and landscape condition than modifying institutional settings governing access to the forage resource.

1. Introduction

Studies of natural resources, including the common pool resources of much of the world's drylands, often neglect how aspects of the resource interact with the external social, physical and institutional environment (Addison et al., 2013; Agrawal, 2001; Turner, 2011). Drylands under an extensive pastoral land-use are characterized by precipitation patterns that are both low and highly variable when compared to higher precipitation landscapes (Retzer et al., 2006; Sasaki et al. 2009; Wehrden et al., 2010). Given that precipitation events are well correlated with vegetation production, forage resources are similarly temporally and spatially unpredictable. Social, institutional and economic factors within the dryland context, such as large distances from markets and decision making centres, and poor road conditions, increase transaction costs and price unpredictability (Kusan and Saizen, 2013; Stafford Smith, 2008). These factors contribute to drylands being considered amongst the most vulnerable areas to global environmental change (Twyman et al., 2011), with pastoral livelihoods often perceived as more marginal or threatened than other resource-based livelihoods (see Fernandez-Gimenez and Le Febre, 2006).

Volatile biophysical and socioeconomic factors occur at a variety of spatial and temporal scales, create feedback loops, interact in different ways and can create or modify both production (unpredictable variations in the production of commodities) and price (unpredictable variations in prices paid for these commodities) risk. Whilst some types of volatility are predictable, high volatility can create forms of risk to which pastoralists must respond *ex ante* or *ex post* (Baas et al., 2012; Ouma et al., 2011), and can amplify exposure or reduce resilience to other stresses. Pressures on the strategies by which pastoralists historically managed shocks and stresses through time and space have increased (Agrawal and Gibson, 1999; Dickinson and Webber, 2004; Ouma et al., 2011; Robinson et al., 2003; Sneath, 1998; Stokes et al., 2006) resulting in more variable and unpredictable livelihoods (Fernandez-Gimenez et al., 2012 and compromised landscape condition (Blaikie and Brookfield, 1987). Understanding and, where possible, predicting the relationship between climatic state and resource user response, within any particular socio-economic context, may assist in the design of

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strategies to improve livelihoods and deal with environmental effects.

Internationally, there has been substantial research on decision making in dryland social–ecological systems (e.g. Bao Li et al., 2008; Janssen et al., 2000; Kong et al., 2014; Stroebel et al., 2011), and the factors affecting pastoral risk management strategies (e.g. Agrawal and Gibson, 1999; Dickinson and Webber, 2004; Fernandez-Gimenez et al., 2012; Robinson et al., 2003; Sneath, 1998; Stokes et al., 2006). However, with few exceptions (e.g. Milber-Gulland et al., 2006; Turner and Williams, 2002), this research has rarely recognised the significant role that fast variables such as weather patterns or commodity prices, and the interactions between them, can have on dryland systems. Ecological and economic vulnerabilities are linked through markets (Barrett and Luseno, 2004; Turner and Williams, 2002) as markets can reduce ecological vulnerabilities by providing options to reduce grazing pressures at key times, or by facilitating the substitution of a declining natural livestock feed source. Exploring the relationship between climate, commodity prices, production and price risk, at different points through time and space may, therefore, highlight where interventions are best placed to improve livelihoods and landscape condition.

Non-mobility options for managing climatic variability, particularly those which are market-based, have been under-examined in the Mongolian Gobi Desert. In this paper, we attempt to address some of these knowledge gaps by exploring the interactions between climate, commodity prices and production and price risk at different scales within that agro-ecological system, and by testing the hypothesis that stochastic shocks in commodity prices and climate overwhelm many of the risk management strategies available to pastoralists. The paper begins by introducing the case study area. Then, it outlines the way in which commodity data and pastoralist accounts of economic and social conditions are drawn upon to create a model that predicts relative pay-offs associated with the use of select risk management strategies during different climatic periods. The results of the model are presented but the risk management strategies implicit in the results are then discussed and interpreted in the context of real world constraints and the nuances of the pastoralists' decisions as identified in a critical qualitative analysis of semi-structured interviews with pastoralists. Through this process, the paper illustrates that pastoralist decision making and livestock productivity is currently constrained by differentially scaled social, economic and climatic realities, the need for food security and the potential opportunity costs associated with forward planning in a landscape significantly impacted by largely unpredictable shocks.

2. Methodology

2.1. Introduction to the case study area

Like other international drylands, the Mongolian Gobi Desert (Fig. 1) is dry and experiences high levels of spatial and temporal variability in precipitation (Begzsuren et al., 2004; Wehrden et al., 2010). Mean annual precipitation varies from about 67.5 mm to 132 mm with annual coefficients of variation estimated to be between 26 and 49%, depending on location (Addison et al., 2012). High variability in precipitation is mirrored by high levels of variability in the production of palatable grasses such as *Stipa* spp. and *Cleistogenes songorica*, forbs/herbs such as *Allium mongolicum* and *Allium polyrrhizum*, and to a lesser extent shrubs such as *Anabasis brevifolia* and *Reaumuria soongorica* (see Addison et al., 2012). Temperature is also highly variable within years. For example, Khanbogd had an average daily maximum of −12 °C in January, and 27 °C in July between 2005 and 2010 (data provided by local official).

Mongolia's economic performance is primarily a factor of the weather and international commodity markets (Nixon and Walters, 2006). In recent years, the Mongolian pastoral sector has become more exposed to both. *Dzud*, a multifaceted term encompassing winter conditions having an unusually adverse impact on pastoral production, result in higher than average levels of livestock mortality (Baas et al., 2012). This type of shock adds a further level of unpredictability to the pastoral environment, and can have long lasting effects on the livelihoods and security of pastoralists (Baas et al., 2012). The Gobi Desert experienced a significant *dzud* during 2009/2010 that resulted in substantial livestock losses for many pastoralists in both Mongolia (Baas et al., 2012; Sternberg et al., 2011) and Chinese Inner Mongolia (Li and Huntsinger, 2011). The southern/central Mongolian *aimags* (states) of Omnogobi and Dundgobi were particularly affected, losing 34 and 37% of their total herd, respectively, in comparison with a national average of 22% (Baas et al., 2012).

The 2009/2010 *dzud* losses were exacerbated by a decline in pastoral support services. From the 1950s to the 1990s, the State carried much of the production risk produced by climatic variability (Mearns, 1993; Sneath, 2012). However during the early 1990s, Soviet era subsidies to Mongolia ceased and gross domestic product (GDP) fell to 20–33% of pre-shock therapy levels (Luvsanjamts and Soderberg, 2005; Mearns, 2004; Nixon and Walters, 2006). One consequence of the decline was a retreat by the State from the pastoral sector, and increased livelihood insecurity (Nixon and Walters, 2006). The State Emergency Fodder Fund supplied 200,000 tonnes of fodder to pastoralists during 1990/91, but this figure dropped to 18,000 tonnes by 1994/95 (Asian Development Bank, 1995). Whilst many pastoralists are still highly mobile (Addison et al., 2013), declines in the transport of livestock, maintenance of water points and livestock breeding services (Nixon and Walters, 2006) have further reduced the ability of pastoralists to manage climatic variability.

With the decline of socialist institutions and services from the early 1990s, the market-dependent proportion of pastoralists' incomes increased (Nixon and Walters, 2006). Significant fluctuations in the global cashmere market have subsequently led to significant fluctuations in rural livelihoods, creating a spiral of debt for many households (Sneath, 2012). Poverty, believed to be almost non-existent prior to economic reforms due to strong social services (Nixon and Walters, 2006), expanded to about 36% of the population by 1995 and wealth inequality increased (Mearns, 2004; Nixon and Walters, 2006). As of 2009 (National Statistical Yearbook, 2010), the mean monthly per capita income earned in the agricultural sector was 175,200T (about $125USD at the time), only 58% of the national average.

More spatially restrictive institutional settings over a very mobile land-use are sometimes proposed in an attempt to address some of the recent changes in the Mongolian pastoral sector (Addison et al., 2013). However more restrictive institutional settings require reduced mobility and a subsequent loss of accessible livestock forage. This loss needs to be offset by, for example, imported fodder to prevent overgrazing and declining livelihoods. Whilst there is little evidence that the Mongolian Gobi Desert is currently degraded at the regional scale (Addison et al., 2012), the relationship between formal commodity and fodder markets, livestock management decisions and resource variability is poorly understood.

2.2. Approach

A state contingent conceptual approach (Rasmussen, 2011) is used to investigate production and price risks faced by Mongolian Gobi Desert pastoralists. The choice of approach is because, in contrast to more equilibrial landscapes, it is not possible to *a priori*

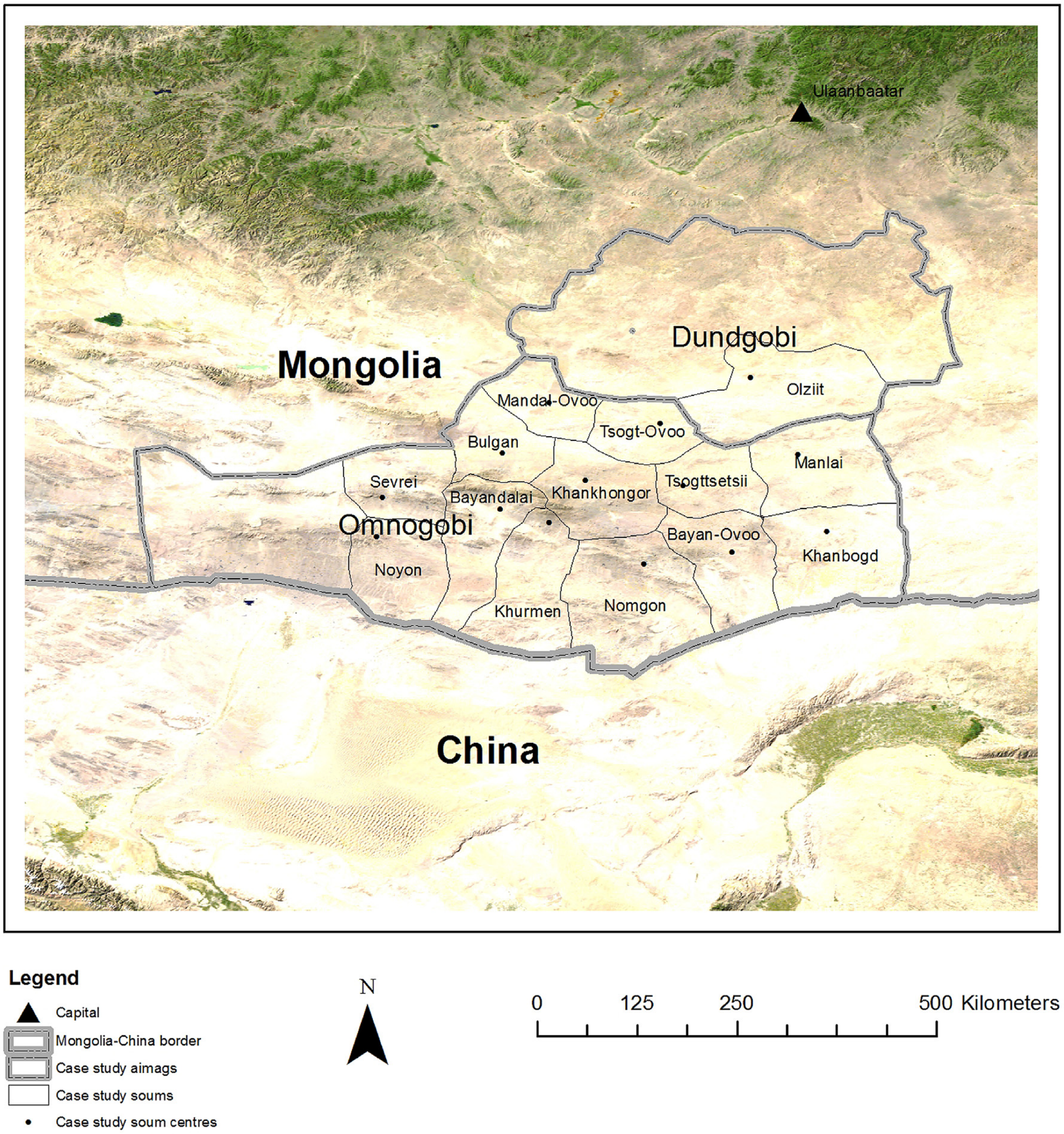

Fig. 1. The Gobi Desert showing case study locations cited in this paper.

identify the management strategy that will best maximise livestock production under the uncertainty created by high climatic variability (Rasmussen, 2011). Data from cashmere goat production in the Gobi Desert were used because the industry is sensitive to changes in both commodity prices and climate. The cashmere industry has relatively high levels of market integration (Kusan and Saizen, 2013) and cashmere is a major contributor to household income in the Gobi Desert region; the research presented here found that pastoralists ($n = 16$) commonly stated that about 70–80% (min = 40%, max = 100%) of their total income came from the sale of cashmere, a proportion similar to that found in other parts of Mongolia (Lkhagvadorj et al., 2013). This proportion of total income is higher than in, for instance, pastoral areas of East Africa (Doss, 2008), and livelihood diversification away from livestock is a much stronger risk mitigation strategy for pastoralists elsewhere (Ellis, 1999; Ouma et al., 2011). As such, Mongolian Gobi Desert pastoralists are particularly exposed to fluctuating commodity prices.

In essence, the relative result of management decisions made by pastoralists at any particular time or place is contingent on the state of nature they experience. In the model analysis below, the definition of these states of nature was based on bio-physical rather than market conditions, and on pastoralists' perceptions including traditional ecological knowledge rather than objective climatic data. In this way, pastoralists' behaviour and decisions can be directly related to their perceptions of the likelihood and severity of the states of nature as per Shabb et al. (2013). In doing so, the limitations of scale associated with the dispersed nature of meteorological stations and the inability of such meteorological data to represent the complexity of meteorological effects (e.g. types of snow) on pastoral production can also be addressed. Definition or elicitation of these states from pastoralists perceptions are described in Section 3.1.

Once the perceptions of the states of nature were determined, attention turned to the strategies or decisions pastoralists made based on the state of nature. To provide structure to the analysis, a simple decision tree framework was developed as a useful initial framework to investigate the state contingent decisions. The decision tree allows for the tracing out of a sequence of decisions and, from a normative perspective, some assessment of the relative merits of different branches of the tree or sequences of decisions. Whilst not exhaustive, four key and sequential decisions or responses to perceived production or price risk were selected. To collect hay or not, to overwinter livestock or not, to mate livestock or not, and to purchase fodder or not were chosen as 'tree branches' based on their relative importance as cited by pastoralists during interviews (see Section 2.3.1). The formal part of the decision tree analysis is described in Section 3.1 with a decision tree outlined in Fig. 2. Data to construct the tree and perform the analysis was based on interviews with pastoralists as described in Section 3.1.

'Real world' constraints to the empirical model include lack of available data and the subsequent use of assumptions – see Shabb et al. (2013) for another example of the need to over-rely on assumptions in a Mongolian pastoral context. In recognition of these, and other, constraints, we chose to explore: i) the relationship between the decision making pathway that the empirical model predicts to be most profitable given any particular state of nature with actual pastoralist decision making; ii) the greater economic, social and biophysical context that may justify, or account for gaps between, predicted and actual decision making behaviour; and iii) variation in the way households experienced this context. Such qualitative elaboration is a crucial complement to the numerical interpretation of the decision tree and is a useful way of identifying the range of social, economic and biophysical factors that constrain the 'ideal' decision-making of pastoralists implicit in the decision tree. For this purpose, we used the results of qualitative interviews proceeding the 2009/2010 *dzud* to discuss in more detail the strategies and decisions made by pastoralists that are only loosely captured in the empirical decision tree analysis.

2.3. Data sources

2.3.1. Interviews with pastoralists

Fifty pastoral households were interviewed between July and October 2010, in the Mongolian Gobi Desert areas of Ulziit *soum* (district), Dundgobi *aimag* (state), and twelve other *soums* in Omnogobi *aimag*. A severe *dzud* was experienced in the winter/spring preceding the interview period, but pastoralists classed precipitation patterns and vegetation production as 'fair' to 'good' at the time of interview. Pastoralists were approached as described by Addison et al. (2012). This involved the lead author and a translator randomly selecting pastoralists in the research area and approaching them at their *ger* (mobile home). A semi-structured interview was conducted after permission was granted.

Specifically, pastoralists were asked what proportion of their income came from the sale of cashmere, and the type of goods or services upon which this income was spent. Cashmere prices and the relative advantages and disadvantages of different livestock types were elicited. Both good and bad years were described by pastoralists, as was the last year in which they had experienced such a year. Pastoralists were questioned about the relative availability and uptake of financial, technical or behavioural tools that allowed them to manage climatic risk. This included the nature and type of State and non-State support for their livelihoods, commodity prices at key times, livestock management in relation to climate, and decision making in choosing risk management options. If further information was volunteered, or a response warranted follow-up, additional questions were asked. Not all questions were answered by all pastoralists, and not all questions were asked of all pastoralists if constraints, such as time, were present. A demographic summary of the pastoralists interviewed is outlined in Table 1.

2.3.2. Commodity and livestock data

We purchased commodity price data from Media for Business, an Ulaanbaatar-based organisation created with seed money from MercyCorps Mongolia, to provide agricultural commodity prices to government and non-government organisations. Price information on key pastoral commodities was purchased for markets in Mandalgobi, the capital of Dundgobi *aimag*, and Dalanzadgad, the capital of Omnogobi *aimag*. Data included prices in Mongolian Tugrik (T), collected twice a week by trained market watchers prior to 2pm each day, for each week between 2007 and 2010 for cashmere (T/kg), hay grass (25 kg packets) and fodder (25 kg packets). At the time of data collection, one USD was equal to about 1400 Tugrik (T). Because aggregate, official or statistical commodity prices may not reflect the prices that pastoralists actually receive (Barrett and Luseno, 2004; Vogel and O'Brien, 2006), we cross-checked the market reported prices with those cited by pastoralists for both *soum* and *aimag* markets, finding Media for Business data to broadly align with the *aimag*-level data cited by pastoralists. Livestock numbers were obtained from officials at the *aimag* level (2) and *soum* level (4). Livestock data from Omnogobi *aimag* was sourced for the period 1960–2007. Livestock data at the *soum* level was collected for the period both before and after the 2009/2010 *dzud*.

3. Results and discussion

3.1. Empirical decision tree analysis

Pastoralists noted that the proportion of their income from cashmere varied with both biophysical conditions and commodity prices. To account for the livelihood variability associated with biophysical conditions, we included state of nature in the analysis, and asked pastoralists to describe the last year that they felt had a significantly positive effect on their livelihood (the last good year), and the last that had a significantly negative effect on their livelihood (the last bad year). Although 'good' and 'bad' are subjective terms, it became evident that pastoralists were not considering commodity prices in their descriptions but, instead, were consistently understanding the terms to refer to the biophysical conditions that produced palatable forage for their livestock. The use of biophysical conditions to define good and bad years relies upon an underlying premise that pastoralists are focused more on survival than production, with Section 3.2.3 and elsewhere providing the basis for this premise.

As pastoralists focussed on these good and bad years, a full gradation of other states of nature was not elicited. Instead, the remaining years implicit in pastoralist responses regarding the frequency of occurrence were categorised as 'normal' years. For the purposes of this paper, 'good' and 'bad' years were assumed to occur on average once in four years with the remaining fifty per cent of years categorised as 'normal'. The timing and nature of the last bad year was particularly consistent between pastoralists. Table 2 summarises key features of the good and bad years as noted or characterised by pastoralists.

Once the states of nature were defined, a decision tree outlining four key sequential management decisions made by pastoralists from autumn to spring was constructed (Fig. 2). The sequential decisions or steps are listed from left to right while the tree is defined for the three general states of nature. At the far right of the decision tree are the payoffs associated with each branch of the tree. The formulae to calculate the payoffs are listed in Table 4 (see Supplementary material) while the definition of the parameters in these formulas and their estimated values are shown in Table 3 (see Supplementary material).

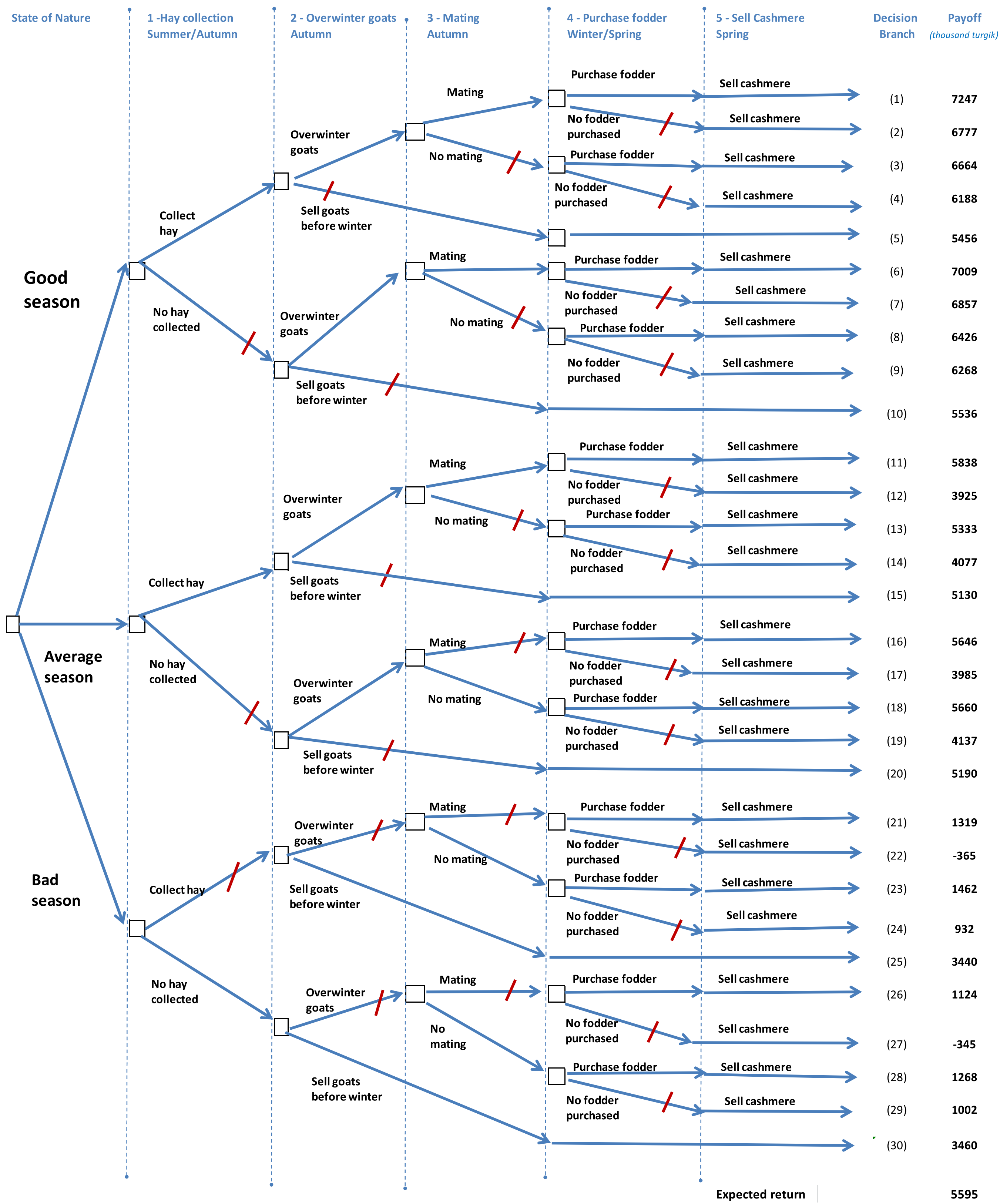

Fig. 2. Decision tree for key pastoral risk management options. Red lines represent sub-optimal branches. (For interpretation of the references to color in this figure legend, the reader is referred to the web version of this article.)

Table 1
Demographic summary of interviewed pastoralists. Results are means, with standard deviations bracketed. Min = minimum, max = maximum.

	Pastoralists
% of household respondents who were female ($n = 50$)	50%
Mean household size ($n = 48$)	4.8 (1.5) (min = 2, max = 8)
Mean years herding ($n = 50$)	22 (8) (min = 5–10, max => 30)
Mean number livestock ($n = 45$)	247 (185) (min = 26, max = 1001)
Mean % of sheep and goats in household herd ($n = 43$)	87%

The four key sequential decisions modelled in the analysis are as follows. First, pastoralists have to make a decision of whether to collect hay in the summer/autumn period. Although collecting hay draws upon household labour, it does provide fodder to meet some of the feed needs of the goats in the winter/spring period. Second, based on the type of year (state of nature), pastoralists then have to make a decision in autumn as to whether to carry the goats over winter or sell them prior to winter. Third, if pastoralists decide to carry them over winter but have concerns about the season and the availability of fodder, they could then make another decision in autumn as to whether to restrict mating so as not to exacerbate the feed gap situation and not to threaten the core breeding herd. Restricting mating would prevent the returns from the value of the kids born in spring but would also reduce mortality rates. Fourth, a key decision then needs to be made as to whether to purchase fodder in the winter/spring period to meet the immediate shortfall between feed requirements and any fodder collected in the summer/autumn period. In deciding not to purchase fodder, pastoralists would avoid the costs of purchasing the fodder but this may be offset by lower cashmere yields or higher mortalities associated with the feed deficit. Another final decision relates to the sale of cashmere but in that the cashmere returns outweigh the shearing/collection costs, then this is represented in the decision tree as a passive decision in which it is assumed that the cashmere is always sold.

The payoffs for each of the decision tree branches are shown in the extreme right of Fig. 1. Through a process of backward recursion, sub-optimal branches (in terms of returns) can be identified and are indicated in Fig. 1 with the red diagonal lines. This can provide some guidance to pastoralists irrespective of where they find themselves on the decision tree.

Based on the parameter values taken from Table 3 (see the Supplementary material), the sequential steps of collecting hay, overwintering goats, purchasing fodder and selling cashmere (decision branch 1) is the dominant return in a good season (good state of nature as highlighted by the top ten branches of Fig. 1). In general, and because of the good feed available, the options of selling the goats before winter are dominated by the retain goats option. Similarly the no-mating options are dominated by the mating options. There is a difference of around 33% between highest and lowest decision branch payoffs in the good season.

In the average season (branches 11 to 20, Fig. 1) the decisions of collecting hay, overwintering goats, purchasing fodder and selling cashmere (decision branch 11) again emerges as the dominant strategy. In general, returns are around 20% lower than for the good season although the options of selling the goats before winter are not dominant to the same extent as in the good season. Indeed selling the goats before winter (e.g. branch 20) dominates the branch associated with no hay collection and no fodder purchases (branch 19).

In the bad season (branches 21 to 30, Fig. 1), the higher mortalities and greater feed requirements switch the dominant strategy to that of selling the goats in autumn. The returns are much lower than the good or average years and indeed for a number of the decision branches are negative. The overall weighted expected return based on the optimal strategies in each state of nature is 5,595,000T. As this is significantly higher than that mean earnings of a Mongolian pastoralist (National Statistical Office of Mongolia, 2010), individual branches should be viewed as comparative rather than absolute.

Whilst the decision tree (Fig. 1) illustrates the impact on returns from pursuing particular courses of action, there are a variety of assumptions and simplifications implicit in both the construction of the decision tree and the formula for the returns highlighted in the right hand side of Fig. 1. Although every effort was made to identify the most appropriate and accurate parameter values as reported in Table 3, the parameters are likely to vary through time and space. Milber-Gulland et al. (2006), for example, used lower mortality rates and lower bad year frequencies in a multi-agent system model applied to a Kazakh pastoral system that shares many similarities with that of the Mongolian Gobi Desert. As such, these values should be carefully checked in light of the specific context in which the model is to be applied, and decision tree branches should be used comparatively for ranking purposes rather than being considered in absolute terms. Other overarching factors or more nuanced or less tangible factors may also constrain the decision tree, but for which datasets suitable for the model were not available or not collected. A more thorough discussion of the key management strategies identified in the decision tree, an additional strategy of accessing external support from NGOs, government or mining companies, and real world constraints in implementing these strategies, now follows.

3.2. Qualitative analysis of factors affecting decision-making of pastoralists

3.2.1. Collecting or not collecting hay

The relative benefit of collecting hay is dependent on state of nature, as well as the perceived relative costs and benefits of the alternative to purchase fodder instead. This is because whilst hay

Table 2
Summary of good and bad years for pastoral production as noted by pastoralists. Level of consistency = level of consistent responses between pastoralists. Ppt = precipitation. Temp = temperature.

	Good year ($n = 39$)	Level of consistency	Bad year ($n = 50$)	Level of consistency
Last experienced	2008/2009	Low	2009/2010	High
Frequency	Variable (rare – every one in three years)	Low	Every three to four years	Moderate
Summer ppt.	Early on-set, low intensity, well-spread, large quantity	High	Late on-set, high intensity, infrequent, small quantity	High
Winter ppt.	Moderate	High	Low or high	Moderate
Summer temp.	Warm but not hot	High	–	–
Winter temp.	Warm	High	Cold	High
Other	Forage tall and dense	High	Forage inaccessible due to deep snow, windy, forage, short, sparse	High

collection is theoretically available to all pastoralists as a tool for managing climatic risk, temporal variation in forage productivity and the different financial ability of households to access and store hay affects the relative costs and benefits of its collection. Self-preparation of fodder is more common in good years than bad years due to the greater availability of forage. In a good year, on average 29% of fodder by weight was purchased and 71% was prepared ($n = 42$). Ninety-five percent of pastoralists who responded ($n = 42$) collected and stored fodder in years that they described as good. In a bad year, this ratio reversed with about 79% being purchased and 21% being prepared ($n = 42$). The reduced ability of pastoralists to self-prepare fodder in bad years as well as the additional financial constraints at the level of the household accounts for why pastoralists are able to obtain more fodder in good years, when they have relatively lesser need for it, than bad years. The choice by pastoralists not to invest effort in collection is validated by the decision tree as in bad years the better payoff decision is to not invest in collecting hay. As such, the constraints presented by minimal hay production are likely to be a more important factor affecting decision making than other factors.

Spatial variation in forage production also affects the ability of some pastoralists to use hay collection as a risk management tool. At a broad scale, the significance of self-preparation was lower in the Gobi Desert than in steppe and mountain-steppe areas during the bad year of 2009/2010 (29% cf. 28–56%) (Fernandez-Gimenez et al., 2012). The likely reason for this difference is that the lower levels of forage availability in the Mongolian Gobi Desert per unit area alter the cost/benefit ratio of collecting and storing fodder. The related higher levels of pastoralist mobility in the Gobi Desert also make the collection and storage of fodder as an additional risk management strategy to mobility more difficult. There is also variation at a more local scale, with five of the six interviewed pastoralists that prepared fodder in the last bad year being registered in *soums* along the Gobi Gurvan Saikhan mountain range. In these *soums*, forage productivity is naturally higher and funding from non-government organisations led to the irrigation of fodder species.

3.2.2. Overwintering or selling goats

The choice to overwinter or sell goats is dependent on state of nature, food security concerns and commodity prices. In good and average years the model predicted that overwintering goats provided higher returns that selling them in autumn, whilst the opposite was the case in bad years. During the last bad year, distress sales were common and some pastoralists waited for the death of livestock to sell their hides to buy fodder for the remaining livestock. This sort of decision-making highlights the importance of concerns for food security and maintaining the means to grow a livelihood by some pastoralists, even if they incur significant risks or short-term opportunity costs in doing so. However culling or selling livestock were options cited by some pastoralists for preempting expected feed gaps in the short to medium term, and for creating income that could then be used to purchase fodder:

> ‘[If we think the winter will be bad] *we will slaughter and sell* [some livestock] *to buy some fodder. We will try to keep the strong ones.*’ (Tsogtovoo *soum*, Omnogobi *aimag*, 30 years herding).

Low off-take rates are common in subsistent drylands under a pastoral land-use (Barrett and Luseno, 2004). This is also the case in the Mongolian Gobi Desert, constraining the use of culling and selling as a tool for managing climatic variability. Autumn sales suggest culling for subsistence or for managing future feed gaps are relatively more important to pastoralists than profit maximisation. With forage availability beginning to decline at the end of autumn and into winter, livestock body condition is almost certain to decline but pastoralists commonly stated that prices were too low to make selling or culling viable at that time. Media for Business (2010) prices did not suggest that autumn prices were any lower than other periods in Dundgobi *aimag*, but this may have been the case in Omnogobi *aimag*. Regardless, the timing of culling allowed the maximum amount of meat to be stored. Pastoralists could convert the forage resource, which was beginning a predictable decline as temperatures dropped, into a stable meat resource for subsistence purposes:

> ‘*If it is a bad year we slaughter the bad animals as soon as possible. And prepare* borth (dried meat). *And then we keep this until spring with the estimation of how much meat we need for the winter. No, we do not normally sell* [livestock]. *We will try to keep animals, finding ways to save their quality and quantity* [if we know the winter will be bad].’ (Sevrei *soum*, Omnogobi *aimag*, 30 years herding)

The incentive to overwinter despite a poor forage outlook is particularly strong for goats. The additional return from one cashmere clip in spring, if the prices are good, can be lucrative. Pastoralists stated that the price for a live goat could vary between about 30,000 T and 60,000 T. Media for Business (2010) prices for live 4 year old goats in autumn were similar to these figures, though having a narrower range of 38,000 T to 52,000 T. Media for Business (2010) cashmere prices for any week between 2007 and 2010 were between 18,000 T/kg and 54,000 T/kg with the higher figure being the price during/immediately after the *dzud*. The average goat can produce between 300 g (as cited by a pastoralist, Manlai *soum*, Omnogobi *aimag*, 15 years herding) and 600 g of cashmere per year (as cited by another pastoralist, Bulgan *soum*, Omnogobi *aimag*, 25 years herding). Using these figures, a pastoralist could receive between 16,200 T and 32,400 T per clip per goat, the upper figure being greater than the lowest sale price of a live goat cited by pastoralists. In addition, retention of a goat over winter comes at little financial cost to the household, and additionally provides dung for the cooking fire, contributes to a compressed warm dung floor and body heating benefits to other livestock, and the price of a skin if it were to die unexpectedly. The incentive to overwinter is therefore high, particularly close to the China where cashmere prices are higher (Kusan and Saizen, 2013; Sunduimijid, 2004) and where 93% of the world's raw cashmere is produced or sold (Waldron et al., 2011).

For secure livelihoods, the factors that create risk for one income source should not be the same as those that create risk for another (Ellis, 1999). The spatial overlap between the cashmere producing area and the area exposed to stochastic *dzuds* means that when herd sizes decline, prices are likely to rise, buffering livelihood volatility. After the 2009/2010 *dzud* in which a disproportionally high number of goats died, a number of pastoralists stated that they were still able to make 1 to 2 million Tugrik from the 2010 cashmere clip due to high cashmere prices. This was equal to about 3–6 months' of the average monthly earnings of a Mongolian working in the agriculture, hunting and forestry sector in 2009 (National Statistical Office of Mongolia, 2010), or enough to pay the fees of one to two children attending university in Ulaanbaatar. The global importance of the Mongolian and Inner Mongolian cashmere industry (Waldron et al., 2011) means that high goat deaths during *dzud* periods probably inflate the global price of cashmere. High prices therefore partially buffer the risk caused by climatic variability during *dzuds* such as that of 2009/2010, but this buffer may decline in importance as cashmere markets grow in areas outside of the ‘*dzud* zone’ of Mongolia and China (such as the Iranian or Afghani cashmere industries).

Spatial volatility in commodity prices creates the same potential risk inequities between pastoralists as temporal volatility creates for individual pastoralists. For those who can afford transport costs, spatial variation in commodity prices changes the way in which pastoralists sell their livestock, or livestock products. During the survey period, Dundgobi *aimag* livestock prices were lower and less volatile than Omnogobi *aimag*. This may reflect the greater access of Dundgobi pastoralists to the Ulaanbaatar market, which is both larger and more competitive than the markets of either *aimag* (Kusan and Saizen, 2013). In contrast, cashmere prices can be higher with proximity to the Chinese border (Kusan and Saizen, 2013). A number of pastoralists also stated that they could get higher prices for their livestock in the *aimag* centres than *soum* centres. This difference can sometimes be significant. One pastoralist stated that:

> '*At the* soum *markets* [livestock prices are] *lower whilst at the aimag market you can gain a little bit of a higher profit … There are big* [price] *differences. For example, cashmere prices are 3,000–4,000T* [/kg] *different, hide and skin 2,000–3,000T* [/kg], *for meat it is about 500T* [/kg].' (Tsogtseggi *soum*, Omnogobi aimag, 25 years herding)

Whilst the empirical model here accounts for climatic volatility (and therefore indirectly accounts for differences in commodity prices through time), spatial variation in commodity prices adds another level of dynamics to pastoralist decision making that is not accounted for by the model. The price inequities associated with spatial variation in commodity prices also suggest that pastoralist livelihoods may be differentially impacted through space, and that not all pastoralists experience price volatility in the same way. Pastoralists with higher initial capital are likely to be better able to travel, and therefore exploit higher prices.

3.2.3. Mating or not mating

Preventing livestock from breeding is a preferred, alternative strategy that pastoralists use for pre-empting expected feed gaps in the medium term:

> '*If the summer was bad or had less rain, we would decide to stop breeding. It is usually time to decide when livestock are at their fattest but there is no grass. Usually in October or November we start to breed, but this year I guess we will not breed.*' (Manlai *soum*, Omnogobi *aimag*, >30 years herding)

The practice of not breeding is largely to prevent high mortality rates in females with the additional energy demands of gestation, lactation and, perhaps, spontaneous abortion. It is used when the risk of a decline in herd size associated with the death of pregnant females is considered to be a greater risk to future livelihoods than not increasing herd sizes in some years. By reducing grazing pressures in the upcoming spring, it also maximizes available forage per head during a period of feed gaps that pastoralists do not usually manage through mobility.

The reliance on lactating livestock for milk products for subsistence purposes in spring/summer constrain this strategy to some extent, but the maintenance of a mixed flock is able to circumvent this constraint. For example, camels have longer gestation periods and a greater resilience to climatic variability than goats and sheep, meaning that milk products can still be produced for subsistence during *dzud* by a relatively small number of livestock. As such, pastoralists with mixed herds are probably more food secure (all else being equal) and have less to risk by choosing not to mate their livestock.

3.2.4. Purchasing or not purchasing fodder

At the broad scale, gross fodder production declined in Dundgobi *aimag* from 8.1 to 1.6 thousand tonnes between 2006 and 2009, and in Omnogobi *aimag* from 7.2 to 3.2 thousand tonnes between the same years (National Statistical Office of Mongolia, 2010). Commercial fodder available to Gobi Desert pastoralists is therefore largely produced in the north of Mongolia, and then delivered to *soum* and *aimag* centres throughout the country. During the 2009/10 *dzud*, Gobi Desert pastoralists reported seeing Chinese manufactured fodder for the first time. It is unclear as to whether this fodder from imported from China because demand rose steeply, or if fodder production in northern Mongolia had been compromised by the same factors that created the bad year in the Gobi Desert. Baas et al. (2012) suggested that a lack of commercial feed at the national level by March 2010 was a result of all high fibre animal feed being purchased (and presumably redistributed and consumed) directly by pastoralists, as well as by relief agencies and mining companies with the intention of redistribution to pastoralists. Regardless, a lack of commercially available forage in the Gobi Desert markets during times when forage is most needed is a significant constraint to the use of commercial fodder for managing feed gaps. This is despite the empirical model predicting that purchasing commercial fodder improved returns irrespective of the state of nature, or whether goats had been mated.

In the Dundgobi *aimag* centre, Mandalgobi, fodder was available for sale during most months in the period from January 2007 to June 2010 (secondary data sourced from Media for Business, 2010). However it was unavailable in Mandalgobi during January 2010, a key period when it was needed. During this period, a lack of commercial fodder directly contributed to pastoralists being unavailable to manage climatic shock. To a lesser extent, pastoralists may have lacked the financial ability to purchase what was available as prices were high during the period in which it was most needed. Purchasing fodder in advance when it was available may have been more affordable for pastoralists with high levels of capital, but the risk of an opportunity cost of lost income if there had been no climatic shock, or a lack of storage facilitates at the household level, may also have reduced the uptake of a such a strategy.

Despite commercial fodder shortages being reported across the country (Baas et al., 2012; Fernandez-Gimenez et al., 2012), there still appeared to be spatial variation in fodder shortages. The Omnogobi *aimag* capital of Dalanzadgad had a less reliable supply of fodder than Mandalgobi, probably due to its greater distance from fodder growing areas, the capital Ulaanbaatar and poor road infrastructure (Kusan and Saizen, 2013). Media for Business data suggested that fodder was unavailable at the market in Dalanzadgad for about 57% of the weeks ($n = 168$) between January 2007 and June 2010. Commercial fodder was usually available over winter and spring when feed gaps and demand were greatest, and absent during summer and autumn. Given that fodder is usually harvested at the end of autumn during peak biomass, the absence of commercial fodder during warmer months probably reflects a lack of demand during this period rather than supply constraints. However an important exception was January 2010, the *dzud* period, when no commercial fodder was available. Unavailability during this period probably reflects supply constraints, despite high demand.

In addition to the belief by pastoralists that '*forage was in deficit*' during critical periods (Tsogtseggi *soum*, Omnogobi *aimag*, 25 years herding), commercial fodder was often considered to be expensive, sometimes prohibitively so. Pastoralists often believed that their longer-term food security depended upon the purchase of fodder, a belief that was largely verified by the empirical model and evidenced by the practise of preferentially feeding young or weakened livestock with supplementary fodder:

> ‘*We do not* [usually] *buy forage for mature livestock. The young have to be fed* [forage] *in the morning and evening. The matured ones* [usually] *go for grazing but* [during the *dzud*] *were weak so we had to give them extra protein … In May the animals were still weak so we still had to give them fodder. Starting from the end of May they could graze by themselves.*’ (Manlai *soum*, Omnogobi *aimag*, 10 years herding)

Pastoralists stated that preferential feeding was largely because stronger livestock were able to access forage over the winter period in years when the standing dead/senescent vegetation remained from the previous growing period and was not covered by deep snow. The desire to reduce overall livestock mortalities to maintain the herd size may have also contributed to the decision of pastoralists to prioritize fodder use in this way. However it is unclear how the preferential feeding of young or weak livestock, rather than livestock likely to produce the most cashmere, would affect the pay-off predicted by the model.

Financial tools can help manage climatic risk by trading between unpredictable natural capital and more predictable financial capital (Ouma et al., 2011). Pastoralists regularly took short-term loans in the form of cash to help them purchase fodder. Loans were often sourced from non-bank lenders, such as cashmere traders, with the upcoming cashmere clip often used to guarantee the loan. The pastoralists interviewed for this research frequently sought loans towards the end of winter or the beginning of spring to cover fodder costs. These are in all likelihood in addition to the late August/early September loans regularly taken out to pay for school fees, repairing wells and producing fodder (Sneath, 2012). Late winter/early spring loans were commonly used to pay for commercial fodder for livestock and for fuel to facilitate livestock mobility:

> ‘*During the* dzud *we bought 40 kg packets of protein that cost 7,000T in winter but increased to 12,000T in spring. We got a loan from Khan Bank to pay for this supplementary feed, and for moving costs. The interest rate was 3% per month*.’ (Ulziit *soum*, Omnogobi *aimag*, 15 years herding)

Some pastoralists stated that they pay back loans once the next year's cashmere had been sold. One pastoralist stated that they had sold an unknown number of livestock to pay their loan of 250,000T that was used to purchase fodder/protein during the *dzud*. That pastoralist had been able to pay back their loan, but was left destitute with only 26 livestock remaining (Tsogtseggi *soum*, Omnogobi *aimag*, 25 years herding). Other pastoralists borrowed what they expected could be paid off with the upcoming cashmere clip:

> ‘*We spent 1 million tugrik on protein/grass this last winter. We couldn't buy more because of the snowstorm. We borrowed money to buy fodder, and then paid these loans off with the money we made from cashmere*.’ (Ulziit *soum,* Omnogobi *aimag*, 25 years herding)

The inability to gain credit also affected the ability of pastoralists to use commercial fodder as a way of managing feed gaps:

> ‘*The supply* [of commercial fodder] *was not that much. If they had more we could have bought. We had some cash problems. Some traders did not allow credits*.’ (Manlai *soum*, Omnogobi *aimag*, 10 years herding)

The widespread use of loans occurs both systematically and during periods of climatic shock. During periods of shock, pastoralists were often buying extremely expensive commercial fodder with loans that used their expected cashmere clip as collateral and selling livestock at depressed prices to repay loans. Whilst such an approach may have smoothed both livestock feed gaps and livelihood volatility, it may also have created long-term stress on pastoral production, particularly for already vulnerable pastoralists (Sneath, 2012) or those more remote pastoralists who experienced higher transaction costs or lower commodity prices.

3.2.5. Support from government, NGOs and mining companies

Governments, non-government organisations and, increasingly, mining companies play a small but potentially significant role in the risk exposure and decision-making of Gobi Desert pastoralists. During the 2009/2010 *dzud*, governments attempted to support pastoralists with fodder purchases, but administrative fairness and implementation concerns meant that the quantity of free fodder provided to pastoralists by government was determined by herd size rather than relative need. Nonetheless, government subsidies for fodder during the 2009/2010 *dzud* did dampen price volatility across all *soums*. One pastoralist in Tsogseggi *soum* stated that in a bad year, a packet of hay normally cost 8000 T–12,000 T at the market, with a packet of protein costing 8000 T–15,000 T (Tsogtseggi *soum*, Omnogobi *aimag*, 25 years herding). *Soum* government subsidies during the 2009/2010 *dzud* reduced this to 4000 T and 5000 T, respectively, a price that was not dissimilar to the prices in good years. There was minor variation between *soums*, with a Mandal-ovoo *soum* pastoralist stating that a packet of protein in a bad year normally cost them 6000 T, with a government subsidy during the 2009/2010 *dzud* reducing this to 3000 T (Mandal-ovoo *soum*, Omnogobi *aimag*, 30 years herding). A Sevrei *soum* pastoralist stated that the market fodder price during the *dzud* was 12,000 T per packet, with the subsidized price being 4000 T–5000 T per packet (Sevrei *soum*, Omnogobi *aimag*, 8 years herding). Gobi Desert pastoralists recognised that they would have benefitted from greater levels of support. However, they appeared to be less critical of the level of support they received than the steppe region pastoralists described by Fernandez-Gimenez et al. (2012), despite what appeared to be the similar level of support offered by the *soum* governments.

Livestock insurance, like that provided through the World Bank Index-based livestock insurance project, can also help reduce livelihood volatility. However, only three of 38 pastoralists who responded to the question of livestock insurance stated that they had joined such an insurance scheme. One pastoralist with insurance stated that:

> ‘[Our livelihoods are] *not safe anymore because* dzud *and droughts have increased. If we lose everything we get compensation from the Mongolian Insurance Company.*’ (Sevrei *soum*, Omnogobi *aimag*, 25 years herding)

Many pastoralists knew of insurance schemes being piloted in other *aimags* by the Mongolian government and the World Bank, and some commented that the piloted schemes would be beneficial:

> ‘*We have no such kind of insurance services. We do not have it in the aimag. The indexed livestock insurance is implemented within a few* aimags *e.g. Bayankhongor and 5–6 other aimags. It is broadcast through the radio but is not implemented here. If we had such a thing, why would we sit like this, having lost nearly all of our livestock?* (laughing)’ (Tsogtseggi *soum*, Omnogobi *aimag*, 25 years herding)

This finding concurs with that of Fernandez-Gimenez et al. (2012) who found that whilst one third of herding households in desert steppe areas in Bayankhongor *aimag* had insurance prior to the 2009/2010 *dzud*, like Omnogobi and Dundgobi *aimag* pastoralists, nearly all wanted insurance after the *dzud*.

Non-government agencies, such as international mining companies and development/relief agencies, provided some support during the 2009/2010 *dzud* when feed gaps were at their greatest. There is evidence that such external support significantly affected decision making for at least some pastoralists. For example, a Tsogtseggi *soum* pastoralist said that they had received free goods from the Tavan Tolgoi mine, and subsequently were changing their *soum* of registration from Luus *soum* in Dundgobi *aimag* to Tsogtseggi *soum* in Omnogobi *aimag* (the location of the mine) to ensure similar support in the future. Another two sold livestock to Tav Tolgoi or Oyu Tolgoi mine or to associated *guanz* (cafe) because they could ask a higher price:

> "*We sell live animals to the* guanz *near Oyu Tolgoi – the prices are higher than at the* soum. *On average, we get about 20–30,000T more from the Oyu Tolgoi* guanz. *We sell in spring/summer/autumn but the mines are closed in winter.*" (Khanbogd soum, Omnogobi aimag, >30 years herding)

Whilst the levels of external support or influence are still fairly low, the examples suggest that significant levels of external support to pastoralists may change the relative benefits of decision tree 'branches' with both changes in decision making and risk profiles. Ouma et al. (2011) also highlighted that external support can abet sedentarisation, undermine local markets and may not necessarily align with household priorities on aid – this certainly appears to be happening for at least some Mongolian Gobi Desert pastoralists.

4. Conclusion

The inverse relationship between cashmere prices and seasonal climatic conditions may reduce the risk of volatile livelihoods in the short-term but climate volatility can also create significant production, ecological and food security risks in ways that are not buffered by commodity price volatility. Mongolian Gobi Desert pastoralists are largely subsistent (National Statistical Office of Mongolia, 2009) and the majority of Mongolian Gobi Desert pastoralists have herd sizes that are below that which they consider to be the minimum viable (Addison, unpublished data). This is evident by the practice of privileging the prevention of livestock breeding over sales/culling during bad years, and preferentially providing newborns or weak livestock, rather than stronger livestock, with the limited supplementary feed. As is the case in the Sahel (Turner and Williams, 2002), markets tend to be utilised as a tool to minimise the effects of stochastic shocks, rather than to recover post-shock. The need for both an income and food security provides a push for a herd that is large and compositionally mixed. Both the shock of *dzuds* and stress of labour shortages currently constrain the ability of pastoralists to achieve these needs.

The use of static empirical models of financial returns in contexts that are subsistent and vulnerable to stochastic shocks can be largely academic when longer term food and livelihood security concerns dominate concerns for immediate financial returns. Pastoralists' subjective risk rankings vary across individuals, households, space and time, and commodity prices and climatic variability are not always seen as the most serious risks faced by pastoralists (Doss, 2008; Ouma et al., 2011). However, such models do help identify potential pastoralist vulnerabilities and may help organisations wishing to support pastoralists for both livelihoods and land degradation reasons more effectively target their resources. This is particularly the case when these models are combined with a more nuanced understanding of how price and production risks are experienced differently by pastoralists through space and time, and how interactions with markets may affect feed-gaps, livelihood and ecological conditions.

As is the case in parts of dryland Africa (Barrett and Luseno, 2004), low commodity prices are linked to low off-take rates resulting in high livestock mortality during climatic shocks. The empirical model used in this research predicts that the purchase of fodder is one of the most beneficial risk management strategies available to Mongolian pastoralists and yet the purchase of fodder requires significant upfront capital (either through cash or livestock). For the poorest or most remote pastoralists, access to affordable commercial fodder at key times is likely to be minimal to non-existent. This creates equity and justice concerns. For poor/remote pastoralists in particular, the lack of affordable and available market-based options for pre-empting or responding to volatility emphasises the importance of alternative options such as livestock mobility.

Longer distance mobility also requires upfront costs and, sometimes, difficult pastoralist-to-pastoralist negotiation, and the relative economic trade-offs of mobility with other risk management tools deserve further investigation. Additional research into the timing and uptake of risk management tools used by different types of pastoralists (e.g. by wealth categories) would help highlight which assistance strategies were most likely to be effective, to whom and under which circumstances. However it is likely that mobility in response to volatility is currently more cost effective, timely, available and practical than the purchase of sufficient levels of commercial fodder, or sale of livestock, particularly for pastoralists who are poor, food insecure or more remote from fodder markets.

Internationally, organisations wishing to support pastoralists for livelihood and land degradation reasons have often focussed upon the modification of formal or informal institutions governing access to the forage resource as a panacea for a multitude of perceived environmental and livelihood problems (Turner, 2011). In the Mongolian Gobi Desert, such a focus has met limited success (Addison et al., 2013). The work presented here suggests that focussing on the larger, non-tenure related context in which pastoralists operate may provide more traction. Pastoralists are not unaware of what is in their best interests – their choices are constrained by both practical realities such as a poor commercial fodder supply chain, and the potential opportunity costs associated with forward planning in a landscape heavily impacted by largely unpredictable stochastic shocks. Assistance that is distributed in a manner that supplements and is compatible with their preferred risk strategy – mobility – could be more strongly emphasised (Doss, 2008).

In Mongolia, one example of this type of support that is likely to be well received may be a general focus on increasing the accessibility and affordability of index-based livestock insurance and loans. Index-based livestock insurance schemes are particularly pertinent in drylands when reciprocal altruism mechanisms are challenged by a dynamic social and political context (Ouma et al., 2011). Mongolian Gobi Desert pastoralists cite a keenness to adopt such an insurance scheme, and already frequently utilise short-term loans at exorbitant interest levels (Sneath, 2012) as a way of shifting capital as needed. Whilst the availability and affordability of commercial fodder may be prohibitive, its use increases returns during all states of nature. Programmes seeking to improve the commercial fodder supply chain, particularly during periods of climatic shock, are therefore likely to provide benefit to pastoralists. Such programmes would increase availability of effective risk management options available to pastoralists, rather than restrict them further.

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Appendix A. Supplementary material

Supplementary material related to this article can be found at http://dx.doi.org/10.1016/j.jaridenv.2014.05.010.

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