How do households depend on grassland ecosystem services? An analysis of household and spatial factors in Inner Mongolia

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Contents

Abstract

Grasslands are one of the most important ecosystems for regulating climate and supporting human livelihoods. While grassland degradation has become a global concern and governments have therefore implemented policies to cope with it, herders often share use rights to grasslands that are commonly presumed to trigger a "tragedy of the commons". Understanding how herders make decisions about grassland use can help to overcome the gap between current policies and intense grazing activities and help contribute to poverty alleviation and food security. In this thesis, I conduct a household and multi-scale spatial analysis on grassland dependence in Inner Mongolia. I first review the literature on ecosystem services, grassland degradation and pastoral livelihoods in Chapter 2. Chapter 3 develops a metric of *grassland dependence* to indicate the relative extent herders rely on grasslands vs. externally purchased forage for livestock energy requirements. After developing this metric, I use a novel dataset of herding households in Inner Mongolia, China, to examine how factors relate to grassland dependence. Our data includes repeated household surveys in 2010 and 2015. Therefore, I utilize statistical techniques that take advantage of the panel nature of our data, building fixed effects, random effects, and double hurdle models. Chapter 4 examines the spatial nature of grassland dependence in Inner Mongolia. I explore spatial clustering and develop models that incorporate spatial interactions to demonstrate how factors influence herders' decision-making strategies on resource usage. Factors may influence not only local dependence, but also dependence in neighboring area.

Environment and individual decision-making are both important for explaining local dependence on grasslands for livelihoods. I find net primary production (NPP) has a positive direct effect on local dependence, suggesting productive grasslands may provide greater amounts of forage, which give households the option to higher local dependence. The number of droughts

household suffered is negatively associated with dependence. The hypothesis I propose is that households suffering from drought are more likely to purchase forage to mitigate losses.

The number of laborers is positively associated with dependence in non-spatial models, while has a negative indirect effect indicating the number of laborers has a negative effect on dependence on nearby area. Findings above suggest more laborers in neighbourhood may motivate herders to purchase forage, while more laborers in a household does not guarantee so. Besides, current grassland subsidies are effective but can be improved in the future. In addition, I found a non-linear relationship between stocking rate and local dependence. The more stocking rate increases, the less it has effect on dependence. Herders depend on natural grasslands for grazing and their livelihoods are vulnerable compared to farmers, requiring more support from organizations and governments. This study fills the gap that little work has be done on local grassland dependence, especially examining the local grassland dependence from the perspective of metabolic energy instead of livelihood income share.

Résumé

Les prairies sont l’un des écosystèmes les plus importants pour réguler le climat et soutenir les moyens d'existence humains. Alors que la dégradation des prairies devenait une opréoccupation mondiale et que les gouvernements ont mis en œuvre des politiques pour y faire face, les éleveurs partagent souvent des droits d'utilisation des prairies qui sont souvent présumés déclencher une «tragédie des biens communs». Si on comprend comment les éleveurs prennent des décisions concernant l'utilisation des prairies, il peut aider à combler le fossé entre les politiques actuelles et les activités de pâturage intenses et contribuer à la réduction de la pauvreté et à la sécurité alimentaire. Dans cette thèse, je mène une analyse spatiale des ménages et à plusieurs échelles sur la dépendance des prairies en Mongolie intérieure. Je passe d'abord en revue la littérature sur les services écosystémiques, la dégradation des prairies et les moyens d'existence pastoraux au chapitre 2. Le chapitre 3 développe une métrique de la dépendance des prairies pour indiquer dans quelle mesure les éleveurs dépendent des prairies par rapport aux fourrages achetés à l'extérieur pour les besoins énergétiques du bétail. Après avoir développé cette métrique, j'utilise un nouvel ensemble de données sur les ménages d'éleveurs en Mongolie intérieure, en Chine, pour examiner comment les facteurs sont liés à la dépendance des prairies. Nos données comprennent des enquêtes répétées auprès des ménages en 2010 et 2015. Par conséquent, j'utilise des techniques statistiques qui tirent parti de la nature de panel de nos données, en construisant des effets fixes, des effets aléatoires et des modèles à double obstacle. Le chapitre 4 examine la nature spatiale de la dépendance des prairies en Mongolie intérieure. J'explore le regroupement spatial et développe des modèles qui intègrent des interactions spatiales pour démontrer comment les facteurs affectent les stratégies de prise de décision des éleveurs sur l'utilisation des ressources. Les facteurs peuvent influencer non seulement la dépendance locale, mais aussi la dépendance dans la zone voisine.

L'environnement et la prise de décision individuelle sont tous deux importants pour expliquer la dépendance locale à l'égard des prairies pour les moyens de subsistance. Je trouve que la production primaire nette (PPN) a un effet direct positif sur la dépendance locale, ce qui suggère que les prairies productives peuvent fournir de plus grandes quantités de fourrage, ce qui donne aux ménages la possibilité d'une plus grande dépendance locale. Le nombre de sécheresses subies par les ménages est négativement associé à la dépendance. L'hypothèse que je propose est que les ménages souffrant de sécheresse sont plus susceptibles d'acheter du fourrage pour atténuer les pertes.

Le nombre d'ouvriers est positivement associé à la dépendance dans les modèles non spatiaux, alors qu'il a un effet indirect négatif indiquant que le nombre d'ouvriers a un effet négatif sur la dépendance vis-à-vis de la zone voisine. Les résultats ci-dessus suggèrent que plus d'ouvriers dans le quartier peuvent motiver les éleveurs à acheter du fourrage, alors que plus d'ouvriers dans un ménage ne le garantissent pas. En outre, les subventions actuelles aux prairies sont efficaces mais peuvent être améliorées à l'avenir. De plus, j'ai trouvé une relation non linéaire entre le taux de charge et la dépendance locale. Plus le taux de charge augmente, moins il a d'effet sur la dépendance. Les éleveurs dépendent des prairies naturelles pour le pâturage et leurs moyens de subsistance sont vulnérables par rapport aux agriculteurs, nécessitant davantage de soutien de la part des organisations et des gouvernements. Cette étude comble le manque de travail sur la dépendance des prairies locales, en particulier en examinant la dépendance des prairies locales du point de vue de l'énergie métabolique au lieu de la part des revenus des moyens de subsistance.

Contribution of Authors

This thesis consists of five chapters. The first chapter is the introduction. Then I review the literature on ecosystem services, grassland degradation and pastoral livelihoods in Chapter 2. Chapter 3 develops a metric of *grassland dependence* and build OLS models, fixed effect model, mixed effect model and double hurdle model to examine how household, community, and regional factors relate to grassland dependence. Chapter 4 incorporates spatial effects to statistical models to examine how factors take effects spatially on local and neighboring areas. Chapter 5 summarizes the findings of this thesis and indicates implications on future research and su.

I am the primary author of all five chapters. My supervisor, Prof. Robinson, contributed to ideas and writing especially in Chapters 3 and 4. Data used in Chapters 3 and 4 come from the Grassland Research Institute at the Chinese Academy of Agricultural Sciences in Hohhot, Inner Mongolia, particularly from project collaborators Dr. Li Ping and Dr. Hou Xiangyang. Dr. Graham MacDonald, who is on my master's thesis committee, has also made editorial and intellectual contributions to this thesis.

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Chapter 1. Introduction

Grassland ecosystems occupy about 40% of terrestrial surface in China and around 10% of the world's population relies on grassland ecosystems directly for livelihoods (Kemp et al., 2015; Schmidt et al., 2001). Grassland ecosystems provide a range of important services, including net primary production, maintenance of biodiversity, sandstorm prevention, and water and soil retention. People benefit from grassland ecosystem directly and indirectly (Daily, 1997). Grassland provide food, drinking water, fiber, industrial and pharmaceutical materials for human to sustain livelihoods directly and indirectly (Costanza et al., 1997; Daily, 1997; Schmidt et al., 2001). In addition to food and water supply, grasslands are the great genetic reservoir and provide continuing genetic resources as well to improve crops and support industrial production (Batello et al., 2008; Schmidt et al., 2001). Grassland are also store large amounts of carbon and perform important watershed functions, including absorbing rainfall, stabilizing soils, and moderating runoff (Miller et al., 2011; Schmidt et al., 2001; Wick et al., 2016). Therefore, grasslands play a crucial role among the world's ecosystems in supporting human livelihoods.

Humans rely on grasslands perhaps most importantly through livestock, which survive primarily on grass for their energy requirements. For millennia communities have grazed livestock on natural grasslands. This fundamental ecosystem service still supports many hundreds of millions of people globally today (Robinson et al., 2011). Overgrazing is considered one the main causes of grassland degradation (Teague and Dowhower 2003; Hua and Squires 2015). Grassland degradation has become a global concern and the grassland in Inner Mongolia Autonomous Region (IMAR) has been degraded or degrading for decades (G. Jiang et al. 2003).

In China, the national government has implemented a set of policies to cope with grassland degradation, including reverting some grazing land "back" to forest or grassland, forbidden and rotational grazing, and ecological migration and compensation. In addition, herders can only engage in 30-year renewable contracts over grasslands, since the State is the ultimate owner of land in China and grassland property rights are fundamentally retained by the government. Herders must comply with policies to protect grasslands, such as when grazing is prohibited which can last from periods of less than one year to indefinite periods of time.

Such grassland protection policies can induce household livelihood changes, sometimes fundamentally changing herders' lifestyles and reshaping the patterns of grassland use that have existed for millennia in Inner Mongolia (Du et al., 2016; Zhen et al., 2014). The impacts of policies on household livelihoods can be substantial. In some cases, herders that struggle to meet their livelihood needs may increase graze intensity to secure higher income, which can then have a negative impact on grassland ecosystem services (Jun Li et al., 2007; David R. Kemp et al., 2013; Li and Bennett, 2019a). In this case, measuring herder's dependence on local grasslands for grazing can help to overcome the knowledge gap between current policies and intense grazing activities. Further analyzing the internal and external factors that impact grassland dependence can help support grassland conservation and herder livelihood.

Most past studies on environmental livelihood dependence mainly focus on forest ecosystems and calculate based on income, which is studied from the perspective of socioeconomic status and interactions with poverty and often overlook ecological aspects such as degradation or depletion of resources (Babulo et al., 2008; Mazumder, 2018; Zenteno et al., 2013). Household livelihood strategies are classified by the portfolio of income from multiple sources. Few studies are set in grassland ecosystems (Alemu, 2012; Peng et al., 2017; Xu et al., 2019, 2015). In those that do cover pastoral settings, grazing livelihood strategies are classified by the share of livestock income (Ding et al., 2018; Du et al., 2016). Some new methods have been proposed but have not been widely adopted. For example, rank of the importance of income or related strategies are used to indicate the extent of dependence (Elizabeth et al., 2018; Kimengsi et al., 2019; Ofoegbu et al., 2017).

In this thesis I first briefly review the literature related to grassland ecosystem services, grassland degradation, and pastoral livelihoods, with a focus on how past work has characterized herder reliance on grasslands and its impact. In Chapter 3, I develop a simple but novel metric of *grassland dependence* – the extent to which a household relies on natural grassland for grazing livestock. This household-level metric is based on livestock energy requirements and can be estimated from household questionnaire data on livestock demographics and feeding practices. In this chapter I also examine household decision-making strategies in Inner Mongolia in relation to their dependence on local grasslands and external markets with fixed effect, mixed effect, and double hurdle models. Chapter 4 then looks at these issues from a spatial perspective, investigating spatial clustering and incorporating spatial components into statistical models. This chapter incorporates environmental characteristics and assesses the impact of external and internal factors on *grassland dependence* with spatial disturbances of error terms to support policy modification and poverty alleviation. I conclude in a final chapter by summarizing my findings, noting implications for policy, and directions for future research.

Chapter 2. Literature Review

To understand grassland dependence, we first need to understand common concepts around grassland ecosystems and herders' livelihoods and how these fits together. In this chapter, I review the literature around grassland ecosystem services, grassland degradation, and pastoral livelihoods. I first begin with defining ecosystem services and why ecosystem services are important and worth studying in terms of grassland livelihood reliance. I then go through one of the biggest problems facing grasslands—grassland degradation—and how it relates to climate change and anthropogenic activities. Finally, I move to pastoral livelihoods to view how herders sustain their livelihoods on grassland and work should be done for sustainable livelihoods on grassland.

2.1 Grassland Ecosystem Services

Ecosystem services are the conditions, processes, and material flows from natural ecosystems, and the species that make them up, that sustain and fulfill human life: that is, the benefits that people derive from functioning ecosystems (Daily, 1997; Viglizzo and Frank, 2006). Ecosystem services only exist if they contribute to human wellbeing, and cannot be defined independently (Braat and de Groot, 2012). Some argue that ecosystem services are therefore a concept that is too anthropocentric in which nature exists as separate entity whose purpose is to 'serve' humans (Gagnon Thompson and Barton, 1994; McCauley, 2006). Others argue that, as a part of biosphere, humans use resources to survive and thrive similar to other species, and the concept of ecosystem services makes it clear that the whole system matters (Costanza et al., 2017).

Ecosystem services have traditionally differentiated into four different categories: supporting services, provisioning services, regulating services and cultural services (Costanza et al., 2017). Ecosystems provide food, drinking water, fibre, fuel and other materials as provisioning functions, and cultural services includes aesthetic, spiritual, educational services and recreational services (Millennium Ecosystem Assessment, 2005). Regulating services comprise climate regulating, flood regulating, water regulating and regulating on some other aspects. Supporting services include things like nutrient cycling and ecosystem production (Millennium Ecosystem Assessment, 2005). Some argue the distinction between supporting and regulating services is not always clear, and some recent literature focuses on the three categories of provisioning, regulating, and cultural services.

Human society and globally interconnected economies depend on ecosystem services. Grassland ecosystems, as an essential part of the terrestrial ecosystem, occupy 40% of land (except in Antarctica and Greenland) (Millennium Ecosystem Assessment, 2005). These ecosystems provide a range of important services, including net primary production, maintenance of biodiversity, sandstorm prevention, and water and soil retention, carbon storage and cultural services. Grasslands provide food, drinking water, fiber and industrial and pharmaceutical materials for human to sustain livelihoods directly and indirectly (Costanza et al., 1997; Daily, 1997; Schmidt et al., 2001). In addition, grassland is habitat for many species including birds, wild animals and plants, and is crucial to biodiversity (Tilman, 1997; Yamamura et al., 2013). Grasslands store one third of the global carbon stocks of terrestrial ecosystems and help maintain watershed functions (Miller et al., 2011; Schmidt et al., 2001; Wick et al., 2016).

Wise management of grassland ecosystem is crucial to the efficient and sustainable use of economic and ecological value. On grasslands, reported impacts of livestock grazing on different ecosystem service can be much more positive than negative for some supporting and regulating ecosystem services, such as habitat provision, nutrient cycling, and bush encroachment/fire control (Leroy et al., 2018). Moderate grazing improves ecosystem services by increasing floristic and functional diversity, improving carbon balance and water infiltration rates, as well enhancing soil attributes (Carvalho and Batello, 2009). While intensive use of the ecosystem yields the greatest short-term advantages, excessive and unsustainable use can lead to long-term losses (Costanza et al., 2017; Millennium Ecosystem Assessment, 2005). Diminished human well-being tends to increase immediate dependence on ecosystem services, and the resultant additional pressure can damage the capacity of those ecosystems to deliver services. This can create a downward spiral of increasing poverty and further degradation of ecosystem services (Millennium Ecosystem Assessment, 2005; Scherr, 2000).

2.2 Grassland degradation

Grasslands are one of the most widely distributed ecosystems on land surface, occupying around 20% of global land area and around 40% of China’s land area (Ren et al., 2008; Scurlock and Hall, 1998). Grassland degradation indicates the deterioration of grassland ecosystem function (Nkonya et al., 2015). The process of grassland degradation is sustained and complex, resulting in the decline in grass quality and primary productivity, loss of biodiversity and complexity, and deterioration of resilience and recovery functions (Jiang et al., 2011; Yang et al., 2007; Zhou et al., 2017). In addition, grassland degradation affects the grassland carbon sink function and trace elements cycling (Abdalla et al., 2018; Yang et al., 2019).

Grassland ecosystems in Inner Mongolia are relatively fragile and sensitive to climate change and anthropogenic activities due to poor soil and low vegetation cover (Huang et al., 2016; Lioubimtseva and Henebry, 2009; Seddon et al., 2016). Climate change, especially temperature and water affect productivity, biodiversity, community composition and growing season length (Lemmens et al., 2006; Levy et al., 2004; Saleska et al., 1999). Among human activities, overgrazing is considered one the main causes of grassland degradation (Hua and Squires, 2015; Teague and Dowhower, 2003). Although overgrazing has been decreasing in recent years, livestock inventories have continued to increase (Hua and Squires, 2015). Grazing pressure could reduce the grassland biomass and have a long-term effect on vegetation community (Laycock, 1991; Liu et al., 2013). When grazing pressure exceeds the ability of the grassland ecosystem to recover in a timely manner, soil exposes and the ecosystem carrying capacity reduces accordingly, and further accelerates soil erosion and deteriorated soil structure, which in turn affects plant communities (Sivanpillai, 2016). The process of grassland degradation is complex, including the change of greenness and the process from grassland to desert (Ying, 2020).

The causes and even nature of grassland degradation are not without debate, even from disparate disciplines. For example, economic theory posits that grassland degradation should not be a serious threat since herders and pastoralists inherently want to reap the benefits of the land, and should therefore find common solutions to mitigating degradation (Bridges, 2019). Some ecologists also consider the effects of overgrazing to be overstated, while the effects of climate change are underestimated (Harris, 2010; Yundannima, 2012). Political ecology notes the degradation narrative is often one told by the State and almost always blames local people for grassland degradation issues (Kolås, 2014). In fact, Ho (2001) suggests non-equilibrium rangeland theory leads us to the conclusion that land degradation is much more likely a climatically rather than an anthropogenically driven phenomenon. Regardless, most policy makers and rangeland ecologists believe degradation to be a real and (to some extent) controllable problem, as it is the subject of numerous policies that affect not just land resources but also human welfare.

Grassland degradation threats development and strategies aimed at poverty reduction (Nkonya et al., 2015). The Chinese Government has proposed and implemented several policies (e.g.: Conversion of Cropland to Forest and Grassland Program, Returning Grazing to Grassland and Rangeland Ecological Compensation Program) for grassland management and brought positive effect on grassland (Hua and Squires, 2015; Zhang et al., 2020). However, some argues that because of the complexity of the process, the decline in grassland degradation cannot all be attributed to policy (H. Zhao et al., 2018). Besides, grassland management cannot be effectively implemented in a simple top-to-bottom approach nor only through uncoordinated efforts of herders. Both policies and decision-making strategies of herders should be investigated for better grassland management.

2.3 Pastoral Livelihoods

Research involving human populations that live in and depend on grassland "pastures" investigates the conditions and circumstances that make up pastoral livelihoods. A livelihood comprises the capabilities, assets (including both material and social resources) and activities required for a means of living. A livelihood is said to be sustainable when it can cope with and recover from stresses and shocks, maintain or enhance its capabilities and assets, while not undermining the natural resource base (Scoones, 1998). Livelihoods are considered as a valuable means to analyze the impact factors of human living and well-beings, especially for the poor in the developing world.

Different livelihood strategies depend on basic material and social, tangible and intangible assets that people have in their possession, which is 'capital' base. There are five types of sustainable capitals from where we derive the goods and services we need to improve the quality of our lives (Ellis et al., 2000; Scoones, 1998). Natural capital refers to the natural resource stocks and environmental services, such as hydrological cycle, pollution sinks etc., from which useful resource flows and services are derived. Financial capital is the essential capital base of livelihood strategies. Human capital is the skills, knowledge, ability, and physical capacity important for productive work. Social capital refers to social resources (networks, social claims, social relations, affiliations, and associations) that people rely on to pursue different livelihood strategies. Physical capital comprises material goods or fixed assets which contribute to the production process rather than the output itself.

Understanding, in a dynamic and historical context, how different livelihood resources are sequenced and combined in the pursuit of different livelihood strategies is critical (Scoones, 1998). Livelihood diversification and engagement in non-farm employment appear to generally decrease the usage of biomass. In most low income countries an enabling and facilitating environment for the spread of diverse non-farm income-generating activities can hardly be said to exist (Ellis et al., 2000).

In Inner Mongolian Autonomous Region (IMAR), people have relied on grassland for nomadic grazing for millennia. Traditional herders cope with the unpredictable forage production with flexible strategies on boundaries and grassland use (for example, otor, which is a traditional practice of sharing grasslands when someone's grassland is uncharacteristically unproductive) within their social institutions (Fernandez-Gimenez, 1999; Fernández-Giménez, 2002; Fernandez-Gimenez and Le Febre, 2006; Humphrey and Sneath, 1999). Since the late 1990s, the Chinese government has allocated 30-year fixed-term contracts that give herders property rights over plots of grassland. Since the privatization of the grassland, herders often fence off their own grassland areas. In some places, herders are not able to afford the fencing expense, and dividing the grassland fairly to each household is difficult when the resources are limited. This can lead to deteriorating social relations due to the pressure of managing common-pool resources, which can also then increase the vulnerability of social-ecological grassland systems (Jun Li et al., 2007; Mccay and Jentoft, 1998).

The grasslands in North China have been degrading for decades (Jiang et al., 2003). Consequently policies have aimed to address changes in rangeland and livestock management in IMAR, China (Ho, 2001; Kang et al., 2007). While livestock production in the grasslands of Inner Mongolia underpins regional economic stability (Jun Li et al., 2007; Robinson et al., 2017), natural resource-based communities occupy a unique interface between society and the environment. Subject to the vagaries of external control and global market demand for resources, these communities often appear particularly vulnerable to the negative effects of environmental and social change (Flint and Luloff, 2005).

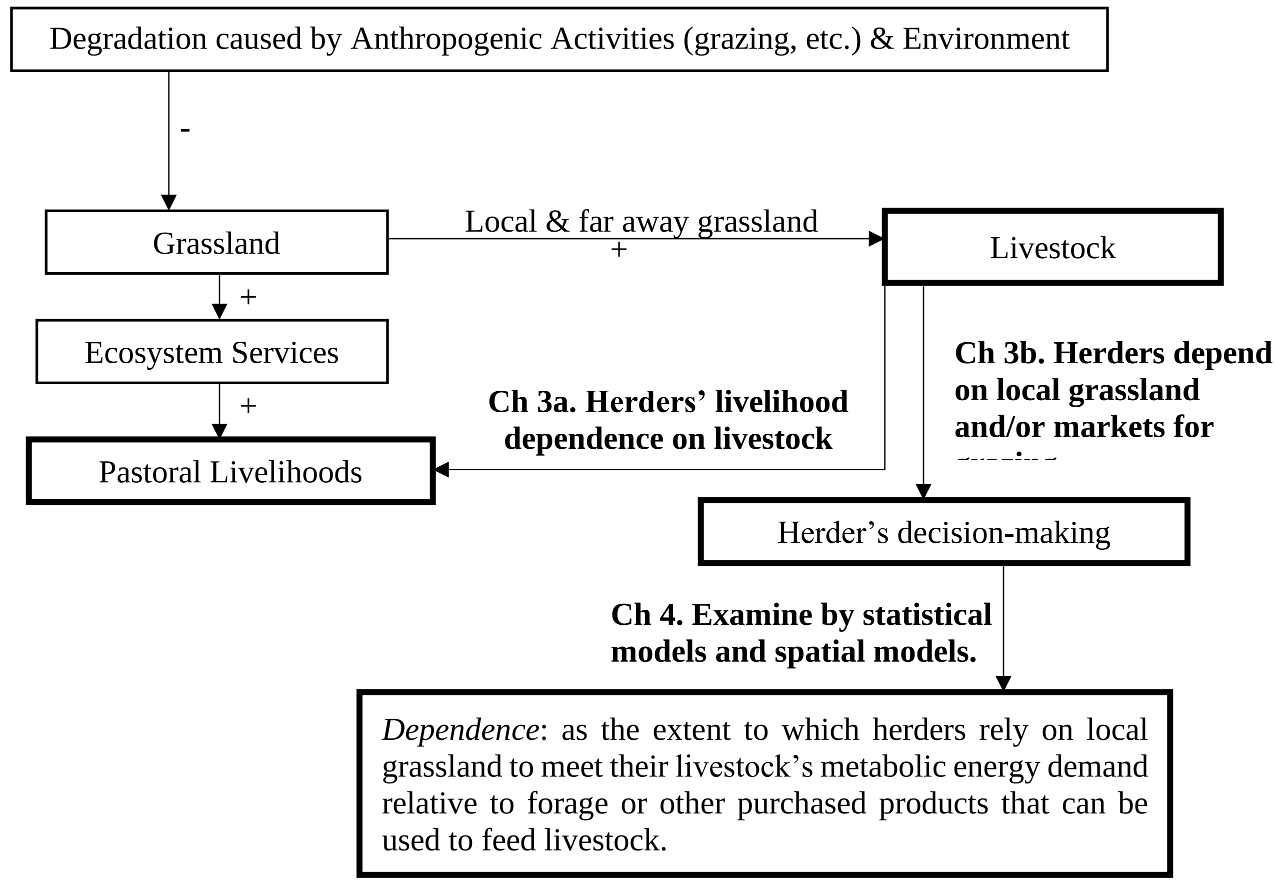
Grassland degradation intensifies human-environment conflicts and changes local herders' livelihoods. Herders build their wealth through assets, specifically land and livestock (Kay et al., 2008). Various case studies have suggested that environmental incomes from forests and other vegetation types are important for rural households in developing countries. Restricted by long-term lease, herders can build their wealth only through livestock and saving their profit over time. Herders want to increase the number of livestock they hold because livestock production provides them with a source of revenue through the sale of animals.While more livestock can damage the quality of grassland resources and have negative impacts on animal growth household incomes over time (Li et al., 2018). Low income may lead some herders to expand their grazing into restricted grassland or increase their number of livestock (Zhen et al., 2014), which accelerates grassland degradation and damages regulating services and provision services. As grassland resources is limited, reducing stocking rates allows for greater overall productivity (Briske et al., 2015a; Kemp et al., 2013; Shang et al., 2014; Zhang et al., 2015).

Environmental income, that is, income that is derived directly from the collection of resources obtained from the environment (Cavendish, 2000), often consists of many different and sometimes irregularly collected resources. Diversification can reduce the risk of livelihood failure by spreading it across more than one income source (Armah et al., 2010). In developing countries rural households pursue a wide range of livelihood activities (Babulo et al., 2008), although distinct livelihood strategies can emerge especially in constrained environmental settings (van den Berg et al., 2010). Households make livelihood choices based on personal preference, local resource availability, and environment. Also, households pursue different livelihood strategies due to the differences in various types of capital (Nguyen et al., 2015). Higher levels of human capital, physical capital, and social capital can also allow better-off households to benefit more from environmental resource extraction.

Education, health condition, income and wealth are also correlated with the extent that farmers or herders depend on ecosystems for their livelihoods (Angelsen et al., 2014; Robinson et al., 2019). Households with more education have a better chance of securing well-paid jobs and working in the commercial and non-farm sectors (Soltani et al., 2012). Dependence on natural resources intensifies when households lose human and social capital (de Sherbinin et al., 2008). The share of income from environmental resources is higher for low income households than for wealthier households, although the latter derive more absolute income from environmental resources (Nguyen et al., 2015; Robinson et al., 2019). High dependence on natural resource extraction by the poor is often associated with asset poverty and lack of access to key markets (Barbier, 2010). Market accessibility is an important determining factor for households' choice of livelihoods. Households with limited access to financial capital are more likely to choose livestock-based livelihood strategies. Access to markets is a pre-requisite for selling commercial goods. With increasing distances, the required time for collecting forest products and grazing increases correspondingly (Soltani et al., 2012).

In reviewing the literature on ecosystem services, grassland degradation, and pastoral livelihoods, we see there are still gaps that remain to be understood about reliance on ecosystem services, especially in grassland and pastoral settings. Figure 2.1 presents a simple conceptual framework that shows the relationship between these aspects of pastoral resource systems. Boxes represent topics; arrows denote proposed positive (+) or negative (-) relationships between boxes. This thesis focuses on the topics and boxes outlined in bold in Figure 2.1, with chapters noted.

The overarching aim of the thesis is to develop a better understanding of how pastoral grazing livelihoods depend on local grassland resources from the perspective of grassland ecosystem usage and metabolic energy derived from herders' grasslands (as opposed to purchased forage from elsewhere). Chapter 3 first develops a simple metric of grassland dependence that can be estimated from easily collected data on livestock feed purchases and examine herding household grassland dependence vs market-purchased forage and fodder (denoted Ch 3a in Figure 2.1). In Chapter 3 I also statistically assess herders' decision-making strategies on local grassland and external market dependence in Inner Mongolia through fixed effect, mixed effect, and double hurdle models (denoted Ch 3b). In turn, Chapter 4 builds on the initial models of Chapter 3 and investigates the role of spatial structure and spatial variables with spatial Durbin, spatial error, and spatial autoregressive models. These address the issues of spatial interactions and spatial dependence. Understanding herders' decision-making strategies can help policymakers manage and conserve grassland, protect herder's interest, and alleviate poverty.



-:negative effect, +: positive effect

Figure 2.1 Conceptual framework of grazing livelihood systems

Chapter 3. Grassland dependence in Inner Mongolia: a household analysis with panel data

3.1 Introduction

The grassland ecosystem is considered as one of the most important common pool resources, occupying 26% of ice-free land surface in the and 42 % of landscape in China (Ren et al., 2018; Shu-hao and Zhong-chun, 2014). About 10% of the world's population relies on grassland directly for their livelihoods (Kemp et al., 2015). Herders share the use rights on grassland, which are commonly presumed to trigger a "tragedy of the commons" (Hardin, 1968; Gadgil et al. 1993; Yan et al. 2005). However, some argue that effective community management can be implemented by common pool resources users (Jeffery and Vira, 2001; Ostrom, 1999). This study aims to examine how herders make use of local grassland resources as they contribute to livelihoods through livestock production.

Intensification of human activities and climate change are the major factors that contribute to grassland degradation (Harris, 2010; Ho, 2000; Jun Li et al., 2007; Waldron and Longworth, 2010). Grassland degradation has become a global concern and about 20% of the grassland degraded globally. The grasslands in North China have been degrading for decades (Jiang et al., 2003). Privatization and top-down government control have been the dominant solutions to manage common pool resources in China. The Chinese government has implemented a series of policies to combat grassland degradation, for example long-term land rights contracts, policies that forbid grazing, rotational grazing programs, and fencing programs. Yet stocking rates are still high and degradation continues to be a concern for both herders and policy-makers (Ho, 2001; Jun Li et al., 2007; Kang et al., 2007).

Understanding how herders make decisions on grassland use can help overcome the gap between current policies and intense grazing activities and contribute to poverty alleviation and food security. Grassland degradation intensifies human-environment conflicts and changes local herders' livelihoods. Yet grasslands are also a vital source of livelihood to herders, providing important ecosystem services that underpin livestock production. Herders build their wealth through assets, specifically land and livestock (Kay et al., 2008). Restricted by long-term land leases, herders generally build their wealth through livestock and saving any profits from animal husbandry over time. With severe degradation and developing market economy, herders want to increase the number of livestock they hold because livestock production provides them with a source of revenue through the sale of animals (Kemp et al., 2011), even though more livestock can damage the quality of grassland resources and in the end have negative impacts on animal growth household incomes over time (Jun Li et al., 2007; David R Kemp et al., 2013; P. Li et al., 2018) . Low income may lead some herders to expand their grazing into restricted grassland or increase their number of livestock (Zhen et al., 2014), which accelerates grassland degradation and damages regulating services and provision services. As grassland resources are limited, appropriate stocking rates can allow for greater overall productivity and still make profits (Briske et al., 2015b; David R Kemp et al., 2013; Shang et al., 2014; Zhang et al., 2015)

In contrast to grasslands, there is considerable literature to guide analysis of dependence on forests and farms. Household forest dependence is commonly measured by forest income, including absolute forest income and relative forest income (Babulo et al., 2008; Mazumder, 2018; Zenteno et al., 2013). A few new approaches were proposed, although they have not been adopted widely. Rank of the importance of forest income or forest related strategy are used to indicate the extent of forest dependence (Elizabeth et al., 2018; Kimengsi et al., 2019; Ofoegbu et al., 2017).

A forest dependence index has been proposed that incorporates effort involved in forest product collection (Nerfa et al., 2020). As for farm dependence, some studies consider the share of agricultural income to household income where household strategies are classified based on multisource of income, including farm, off-farm, remittance, livestock husbandry and forest income (Alemu, 2012; Peng et al., 2017; Xu et al., 2019, 2015). Still, few studies examine dependence on local grassland ecosystems. Livelihood strategies have been classified by the share of livestock income, or even as part of farm income (Ding et al., 2018; Du et al., 2016). In these, stocking rate is used as a proxy for the extent of livestock impact on grassland, while with the implementation of grazing policies and wide use of market forage, bias can still exist when the goal is investigating actual dependence on grassland (Powell et al., 2010). In this study, I incorporate forage from markets and propose a new grassland dependence metric to fill the gap in grassland dependence measurement.

This paper aims to contribute to literature in several ways. This paper develops metric of *grassland dependence* to indicate the relative extent herders rely on grasslands (vs external forage) for livestock energy requirements. After developing this metric, I use a dataset with 1636 valid questionnaires obtained from sampling repeated households in 2010 and 2015 to examine household dependence on grassland. I first assess the external and internal drivers for whether herders completely rely on local natural grassland, and if not, the extent herders rely on markets. Then I build models to demonstrate how factors influence herders' decision-making strategies on resource usage. *Dependence* provides a new way to assess how grassland versus forage resources are used and help support future grassland management.

3.2 Materials and Methods

3.2.1 Study Area

Inner Mongolia Autonomous Region locates in the northern frontier of China and stretches 2,400 km from west to east and 1,700 km from north to south. The wide range and diverse topography form a complex and diverse climate pattern dominated by temperate continental monsoon climates. The annual precipitation decreases from 500 mm to 100 mm around from northeast to southwest, which simultaneously coupled with temperature shapes a graded grassland type pattern. There are 5 grassland types involved in this study, which are typical steppe, meadow steppe, sandy steppe, desert steppe and desert. From typical steppe to dessert, the annual precipitation decreases successively.

3.2.2 Data description

Households were selected by stratified random sampling in 15 counties in 2010 and 2015. Three counties were randomly selected for each grassland type that broadly exists in Inner Mongolia: meadow steppe, typical steppe, sandy steppe, dessert steppe, dessert, and then 3 towns (sumu) in each county were selected to represent the typical situation for each grassland type.

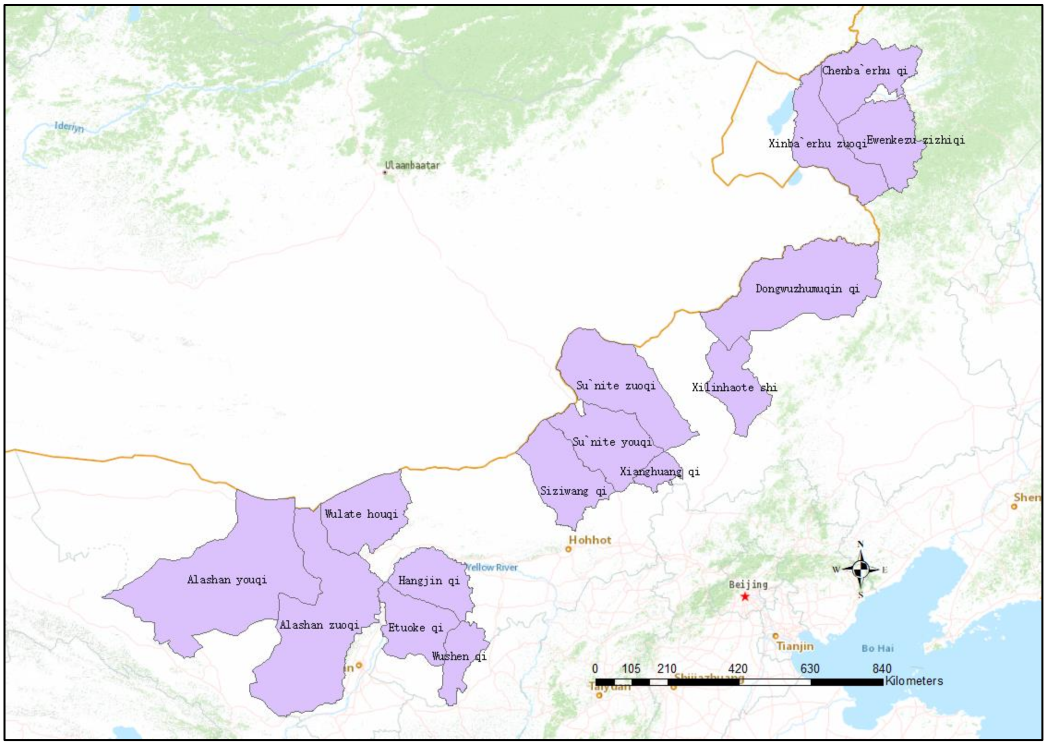


Figure 3.1 Study area in Inner Mongolia

Surveys were carried out in collaboration with Dr. Li Ping and Dr. Hou Xiangyang from the Grassland Research Institute of China Academy of Agricultural Sciences in Inner Mongolia Autonomous Region (IMAR), who conducted the initial 2010 survey. The study assessed characteristics of a household livelihood (demographics, jobs, unanticipated shocks, assets, income, etc.), land (grassland area, land for forage, rented in/out, etc.), and livestock characteristics to investigate the adaptation and management of herders. The survey was originally conducted to study the adaptation and management of northern grassland herders in the context of ecological compensation implementation. In 2015, Prof. Brian Robinson joined the team to design a follow-up survey repeated in the same households. In 2010, 861 households were surveyed and then 849 in 2015, leading to 1636 valid questionnaires after removing households with no livestock. I exclude households with unknown education level. Also, I remove households surveyed only in

2010 or 2015 when building fixed effect model and mixed effect model, leading to 1362 valid questionnaires for panel dataset models. In addition, I build OLS model for whole dataset with 1636 questionnaires.

3.2.3 Calculating grassland dependence

I define grassland dependence as the extent to which herders rely on grassland to meet their livestock's metabolic energy demand relative to forage or other purchased products that can be used to feed livestock. This allows me to examine how herders rely on markets versus rely on ecosystems services (via use of natural grassland) with easily obtainable data. Especially during winter months, modern livestock herd sizes may not be able to acquire enough energy from the natural grassland since not all grasses are digestible to livestock (Allden and Whittaker, 1970) and, in the ideal, at least 45% of the peak standing grass should be left to keep the grassland ecosystem healthy (Hocking and Mattick, 1993; Wijngaarden, 1985). This can make procuring or purchasing forage from external sources important.

Our general goal is to better understand the ecosystem services that come from the grassland. I assume livestock have two potential sources of energy: grass grazed from the grassland or forage/fodder that has been procured from the market. I cannot quantify the magnitude of natural grazing directly, so I estimate this as

$$D_{it} = 1 - U_{it} \qquad \text{(eq 1)}$$

where D_{it} is the percent that household *i*'s livestock herd depends on the grassland to meet its energy requirements at time *t*. We can calculate U_{it}, the relative contribution of purchased forage, from the data as

$$U_{it} = \frac{P_{it}}{Q_i}. \qquad \text{(eq 2)}$$

P_{it} is the purchased forage in equivalent standard hay units (kg of dry matter) and Q_i is the total forage required by household *i*'s herd in standard sheep units (SSU). Let us take examine the calculation of each of the right-hand side terms in turn.

First, P_{it} is the weighted average of all foraged purchased converted into standard dry matter hay equivalents, given in Table 3.1. I convert each forage type consumed to "standard hay" based on the embedded metabolic energy (ME) needs for sheep, net energy needs for lactating dairy cattle (NEL), and net energy needed for maintenance and weight gain for cattle (NEmf). We take the average energy ratio for each forage type and transform forage to a standard hay dry matter (DM) equivalent basis. Plant DM consists of all its constituents – carbohydrates, fats, proteins, vitamins, minerals, and antioxidants (e.g., thiocyanate, anthocyanin, and quercetin) – but excluding water. The conversion ratio (CR) for each forage type is its energy (MJ/kg) relative to standard hay.

Q_i is calculated as $SSU \times \frac{1.8\ kg}{day} \times \frac{0.92\ wet\ matter}{dry\ matter} \times 365\ days$, following the Chinese Sheep Feeding Standards (2005) total energy requirements. SSU is a standard sheep unit, defined as a female sheep with a body weight of 50 kg who requires 1.8 kg standard hay per day (see Appendix Table 2) (Chinese Sheep Feeding Standard, 2005). I did not include any forage sold by the households in the calculations here, but this was uncommon – only 10 households sell forage and comprises about 0.6% of our dataset.

Table 3.1 Forage energy for livestock and conversion ratio to standard hay

	Sheep (metabolic energy requirements)		Dairy (net energy for lactation)		Cattle (combine net energy)		Avg. CR	# of HH purchased
	MJ/kg DM	CR	MJ/kg DM	CR	MJ/kg DM	CR		
Hay	8.68[1,2]	1	5.57[1,3]	1	4.89[1,4]	1	1	837
Silage†	8.12[2]	0.94	4.98[3]	0.89	4.40[4]	0.90	0.91	132
Straw±	5.31[2] 4.80[2] 4.86[2]	0.60	4.22[3] 3.45[3]	0.72	2.81[4] 2.10[4] 2.18[4]	0.51	0.61	289
Grain	10.84[2,5] 12.29[2] 10.07[8]	1.33	6.78[5]	1.22	6.35[5]	1.30	1.28	992
Pellet‡	11.23[2,6] 10.73[2,6] 11.27[2,6]	1.28	6.81[7] 7.06[7] 6.84[7]	1.24	6.39[7] 5.25[7] 6.10[7]	1.21	1.24	663
Corn	11.67[2,5] 13.42[2] 10.69[8]	1.44	7.66[5] 8.10[3]	1.41	8.11[5] 9.12[4]	1.66	1.51	276

DM = dry matter
CR = conversion ratio
† Corn silage as is commonly used in Inner Mongolia(China's Ministry of Agriculture, 2005a, 2005b, 2005c).
± Includes an average of corn, wheat, straw, and corn straw, commonly used in Inner Mongolia(China's Ministry of Agriculture, 2005a, 2005b, 2005c).
‡ Pellets are composed of different kinds of materials. Therefore, pellet energy is calculated based on a standard feeding formula(China's Ministry of Agriculture, 2005a; Guo, 2002; Lv, 2015).

This approach has several advantages over other methods. McEniry et. al calculate rough grass Dry Matter Intake (DMI) at the country level with livestock and grassland biomass estimation directly (McEniry et al., 2012). Also, livestock intake can be estimated by field

1 (Liu et al., 2009)
2 (China's Ministry of Agriculture, 2005a)
3 (China's Ministry of Agriculture, 2005c)
4 (China's Ministry of Agriculture, 2005b)
5 (Chinese Feed Database, 2018)
6 (Guo, 2002)
7 (Lv, 2015)
8 (Ma, 2018)

experiments, but is time consuming and hard to apply on a regional scale (Rongzheng et al., 2016;Wurina, 2015). One common way to assess grassland available for livestock is through the use of remotely sensed imagery and estimates of NPP or NDVI (Xie et al., 2009; Zhang et al., 2016). However, aside from measurement error on its own, these measures only show the standing biomass on the landscape, making it impossible to separate the ecosystem service potential of the grassland (i.e., how much grass would be produced in an un-utilized state) and the ecosystem services utilized by herders (Congalton, 1991; Herrero et al., 2013; McEniry et al., 2012b).

3.2.4 Calculating a measure of socioeconomic status

I calculate an asset index as an indicator of a household's socioeconomic status, the wealth accumulation in each household. Principal component analysis is applied to reduce dimension and extract representative component (Filmer and Pritchett, 2001; Harttgen and Vollmer, 2013; Howe et al., 2008; Poirier et al., 2020). In this study, the asset index is constructed following Crook et al. (2020) by taking the first principle component from a principle components analysis with the number of passenger cars, motorcycles, mowers, tractors, wells, shed area, and the natural logarithm of the house area. PCA results and components for asset index are listed in Appendix Table 4 & 5.

3.2.5 Descriptive analysis

To look at how grassland dependence varies among our sample, I group households based on how much they rely on grasslands and summarize the household characteristics by group in Appendix Table 7. Variables of interest are listed in Appendix Table 1. I divide our sample into 6 groups: those in the lowest 20th percentile of grassland use, those in the 20-80th percentile of grassland use, those in the top 20th percentile of grassland users, those in the lowest 20th percentile of asset index, those in the 20-80th percentile of asset index, those in the top 20th percentile of asset index. I summarize household grassland dependence on local natural grassland for grazing, forage usage from markets, household size, householder education level including illiterate, primary school, middle school, high school and college or higher, household ethnic group (Mongol or Han), children under 16, elders above 60, household livestock stocking rate (livestock number in sheep unit per acre), number of shocks (drought, snowstorm, or locust outbreak) that occurred in last 5 years, laborers, grassland type including meadow steppe, typical steppe, desert steppe, sandy steppe and desert, asset index, distance to nearest city (km), distance to nearest road (km), household grassland-related subsidy (thousand RMB), grassland own area (mu), income from livestock (thousand RMB), and income from other sources (thousand RMB) to describe how household characteristics are different for high grassland dependent households and high market dependent groups. Shocks, number of laborers, distance to nearest city (km), distance to nearest road (km), grassland subsidy, and income from other sources are only surveyed in 2015.

3.2.6 Multiple variable analysis

Our interest is in understanding who has a preference for natural grassland and why some households purchase forage as supplement. Such insight could help policymakers manage grassland and protect herders' interest. Education, income and wealth may indicate the extent that farmers or herders depend on ecosystems for livelihood (Angelsen et al., 2014; Robinson et al., 2019). Households with more education have better chances of securing well-paid jobs and working in the commercial and non-farm sector (Soltani et al., 2012). High dependence on natural resource extraction by the poor is often associated with asset poverty and lack of access to key markets (Barbier, 2010). Family financial income is a key factor on deciding participating environmental programs (Y. Zhao et al., 2018). Herders with low levels of government-sponsored subsidies tend to have a high stocking rate (Yin et al., 2019). Household head age and ethnicity have been found to be related to herders' desirable stocking rate (Knight Lapinski et al., 2019;X. Hou et al.,2014).

With these lessons from past literature, the basic model I would ideally estimate is

$$D_i = \alpha + \boldsymbol{x_i \beta} + \varepsilon_i \qquad \text{(eq 3)}$$

where D_i represents dependence, the percent that household *i*'s livestock depend on natural grassland versus purchased forage and fodder. There are two fundamental changes we mut make to the model we estimate in practice due to data we have available. First, we do not observe grassland usage directly, so we must estimate grassland consumption as the difference in total livestock energy requirements less forage purchases per equation 1, $D_i = 1 – U_i$, where U_i, is the percent that household *i*'s livestock depend on purchased forage for their nutritional requirements. Second, estimates of dependence (and therefore utilization) are skewed, so I log-transform the dependent variable. Therefore, the model we are able to estimate is

$$ln(U_i) = \alpha + \boldsymbol{x_i \beta} + \varepsilon_i. \qquad \text{(eq 4)}$$

When interpreting our coefficient estimates, I must be sure to put these estimates in terms of D_i, not U_i, so I must back-transform our results. To do so, I recognize that $\ln(U_i) = \ln(1 - D_i)$. Interpretation of standard coefficient estimates with a log-transformed dependent variable is $\%\Delta y = 100 \cdot \left(e^{\beta_1} - 1\right)$, that is, for a unit change in *x*, we expect *y* to change by 100 times $\left(e^{\beta_1} - 1\right)$ percent. To recover our coefficient estimates to relate back to *dependence*, we have

$\%\Delta(1-U_i) = 100 \cdot (e^{\beta_1} - 1) \rightarrow \%\Delta(u) = -\left(100 \cdot (e^{\beta_1} - 1)\right)$. Interpretation of dependence given the data presented in regressions below is then: "for a unit change in x, we expect D_i to change by approximately $\left[-\left(100 \cdot (e^{\beta_1} - 1)\right)\right]$ percent."

Building on this basic framework, I estimate and compare four regression models to examine factors that relate to household dependence on grasslands as described in the following sections.

Model 1: simple OLS model

The basic ordinary least squares (OLS) model is as given in eq 5. The dependent variable is ln(U_i +0.001), x_i represents a vector of household and community factors pertaining to household *i* that affects forage utilization and therefore grassland dependence, β represents the coefficient to be estimated, α is the model intercept, and ε_i captures the residual error of the model. Independent variables x_i include household factors such as stocking rate in log-transform, square term of stocking rate in log-transform, head age, sex, ethnic group, laborers, members under 16 years old, members above 60 years old, education level, health, asset index, shocks non-grassland subsidy, grassland subsidy, income from other sources. Other community level factors include grassland type and county.

Model 2 & 3: Fixed effect and mixed effects model

The basic framework for a fixed effect and a simple mixed effects model with only a random intercept can both be represented by:

$$Y_{ik} = \alpha + \boldsymbol{x_{ik}\beta} + v_i + \varepsilon_{ik} \quad \text{(eq 5)}$$

where Y_{ik} is ln(U_i +0.001) for each case *i* in each group *k*. The vector x_{ik} represents the independent variables for household *i* within group *k* that effect household forage utilization and β represents the vector of coefficients. The linear household-level fixed effect or random intercept is v_i, and ε_{ik} captures the overall residual error of household *i* within group *k*. The independent variables in the vector x_{ik} for mixed effect model are stocking rate in log-transform, square term of stocking rate in log-transform, grassland type, head age, sex, ethnic group, laborers, the number of children, the number of elders, education level, grassland type, panel year (whether the observation was collected in 2015), health and asset index. For the fixed effect model, I only keep variables that change over time, which are stocking rate in log-transform, square term of stocking rate in log-transform, panel year and the number of laborers in a household.

Model 4: Double hurdle model

The double-hurdle model takes the form

$$y_{i1}^{*} = \omega_i' \alpha + v_i \quad \text{(eq 6)}$$

where the dependent variable can be described as

$$y_i = x_i' \beta + u_i \; if \; y_{i1}^{*} > 0 \quad \text{(eq 7)}$$

$$y_i = 0 \text{ otherwise.} \quad \text{(eq 8)}$$

In this setup, y_{i1}^{*} is a latent variable describing the household's decision to purchase forage from market, that is, whether household *i* decides to completely depend on grassland. The observed dependent variable (the extent households rely on outside markets) is y_i, and ω_i is a vector of variables explaining the decision on whether household completely depend on grassland, xi is a vector of variables explaining how households make use of forage. The terms v_i and u_i are the respective error terms. I evaluated the internal and external factors that influence the household decision on whether household started to purchase forage and how much they rely on grassland with Cragg's double-hurdle models. The model separates the decision-making strategy into 2 parts: 1) households decide not to completely depend on local grassland and 2) the extent households rely on local grassland.

3.3 Results

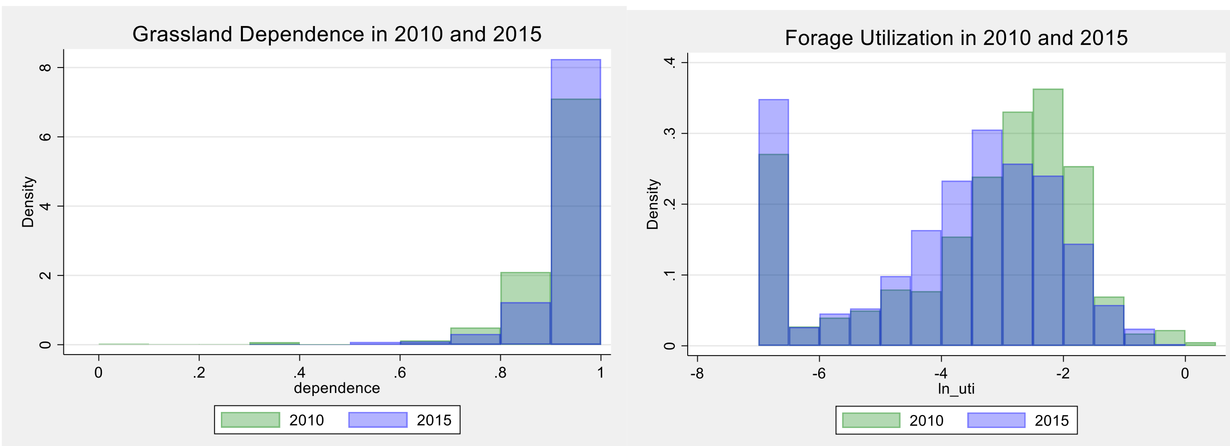


Figure 3.2 (a) Grassland dependence in 2010 and 2015; (b) Log of Forage utilization in 2010 and 2015

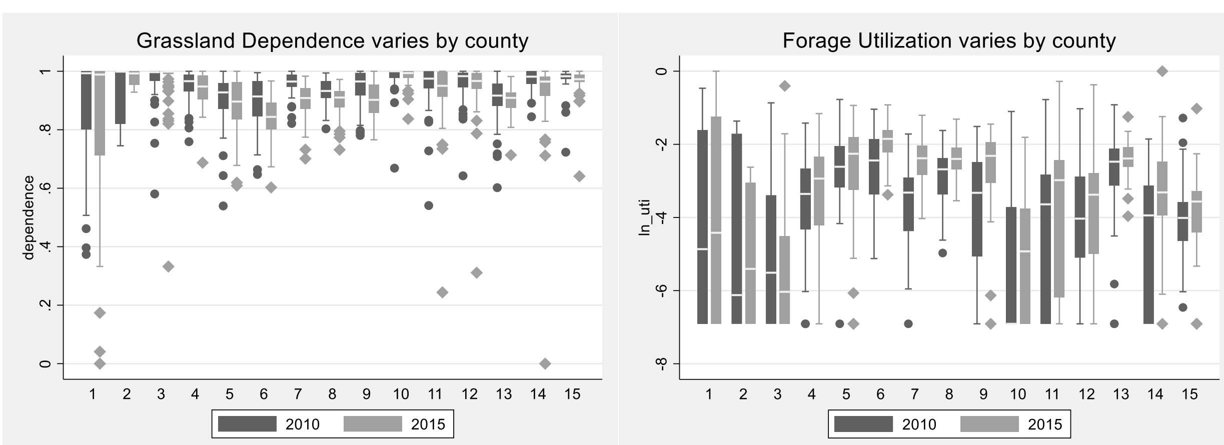


Figure 3.3 (a) Grassland dependence by county ID number; (b) Forage utilization varies by county ID number

The distribution of grassland dependence and forage utilization is presented in Figure 3.2 and variation by county, ordered from 1 to 15 by east to west (Appendix Table 3) which is roughly from humid to arid region, in Figure 3.2. Figure 3.2 shows how grassland dependence is distributed in 2010 and 2015 in both terms of dependence (Fig 3.2a) and the log of forage utilization (Fig 3.2b). D_i is more clustered more toward values of 1 (full dependence on natural grassland) and has greater variance in 2015. Figure 3.3a shows dependence roughly increases from east to west, and is relatively low in Wushen, Hangjin and Etuoke (County 10-12). Average dependence D_i in 2015 is lower compared to that in 2010 in most counties, except Xinzuoqi (County 3).

3.3.1 Descriptive analysis

How household characteristics, grassland type and family income vary between groups by D_i, groups by wealth and between 2010 and 2015 are given in Appendix Table 1 (though shocks, laborers, grassland type, household grassland-related subsidy (thousand RMB), and income from off-farm sources (thousand RMB) are only surveyed in the 2015 wave). The values of U_i and D_i were estimated for 1636 households. The high (top 20th percentile), mid (20-80th percentile), and low (bottom 20th percentile) D_i groups are broken up at 0.995 and 0.87, including 328, 981 and 327 observations for each group. The average stocking rate varies from 1.30 to 0.88 in three D_i groups. The average shocks number occurred between 2009 and 2014 is 1.38 in high D_i group and increases to 2.44 in relatively low D_i group. The average household asset index is 1.58 in high group, 1.04 in mid D_i group, and 0.99 in relatively low D_i group.The average household grassland area is 5986 mu in high D_i group,9640 mu in mid D_i group and 5697 mu in low D_i group.The average household livestock income varies from 118,658 RMB in high D_i group to 91915 in low D_i group.

Households are characterized by asset index that ranges from -0.38 and 2.23, including 328 observations in wealthy group, 981 in middle group and 327 in poorest group. The average household size varies from 3.47 in poorest group to 4.26 in wealthy group and average household children varies from 0.50 in poorest group to 0.66 in wealthy group. Average stocking rate is 0.75 in poorest households, 1.04 in middle households, and 1.38 in wealthy households. The average shocks household suffered is 2.34 and 1.93 in poorest and middle group and decreases to 1.38 in wealthy group. Average household grassland area varies from 6128 mu in poorest group to 11814 mu in wealthy group, which is consistent with average household grassland subsidy change, varying from 7,145 RMB in poorest group to 11,121 RMB in wealthy group. Average household livestock income is 58,144 RMB in poorest group, 95,007 in middle group and 186,706 in wealthy group. The household average elder number is 0.33 in 2009 and increases to 0.44 in 2014. The average laborers number increases from 2.29 in 2009 to 2.82 in 2014 and household asset index increases from 0.97 to 1.30.

3.3.2 Inferential statistics

Moving from the descriptive analysis to inferential statistics, I compare several regression models in to better understand what factors are associated with grassland dependence. Table 3.2 shows determinants of grassland dependence (D_i) interpreted from U_i. The original results of models on U_i in log-transform is shown in Appendix Table 8. Log-transformed stocking rate in is positively related to grassland local dependence in fixed effect and mixed effect model, while the square term of stocking rate is not significant in any model. Age is negatively related to D_i in OLS model for both years and positively related to in OLS model for 2015. The number of elder residents is not significant in any models, but number of children are positively associated with D_i in OLS model for 2015 and mixed effect model. Mongol herders are more likely to depend on grassland. D_i for Han herders will decrease by around 38-56% in OLS models and mixed effect model. Households with more laborers are positively correlated with dependence on grassland. Households that suffer from droughts seem to purchase more forage – an additional drought in past five years decrease D_i by around 10% in OLS model for 2015. Animal disease is negatively associated with D_i. An occurrence of animal disease makes D_i decrease by 29% in OLS model. Longer distance to city is positively related to grassland local dependence. Finally, an increase in government-sponsored grassland subsidy of 1,000 RMB is associated with an increase in D_i of around 0.80%. Overall, AIC and BIC results put weight on fixed effects. In addition, the variable for panel year is significant, so the effects across time period should be considered.

Table 3.2 Determinants of Grassland Dependence Interpreted from utilization

Variable \ Model		OLS_hh	OLS_15	FE	ME
ln (stocking rate)		10.147**	7.873	15.295***	11.308***
ln^2(stocking rate)		-8.546***	-8.329***	-3.977***	-5.760***
Age		1.094**	1.292**		0.499
Sex		-0.100	-12.637		-9.856
Ethnic group (Mongol-0, Han-1)		-37.851***	-56.205***		-55.426***
Laborers		11.041***	13.757***	8.515**	11.397***
Children		9.244*	12.541*		8.154*
Elder		3.149	0.399		5.635
Asset index		-3.149	0.100		3.439
Household max education (ref: illiterate)					
Primary school		-21.288	-28.531		-12.412
Middle school		0.200	3.343		-15.835
High school		8.881	13.671		-19.856
College or higher		21.494	16.723		-17.939
Grassland Type (ref: meadow steppe)					
Typical		-1005.630***	-841.214***		-451.240***
Desert steppe		-252.190***	-408.859***		-450.689***
Sandy steppe		-94.255**	-26.238**		-8.546
Desert		-46.815	-31.653		-180.667***
Shocks	Drought		-8.981**		
	Snowstorm		6.574		
	Locust		0.200		
Sandstorm			2.176		
Other disaster			-5.127		
Animal disease			-29.305*		
Distance to city (km)			0.200*		
Distance to road (km)			0.599		
Non-grassland subsidy (‘000 RMB)			-1.106		
Grassland subsidy (‘000 RMB)			0.797**		
Other income (‘000 RMB)			0.000		
Health			-7.896		
Year (2015)		-87.949***		-27.252***	-36.438***
constant		0.986***	0.956***	0.967***	0.986***
Obs.		1636	804	1362	1362

*** $p < 0.01$, ** $p < 0.05$, * $p < 0.10$

Table 3.3 shows results of double hurdle model for i) model only for 2014 and ii) model with panel data that estimates the impact of household characteristics, grassland type and family income on D_i interpreted from U_i. The original results in terms of U_i are shown in Appendix Table 9. We can see stocking rate is positively associated with D_i in the second stage of double hurdle model, while the square term of stocking rate in log-transform is negatively related to D_i in first stage of double hurdle model for both years and in second stage of both double hurdle models. Number of laborers is positively related to D_i for both stages at 95% confidence level. Living on typical steppe, desert steppe, and desert are positively related to forage uptake compared to meadow steppe. In addition, households located on desert steppe is negatively related to D_i after forage uptake, while households on sandy steppe are positively associated with depending on local grassland for feeding. Drought is positively related to U_i at 99% confidence level in second stage, indicating households suffered more droughts tend to purchase forage from markets once they started to. The amount of income from other sources is positively associated with D_i in first stage and negatively related to grassland local dependence after forage uptake. After forage uptake, grassland-livestock balance subsidy and forbidden grazing subsidy are positively related to grassland local dependence. For an increase of 1,000 RMB subsidy, the household local grassland dependence will increase by approximately 1.784% and 0.995%.

Table 3.3 Determinants of how households depend on grassland via double-hurdle models

		Does the household completely depend on grassland? (stage 1, probit)		How much households rely on grassland? (stage 2, lognormal)	
Grassland dependence (D_i)		i)	ii)	i)	ii)
ln (stocking rate)		1.784	3.729	11.041**	9.787***
ln (stocking rate^2)		-4.185	-4.769**	-3.977***	-5.443***
Age		0.499	0.300	0.598	0.300
Sex		-15.720	9.607	-11.851	-18.057
Ethnic group		-15.142	-5.971	-56.049***	-49.033***
Laborers		15.549**	6.012	9.244**	9.697***
Children		14.015	0.995	8.698	12.366***
Elder		-3.355	-1.005	1.390	8.789*
Asset index		-4.603	-5.443***	6.293***	5.257***
Household max education (ref: illiterate)					
Primary school		-63.558	-31.917	-15.604	-2.634
Middle school		-29.823	-13.428	-8.329	-5.338
High school		-19.722	-3.977	-12.975	-11.851
College or higher		-110.434	-83.859	23.586	36.173
Grassland Type (ref: meadow steppe)					
Typical steppe		-506.176***	-507.997***	-116.193***	-100.171
Desert steppe		-1065.479***	-429.626***	-122.777***	-56.205***
Sandy steppe		-60.641**	-45.354***	32.632**	9.968***
Desert		-542.374***	-308.777***	-17.117	4.591
Shocks	Drought	-6.396		-11.187***	
	Snowstorm	12.366		2.566	
	Locust	0.300		0.100	
Sandstorm		-2840.016		-1.715	
Other disaster		-3423.359		-5.760	
Animal disease		-77.891**		-2.634	
Distance to city (km)		0.100		0.300***	
Distance to road (km)		-0.200		-0.200	
Non-grassland subsidy		-3.149		0.399	
Income from other sources (‘000 RMB)		0.100*		-0.100**	
Amount of forbidden grazing subsidy (‘000 RMB)		0.200		0.995***	
Amount of grass-livestock balance subsidy (‘000 RMB)		-1.511		1.784***	
Health		-7.251		-8.112	
Panel year (2015)			-38.680***		-57.933***
_cons		0.999***	1.000***	0.931***	0.959***
ln (sigma)				0.050*	0.088***
Obs.		804	1636	804	1636

*** $p < 0.01$, ** $p < 0.05$, * $p < 0.10$

Across all the models presented above, when comparing the results of double hurdle model, fixed effect model, and mixed effect model above, stocking rate is significant among all models. Stocking rate is positively related to grassland dependence, while the square term of stocking rate in log-transform is negatively related to D_i, suggesting a non-linear relationship between stocking rate and grassland dependence. Ethnic group, grassland type, and children are significant both in mixed effect model and the second stage of double hurdle model. Additionally, asset index is not significant in OLS models or mixed effect model, while it is significant in double hurdle models. Number of laborers is positively related to grassland local dependence in three models. Considering the base assumptions of the models, I am cautious to trust the results of the fixed effect model since in our dataset zeroes occupy about 15% of the independent variable. Thus, the double hurdle model provides a more theoretically proper way to cope with zeroes in the model and thus determine the impact factors on grassland local dependence.

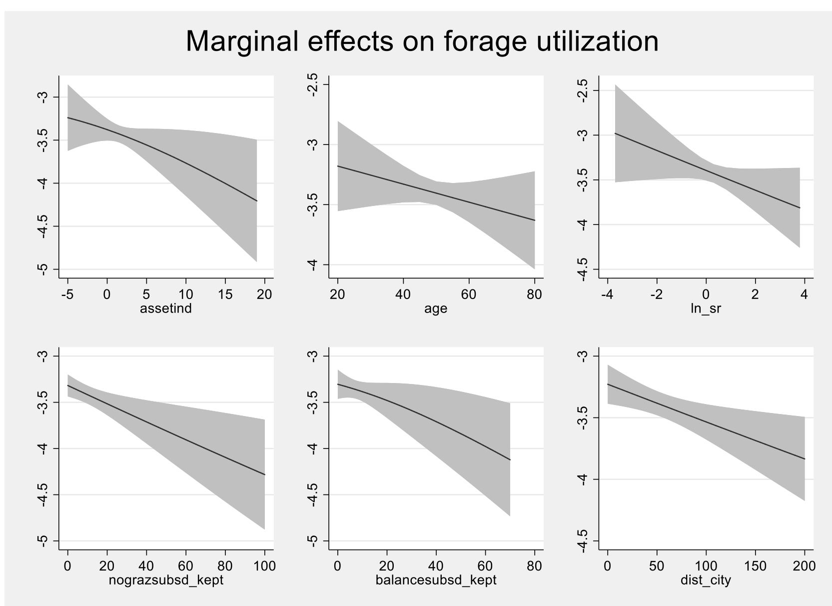


Figure 3.6 Marginal effects of variables of interest in double hurdle model

The marginal effects of several factors of interest from the double hurdle model are shown in Figure 3.6 and Appendix Table 10. Marginal effects consider the impact of an independent variable on an "average" household, i.e., holding all other factors at their average values. The marginal effects of household wealth (indicated by asset index), head age, amount of forbidden grazing subsidy kept in the household (thousand RMB), the amount of grass-livestock balance subsidy kept in the household (thousand RMB), and distance to the nearest city(km) all show a negative and sometimes slightly non-linear relationship with forage utilization, consistent with results obtained from models above.

3.4 Discussion

I provide a relative estimation on local grassland dependence for grazing and interpret the results of understanding who is dependent on local grassland for grazing livelihood. In this study, I found humid grassland type, poor households with more laborers, and more income from other sources and households did not suffer from animal disease indicate a preference on completely depending on grassland. While further distance to nearest city, less droughts, less "other" income and wealthier Mongol households with more laborers and higher stocking rate are associated with depending more on grassland to sustain grazing livelihood once they decided to purchase forage from markets.

3.4.1 Impact of shocks on grassland local dependence

Droughts limit the use of grassland for grazing in summer-the growing season. As livestock don't gain enough weight in summer will lose out in markets and be sold at low prices, most herders will first purchase forage as a supplement rather than leave it and sell directly. Therefore, the dependence on local grassland for grazing will increase significantly and the forage cost increases correspondingly to alleviate the impact of droughts, which is consistent with previous findings from Crook et al., 2020. Crook et al. also found different from droughts, snowstorms are rapid and hardly anticipated with intense effects on livestock, making it difficult for herders to adapt to. However, in the models examined here, the number of snowstorms suffered in past five years is not significantly related to grassland dependence in any of the models. Still, our dependent variables are not the same and the models we test are very different.

3.4.2 Individual decision-making effects

High socioeconomic status (indicated by asset index) is related to forage uptake. Wealthier households are able to purchase forage as supplementary to livestock for higher production or to deal with unexpected instances. It seems wealthy households do not need to invest as much time and effort in purchasing and transporting forage since wealthy households often holds diversified income sources or opportunities. This is consistent with the findings that a higher asset index is often associated with lower relative dependence on natural resources for household livelihood, while absolute income can be high for wealthy households compared to poor households (Robinson et al., 2019; Charley et al., 2015; Angelson et al., 2014). Further, households with more income from other sources are more capable to afford forage from markets for feeding after forage uptake. This could be because income from other sources is part of disposable income and can be spent more flexibly.

Market access often depend on distance to markets, transportations and available infrastructures, so here I use distance from households to the nearest city and nearest road reported by the households as market access indicators (Godde et al. 2018). Market access relates to forage supply. Households with similar characteristics otherwise, the better market access they have, the easier households buy forage with less time and efforts spent on transportation. In remote areas, market access relates to high labor costs as well, which possibly increases the investment on forage transporting. However, market access affects selling and buying livestock at the same time, which may have then neutral net effects on household income and wealth.

High stocking rate is related to local grassland dependence for feeding, while the square term of stocking rate in log transform is negatively associated with grassland dependence, suggesting a non-linear relationship between stocking rate and D_i. When the stocking rate increases first, dependence will increase. After the dependence reaches certain level, when stocking rate keeps increasing, the dependence does not change much. The more stocking rate increases, the less it affects dependence. Laborers are positively related to local grassland for grazing, which is household with more laborers seem to depend on local grassland rather than purchasing forage. These findings are a bit counterintuitive, and further investigation is shown in Chapter 4.

3.4.3 Policy

Two main grassland-related subsidies are involved in this survey: forbidden grazing subsidy and grassland and livestock balance subsidy. I use the amount of each subsidy obtained by the household as indicator for each policy subsidy. Grass-livestock balance subsidy and forbidden grazing subsidy have positive effects on household grassland local dependence. Overall grassland subsidy in the OLS model has a positive effect on household grassland local dependence for grazing and decreases household utilization for forage from markets, indicating that grassland-related subsidies are taking effect.

There are two possible ways D_i could increase as suggested by my results. First, under the effect of policy restrictions and compensation, if households reduce the amount of livestock and purchase less forage, then D_i will increase. Second, household simply choose to rely on local natural grassland instead of purchasing forage from markets. After checking the effect of subsidies on stocking rate, I found subsidies are negatively related to stocking rate, which is consistent with the findings that herders with lower subsidy levels tend to grazing in high stocking rate (Yin et al., 2019). Therefore, I have a preference on the first explanation that households reduce the amount of livestock after receiving subsidies and increase D_i. Nevertheless, this finding seems to be inconsistent with the conclusion that dependence on forage from markets for feeding increases with grazing restrictions (Dong et al., 2007). A possible reason is that the conclusion above was provided that the livestock numbers remain unchanged. Coupled with the reduction of livestock numbers, the increase of forage from markets for feeding is not significant and finally shows increase on D_i. Besides, the impact of subsidies on grazing intensity is mixed in Inner Mongolia (Byrne et al., 2020; Gao et al., 2016). In certain areas, subsidies may be included as part of their financial capital for livestock expansion. Still, we need to be cautious on examining the relationship between policy and D_i. Since data on subsidies, shocks and income are not reported on 2010, we can't observe dynamic changes and the impact on panel data.

3.5 Conclusions

D_i indicates the extent that herders depend on local grassland for feeding livestock under the impact of internal and external factors, which provides an analytical direction from both livelihood and ecological perspectives. D_i provides a relative estimation on household local grassland dependence for feeding and thus can observe the changes of herders' subjective intentions on local grassland use for grazing other than income-based methods or remote sensing. D_i estimation requires main forage energy per unit which is easily obtained in Feeding Standard and another self-reported variable required is livestock number, making this indicator easily calculated and indicate relative extent of dependence on local grassland for grazing in regional scale. In this study, I examine herder's local grassland dependence for grazing livelihood with OLS, fixed effect, mixed effect and double hurdle model. Each model has own advantages. Fixed effect model and mixed effect model allow to examine grassland dependence with the consideration of time series. Double hurdle model takes the effect of a large amounts of zeroes in dependent variable into account, so we can look at whether households completely depend on local grassland and how they make use of grassland if herders started to purchase forage from markets.

As anthropogenic activities and climate change have resulted in severe grassland degradation and desertification, the Chinese Government has implemented several policies regarding reducing grazing intensity and thus cope with grassland degradation. The eco-compensation subsidy policies are found effective in many regions but required to increase eco-compensation subsidies as well (Byrne et al., 2020; Gao et al., 2016; Yin et al., 2019). There is an urgent need for the government to develop effective policies to secure the livelihoods of herders while addressing grassland degradation. Grassland management should be a "community responsibility" like local government, rather than pinning hopes on individual families (Taylor, 2012). Currently, it's important to understand how herders respond to policy changes and make decisions on grassland use to support for poverty alleviation and grassland conservation. In the next chapter, I turn to a spatial analysis of grassland dependence. I incorporate spatial interactions to statistical models to examine how spatial effects impact on local grassland dependence.

Chapter 4. A spatial analysis of grassland dependence in Inner Mongolia

4.1 Introduction

Human society and globally interconnected economies depend on ecosystem services and support. Grassland ecosystems, as an essential part of the terrestrial ecosystem, occupy 40% of occupied land. These ecosystems provide services such as net primary production, maintenance of biodiversity, sandstorm prevention, and water and soil retention. People live on the grassland graze livestock to sustain their livelihoods. Meanwhile, grassland degradation has become a global concern. Grassland ecosystems in Inner Mongolia are relatively fragile and sensitive to climate change and anthropogenic activities due to poor soil and low vegetation cover (Lioubimtseva and Henebry 2009; Huang et al. 2016; Seddon et al. 2016). Overgrazing is considered one the main causes of grassland degradation (Teague and Dowhower 2003; Hua and Squires 2015). Grazing pressure may reduce grassland biomass and have long-term effects on vegetation communities (Laycock 1991; Y. Y. Liu et al. 2013). The increasing effects of climate change and human activities impact herders who rely on healthy pastures for livelihood. Grassland degradation threats sustainable development and poverty reduction (Nkonya, Mirzabaev, and von Braun 2015).

Current analysis of how much households depend on grasslands is limited, especially considering the impact of spatial interaction effects (Januardi and Utomo, 2017; Powell et al., 2010). Household dependence is measured by family absolute income and relative income (Babulo et al., 2008; Mazumder, 2018; Zenteno et al., 2013). Household strategies are classified by multisource of income, while few studies examine dependence on local grassland ecosystems (Alemu, 2012; Peng et al., 2017; Xu et al., 2019, 2015). Grazing livelihood strategies are classified by the share of share of livestock in household income (Ding et al., 2018; Du et al., 2016). Some new methods were proposed, but they were not widely used. Rank of the importance of income or related strategy are used to indicate the extent of dependence (Elizabeth et al., 2018; Kimengsi et al., 2019; Ofoegbu et al., 2017). Efforts involved in product collection are incorporated to examine dependence (Nerfa et al., 2020). Stocking rate is used to measure the extent livestock impact on grassland, while with the implementation of grazing policies and widely use of market forage, bias exists on revealing the actual dependence on grassland for households (Powell et al., 2010). I incorporate forage from markets and propose dependence to fill gap in grassland dependence measurement.

In traditional livelihood analyses, including those that use statistical models, geospatial nuances are often ignored which can lead to underestimation of errors (Anselin, 2001). Spatial models contain explicit spatial factors or spatial structural features, which are used to express the interactions and interaction effects between spatial units. Data collected spatially often exhibits dependence on neighboring areas, that is observations may aggregate and become more similar or less similar compared to observations far away (Al-Momani et al., 2017; Tobler, 1970). Although traditional variable coefficient models can reflect heterogeneity, due to the interdependence and interactions between spatial units, variable coefficient models consider spatial heterogeneity not purely within the region itself, but also differences caused by the influence of neighboring regions on the region.

This paper develops spatial models based on *grassland dependence* proposed in Chapter 3 to analyze the impacts of variables of interest on local grassland dependence for grazing considering spatial interaction effects. In Chapter 3, I found counties and grassland type are significant indicating spatial effects should be incorporated. I use a panel dataset of 481 households with data collected in 2010 and 2015 to examine household dependence on grassland. In this chapter, I include spatial data (household location and growing season Net Primary Productivity

(NPP) and utilize spatial statistical models. The spatial models take impact of surrounding areas into account and therefore provide a more nuanced understanding on *grassland dependence* and herders decision-making on local grassland use.

4.2 Methods

4.2.1 Study Area

Inner Mongolia Autonomous Region is a region locates in the northern frontier of China and stretches 2,400 km from west to east and 1,700 km from north to south. Figure 4.1 shows the map of Inner Mongolia. The wide range and diverse topography form a complex and diverse climate pattern dominated by temperate continental monsoon climates. The annual precipitation decreases from 500 mm to 100 mm around from northeast to southwest, which simultaneously coupled with temperature shapes a graded grassland type pattern. There are 5 grassland types involved in this study – typical steppe, meadow steppe, sandy steppe, desert steppe and desert. From typical steppe to dessert, the annual precipitation decreases successively.

Figure 4.1 Location of Inner Mongolia, China (source: Google Earth)

4.2.2 Data description

Households were selected by stratified random sampling in 15 counties in 2015 and 2010. Three counties were randomly selected for each grassland type that broadly exists in Inner Mongolia: meadow steppe, typical steppe, sandy steppe, dessert steppe, dessert. Three towns (called sumu) in each county to represent the typical situation for each grassland type. Surveys were carried out in collaboration with the Grassland Research Institute of China Academy of Agricultural Sciences in Inner Mongolia Autonomous Region (IMAR) to collect data on characteristics of a household livelihood (demographics, jobs, unanticipated shocks, assets, income, etc.) land (grassland area, land for forage, rented in/out, etc.) and livestock characteristics to investigate the adaptation and management of herders. In total, 849 households were surveyed in 2015 and 861 in 2010. Importantly, only 481 households comprise complete panel data from both interview years *and* have location records. The core variables of interest are listed in Table 4.1.

May to September are the growing season in Inner Mongolia grasslands. Net primary productivity (NPP) (g/m^2y) is one of the most important indicators to ecosystem vitality and reflects local forage availability directly. The NPP (g/m^2yr) data was obtained from dataset developed by Chinese Academy of Sciences (Chen, 2019). This NPP dataset was developed by Carnegie-Ames-Stanford Approach (CASA) model based on monthly meteorological records and MODIS and AVHRR remote sensing images with 1 km resolution. Also, average NPP data was calculated in ArcGIS 10.7.1 and extracted for different households for the growing season (May-September). Figure 4.2 and Figure 4.3 show the distribution of household dependence, as developed in the Chapter 3, and NPP in 2009 and 2014 across the study area.

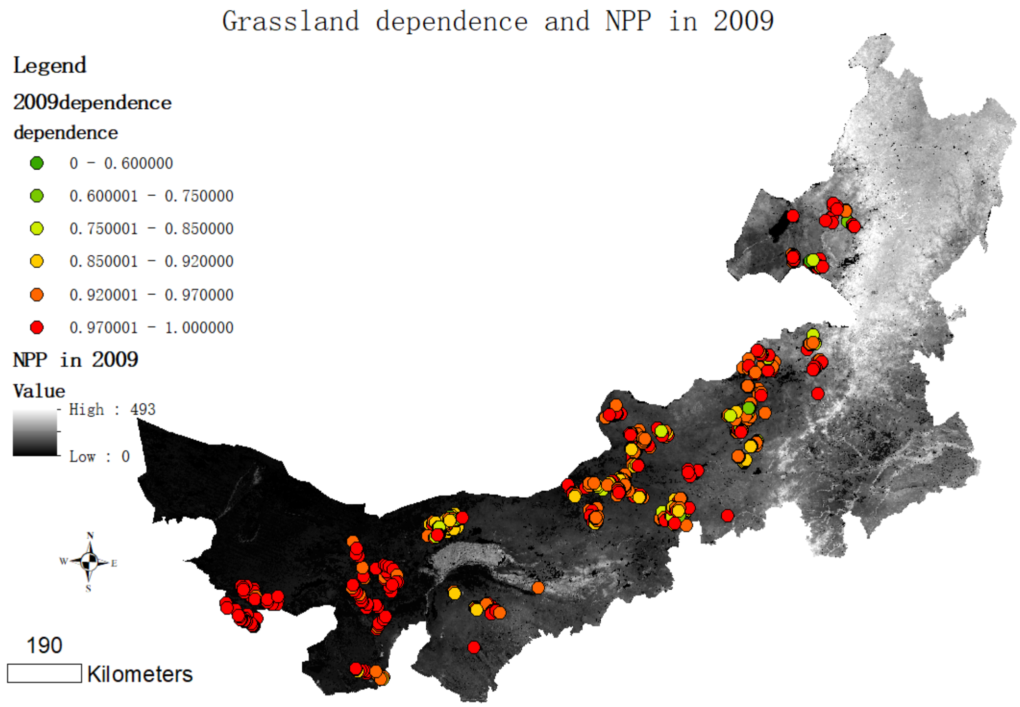


Figure 4.2 Grassland dependence and NPP in 2009

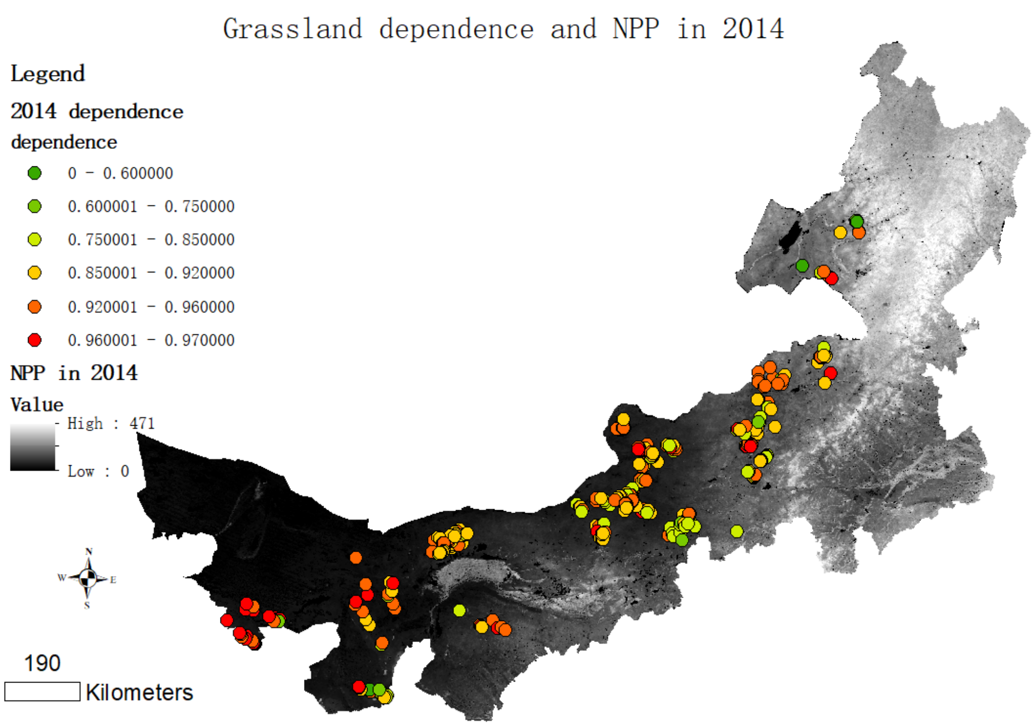


Figure 4.3 Grassland dependence and NPP in 2014

Table 4.1 Variable description

Variable	Description
ln_uti	Household forage utilization in log-transform
laborers	Number of laborers in the household
ln_ani	Amount of total livestock in standard sheep unit in log transform
ln_sr	Stocking rate (number of livestock in standard sheep unit per hectare) in log
lnsr2	Square of Stocking rate in log transform
lnnpp	Net Primary productivity ($g/m^2 \cdot year$) in log transform

4.2.3 Spatial analysis

My goal is to better understand what factors influence households' reliance on grasslands for their livelihood. To do so, I calculate the global Moran's I values for on grassland dependence to evaluate the existence of spatial autocorrelation in this dataset. Then I conduct local Moran's I to examine spatial association of grassland local dependence for individual households. Local Moran's I results in whether a household falls into a High-High or Low-Low cluster, which indicates households with high dependency values or low values of dependence are clustered spatially. Households may also be identified as a High-Low (or Low-High) outlier, which suggests the observation is a high-valued (low-valued) outlier among their neighboring low-valued (high-valued) observations. Then I use a Generalized Nesting Spatial model (GNS) as a starting point, which incorporates standard spatial lag, spatial error, and spatial Durbin models. The GNS can thus be easily transformed to other widely used spatial models (Elhorst, 2010; Halleck Vega and Elhorst, 2015). The GNS model takes the form:

$$Y = \rho WY + \alpha I + X\beta + WX\delta + \mu \quad \text{(eq 9)}$$

where the error term can be expanded to:

$$\mu = \lambda W\mu + \varepsilon. \quad \text{(eq 10)}$$

Here Y is the dependent variable matrix and X is the independent variable matrix. The dependent variable here is grassland dependence, and the independent variables are number of laborers in the household, amount of total livestock in standard sheep unit, stocking rate and Net Primary productivity (g/m2-y). W is nonnegative $N \times N$ row standardized spatial weights matrix. So, WY is the endogenous interaction effects of dependent variable and WX is the exogeneous interaction effects of independent. The variables ρ, α, β, λ, δ are the corresponding regression coefficients. I represents a column vector with element 1. $W\mu$ is the interaction effects among the disturbance terms of the spatial observations. From GNS model, if δ=0 and λ=0, the model becomes Spatial Autoregressive model (SAR) which represents the variation of dependent variable is affected by dependent variables in surrounding area. If λ=0, then the model is Spatial Durbin model (SDM) with exogeneous and endogenous interaction effects. If ρ=0 and δ=0, the model will be Spatial Error model (SEM), which assumes exogeneous interaction effects and endogenous interaction effects are in omitted variables with only spatial autocorrelation error terms. If δ, λ and ρ are zero, then the model is Ordinary Least Squares model (OLS). However, GNS is not typically used in an applied way. As GNS incorporates exogeneous, endogenous and disturbance terms interaction effects, the parameters are unidentified (Elhorst, 2010).

Considering the panel form of dataset, the model is transformed as follows.

$$Y_{it} = \rho \sum_{j=1}^{N} Y_{it} W_{ij} + \alpha I + X_{it}\beta + \sum_{j=1}^{N} X_{it} W_{ij}\delta + \mu_i \quad \text{t=1,2; i=1,2...N} \quad \text{(eq 11)}$$

Where W_{ij} is the element in the weight matrix. Y_{it} refers to the dependent variable of the space unit i at time t. X_{it} is the independent variable of $Nt_{max} \times K$. K is the number of independent variables. I applied fixed effect and random effect to SDM, SEM and SAR model. In this study, Y is ln (U_i +0.001) for each household.

As a starting point, I aim to use the same models as proposed in Chapter 3, but now include and control for spatial interactions to investigate the influence of space on grassland dependence. However, given the differences in model assumptions and data needs, the final spatial models included here are more parsimonious than those in Chapter 3. For example, since I use spatial models that incorporate panel methods, I exclude variables that do not change from 2010 to 2015, like the non-spatial models in Chapter 3.

The following independent variables are included in the spatial models: the number of laborers in each household, mean NPP in growing season in 2014, total livestock number (in standard sheep units), stoking rate in log transform and square term of stocking rate in log transform. The square term of stocking rate in log transform here is to check if there's non-linear relationship between grassland local dependence and stocking rate. Variance Inflation Factor test (VIF test) is applied to check for variable multicollinearity. Figure 4.6 shows correlation of independent variables. I applied a likelihood ratio test (LR test) and Lagrange multiplier test (LM test) to SAR, SEM and SDM to decide if SDM should degenerate to SAR and SEM and which model performs better. If the LR test rejects null hypothesis, then models should be simplified. LM test and robust LM test are used to examine spatial lag term and spatial error term. If LM test or robust LM test rejects null hypothesis, then the tested spatial lag/ spatial error should be incorporated to the spatial model. The results show that SDM cannot simplify to SEM or SAR. Then I applied Hausman test to help determine differences in fit between random effect and fixed effect models.

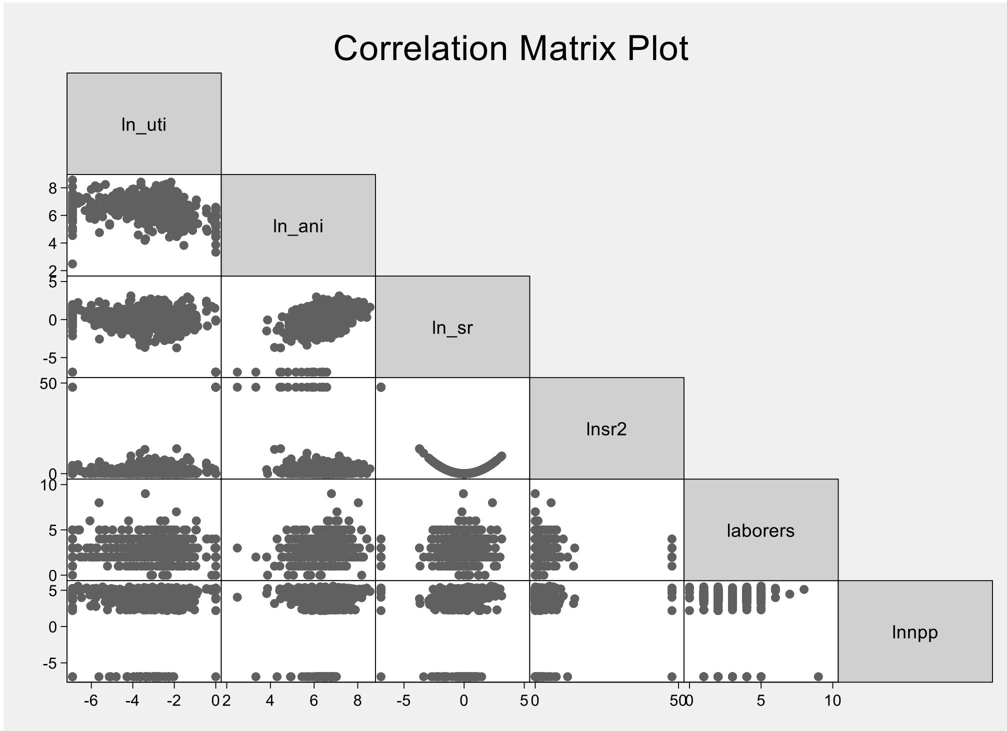


Figure 4.6 Correlation matrix plot

4.3 Results

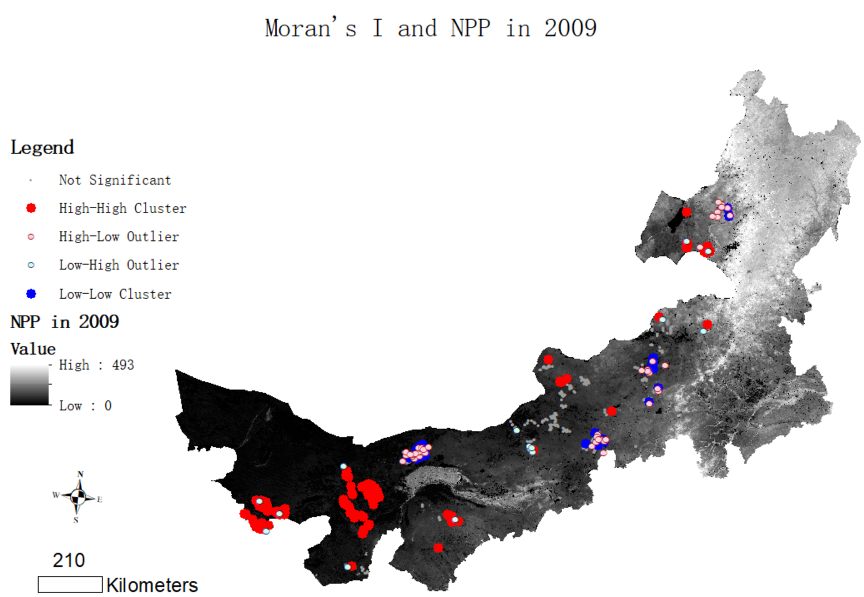


Figure 4.4 Local Moran's I and NPP in 2009

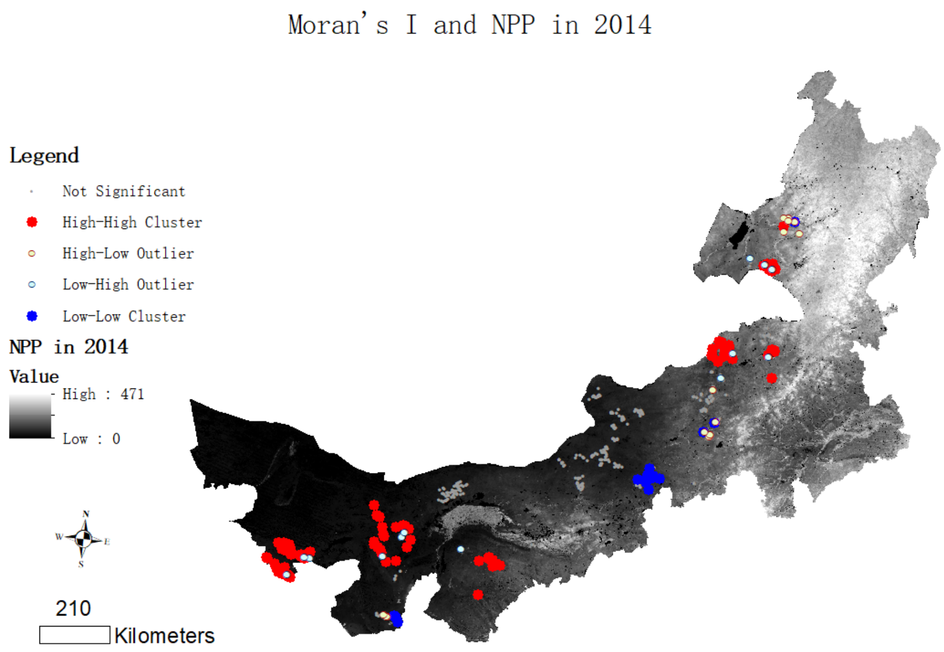


Figure 4.5 Local Moran's I and NPP in 2014

The Global Moran's I index is 0.3754 (z-score is 15.8716 and p-value is <0.0001) in 2010 and 0.3932 (z-score is 15.7804 and p-value is <0.0001) in 2015, indicating a significant positive spatial autocorrelation in study area and similar observations aggregates. Figure 4.4 and Figure 4.5 show local Moran's I clusters and NPP in growing season across study area in 2009 and 2014. In 2009, high dependence households cluster in western part of IMRA (Alashan youqi, Alashan zuoqi and Hangjinqi) with relatively low NPP, and low dependence household clusters are distributed in Wulate houqi, Xianghuangqi and Xilinhaote shi. While in 2014, high dependence households are clustered in Dongwuzhumuqin qi, and low dependence households are mainly clustered in Xianghuangqi. In western part of IMAR with relatively low NPP, high dependence households are clustered. In addition, households in Xianghuangqi and Dongwuzhumuqinqi become clustered from 2009 to 2014.

In LR test in Table 4.2, the hypothesis that SDM should be converted to SAR is rejected (LR test=50.80, $p<0.0001$), and the hypothesis that SDM should be converted to SEM is rejected as well (LR test=43.19, $p<0.0001$). LM test in spatial error and spatial lag are significant at 1% level, so spatial lag and spatial error should be considered. Additionally, AIC and BIC indicate that SDM best fits our dataset as well. Therefore, even though I present the results from all models, I give most attention to the SDM in the text below.

Table 4.2 Spatial model Test results

Spatial tests	Statistic	P-value
Spatial error		
Moran's I	19.305	<0.0001
Lagrange multiplier	359.319	<0.0001
Robust Lagrange multiplier	8.511	0.004
Spatial lag		
Lagrange multiplier	355.938	<0.0001
Robust Lagrange multiplier	5.13	0.024
LR test		
SAR nested in SDM	50.80	<0.0001
SEM nested in SDM	43.19	<0.0001

Table 4.3 shows interpreted results of determinations on grassland dependence from grassland utilization for OLS model and spatial models. The original estimation results are shown in Appendix Table 11. The spatial autocorrelation parameter ρ and the spatial autoregressive coefficient of error term λ are significant at 1% level in SAR with random effects, SDM with random effects and SEM, suggesting there are spatial dependences in the sample, indicating that grassland dependence D_i has a strong spillover effect on geospatial neighborhood connectivity and that the spatial interaction of D_i clustering can be interactively transmitted and homogeneously clustered through neighboring regions. And thus, they should be taken into consideration. In SAR

and SDM models, spatial models with fixed effects are favored by applying Hausman test (SAR: p=0.0237; SDM: p=0.0004).

In the examination of the factors influencing D_i among spatial models, the results are quite consistent between different models. I found that the regression coefficients of the total animals' amount in standard sheep unit pass the 1% significance tests respectively in all spatial models, indicating that the influence of herd size to herder's local grassland dependence is significant. We can see growing season NPP is positively associated with household grassland D_i in SEM, SAR and SDM with fixed effects in any confidence level. Stocking rate is positively related to D_i in all spatial models while square of stocking rate in log transform is negatively related to D_i. This indicates a possible non-linear relationship between D_i and stocking rate. Besides, the number of laborers has a spatial lag effect in SDM model with fixed effect.

Table 4.3 Interpretation of determinants of grassland dependence in spatial models

	SAR		**SEM**	**SDM**	
Main	Fixed effect	Random effect	Fixed effect	Fixed effect	Random effect
ln_animals	30.650***	27.530***	29.390***	28.538***	25.323***
ln_sr	7.965***	6.667*	7.965***	7.965***	8.241**
lnsr2	-2.737***	-2.532***	-3.149***	-3.873***	-3.977***
laborers	-1.005	1.193	0.100	1.686	2.371
lnnpp	12.628***	-1.005	13.151***	16.973***	0.797
Spatial lag term					
ln_ani				11.750	2.664
ln_sr				1.292	-4.917
lnsr2				3.052**	2.955**
laborers				-17.704***	-7.144
lnnpp				2.858	-2.634
N	962	962	962	962	962

Note: The determinants on grassland dependence in spatial models are interpreted by $\%\Delta(D_i) = -\left(100 \cdot \left(e^{\beta} - 1\right)\right)$, as justified in Section 3.2.6.

The marginal effect of independent variables on dependence is not reflected by the coefficients of SDM (Elhorst, 2012). If the independent variable of a spatial unit changes, it will affect not only the local dependent variable, but also the dependent variables of other spatial units. The effect of the independent variable on the local spatial unit is thus split into a direct effect and an indirect effect on the other spatial units. Combining these, the effect of the independent variable on all spatial units is the total effect.

In this study, direct effect indicates the impact of independent variables on grassland local dependence D_i. Indirect effect presents the impact of independent variables in surrounding areas on grassland local dependence D_i. And total effect represents the impact of independent variables in all regions on the dependent variable in local area. Thus, direct effect, indirect effect and total effect are shown in Table 4.4. The original marginal effects on utilization in log transform are shown in Appendix Table 10. Direct effect in Table 4.4 is different from coefficients in Table 4.3 as spatial dependence is incorporated to the model. Livestock amount is positively related to local grassland dependence at 1% significance level, while associations with surrounding areas is not significant. The results of stocking rate and its squared term indicate a non-linear relationship between stocking rate and local grassland dependence. Laborers does not show significant relationship on local D_i while it is negatively related to neighbouring D_i. Grassland NPP indicates a preference on local grassland dependence while shows no effects on surrounding areas. The number of household laborers doesn't directly impact on local grassland while has a strong negative effect on surrounding areas.

Table 4.4 Interpretation of marginal effects on Grassland dependence in SDM

	Direct effect	Indirect effect	Total effect
ln_ani	28.538***	13.929	38.492***
ln_sr	8.149***	2.078	10.058
ln_sr^2	-3.873***	3.052**	-0.702
laborers	1.489	-19.125***	-17.351***
lnnpp	16.973***	4.305	20.626***

4.4 Discussion

I compared main spatial models, SEM, SAR and SDM, on local grassland dependence for grazing. Based on the results of LR tests, LM tests, AIC, BIC, and Hausman test, the SDM model with fixed effects seems to fit our data best. I interpreted these results to see how variables interested in are related to grassland dependence spatially with endogenous interactions and exogenous interactions. D_i aggregates in study area and cannot be studied as individuals. In this spatial analysis, I found high NPP and livestock numbers are associated with a preference on depending on local grassland for grazing livelihood, while herders may be motivated to purchase more forage when neighbors hold more laborers. Additionally, stocking rate has a non-linear relationship with D_i.

4.4.1 Environment impacts

NPP shows a significant positive impact on local grassland dependence. Commonly, grassland productivity in growing season is predictable in grassland, leaving herders plenty of time to respond in advance. Thus, households grazing on grassland with high NPP can depend on local grassland for grazing livelihood to the full extent. Households grazing on low productivity grassland seem to prefer to purchase forage as supplement rather than selling them directly to mitigate losses. In this way, the dependence on local grassland decreases passively and the pressure on local grassland is shifted to grassland far away. Therefore, NPP mainly impacts on local herders' grazing activities rather than those far away. Herder's livelihoods depend on natural environment to a great extent, especially threatened by unanticipated natural shocks or anticipated shocks with high response cost. Herders' livelihoods are quite vulnerable compared to other agricultural livelihoods and require more support from organizations and governments.

4.4.2 Individual decision-making effects

I choose stocking rate, total livestock number, and squared term of livestock to analyze the impact of stocking rate to local grassland dependence. Stocking rate seems to show a positive relationship with local grassland dependence for grazing and squared term of stocking rate indicates a non-linear relationship between stocking rate and local grassland dependence, which is consistent with the results in Chapter 3. This finding indicates an interesting decision-making strategy of herders on grazing livelihood. That is, dependence increases first when stocking rate increases. After stocking rate reaches certain level, if stocking rate keeps increasing, local grassland dependence does not change much. The more stocking rate increases, the less it has effect on dependence. Considering households in Inner Mongolia are restricted by 30 years renewable contract policy, the available grazing grassland area will not change dramatically. For the first stage, D_i increases when stocking rate increases. A possible reason is as follows. For certain households with a very low number of livestock, the marginal effects of livestock number on D_i is higher than that of households with many livestock. At the same time, the stocking rate increases when the number of livestock increases as the grazing area is relatively settled. Therefore, the dependence increases when stocking rate increases in first stage. When stocking rate reaches certain level, household prefers to depend on local grassland for grazing livelihood. The stocking rate does not impact much on local grassland dependence.

The number of household laborers was found to have a negative effect on D_i in surrounding space units. While in Chapter 3, the number of household laborers has a significant positive effect in OLS, fixed effect model, mixed effect model and double hurdle model. Considering spatial interactions incorporated in SDM, households may be motivated to purchase forage for higher animal income when neighbors has more laborers, while in a family, more laborers in a household means higher ability to harvest fodder and feeding livestock (Tan et al., 2017). Still, laborers in a household may not be completely devoted to grazing livelihood. Laborers seek off-farm opportunities for higher income or better well-being, such as health care or education (A. Li et al., 2018; Tan et al., 2017). Due to the absent of part of households' location, the dataset in chapter 3 and chapter 4 are not completely the same.

Looking at the impact of NPP, stocking rates and laborers on D_i, I found environment and individual decision-making are both significant. Environment influence household grazing strategy directly by limiting households available grazing resources, especially when herders depend on natural environment to a great extent compared to farmers. While for individual decision-making strategy, herders are influenced by desire to more family assets and neighbouring herders directly and indirectly, leading to a complex process. In addition, herders move to urban area for better education, seeking higher income-earning opportunities, or simply have insufficient livestock to earn sufficient livelihood (Mijiddorj et al., 2019). However, new problem also arise regarding how to allocate or transfer the grasslands that are under 30-year contracts. These are active areas of policy and academic research. Grazing is one of the most important anthropogenic activities leading to grassland degradation besides climate change. A series of policies were implemented to cope with grassland degradation, such as forbidden grazing policy, grassland and livestock balance policy, grazing rotation policy and so on. In the meantime, grazing livelihood is vulnerable for herders who completely relay on natural environment. Therefore, the government must protect both herders' vulnerable livelihood and degrading grasslands. In this way, the government should not only monitor and manage grassland, but also how herders making decisions subjectively to support poverty alleviation and grassland conservation.

4.5 Conclusions

This study incorporates spatial effects into account based on statistical models. I expand statistical models in Chapter 3 to spatial models. Spatial models are specialized at examining spatial effects with time series, while they cannot take zeroes in observations into account. Individual decision-making and environment are both significant to D_i. Herders respond to environment change passively and directly, while the individual decision-making is influenced by neighbors and desire for wealth accumulation and limited by household characteristics.

NPP impacts on local grassland dependence rather than neighboring grassland. Households grazing on productive grassland are capable to depend on local grassland for grazing livelihood to the full extent. While for households grazing on less productive grassland, herders prefer to purchase forage as supplement rather than sell them directly to mitigate losses and the pressure on local grassland is shifted to grassland far away.

A non-linear relationship was found in stocking rate and D_i. Dependence increases first when stocking rate increases. After stocking rate reaches certain level, if stocking rate keeps increasing, local grassland dependence does not change much. The more stocking rate increases, the much stocking rate impacts on household local grassland dependence for grazing. The relationship in first stage might be due to the marginal effects of livestock number when households start increasing livestock number from a low level. After exceeding local grassland carrying capacity, the household must purchase forage as supplementary for feeding. Besides, households are motivated to purchase forage when neighbors have more laborers. While laborers in a household were found positively related to local dependence. One possible reason is more laborers in a household means higher ability to harvest fodder and feeding livestock or laborers in a household doesn't completely devoted to grazing livelihood.

D_i provides a relative estimation on household local grassland dependence for feeding and thus can observe the changes of herders' subjective intentions on local grassland use for grazing with only questionnaire dataset. Combined D_i and SDM take spatial exogenous effects and endogenous effects into account, allowing us to examine how individual and environmental factors effect on local and neighboring area. It's more appropriate to build a spatial model with interaction effects when the effect is significant compared to non-spatial models. However, I didn't incorporate spatial effects to double hurdle model in Chapter 3, which can be investigated in the future.

Chapter 5. Thesis Conclusions

5.1 Thesis summary

The metric I developed in this study, grassland dependence (D_i), indicates the extent of herders' dependence on local grasslands under the influence of internal and external factors, providing direction for analysis from both livelihood and ecological perspectives. D_i provides relative estimates of household dependence on local grassland feeding, thus allowing observation of changes in herders' subjective intentions to use local grasslands for grazing, rather than income-based methods or remote sensing. In study area, there’s significant positive spatial autocorrelation and similar observations aggregates to clusters.

Droughts showed significant negative effects on local grassland dependence. Typically, drought in the grasslands is predictable and herders have enough time to respond in advance. As a result, herders prefer to purchase forage as a supplement rather than sell it out right to reduce losses Besides, I find that wealthy households tend to start buying forage and choose to rely on local grasslands after forage uptake. It might because wealthy households are more resilient to unexpected instances and can afford the increased financial burden associated with forage purchases. Nonetheless, wealthy households do not need to invest much time and effort in purchasing and transporting forage after forage uptake, as wealthy households tend to hold diversified income sources or opportunities, which is consistent with the finding that high asset indices tend to be associated with lower relative dependence on natural resources for household life, and that wealthy households may have higher absolute incomes than poor households (Angelsen et al., 2014; Robinson et al., 2019). Overall, grassland subsidy, forbidden grazing subsidy and grassland livestock balance subsidy are positively related to local grassland dependence, suggesting grassland policies are having an effect.

After incorporating spatial effects to spatial models, I found NPP has a significant positive effect on local grassland dependence. Households grazing on grassland with high NPP can depend on local grassland for grazing livelihood to the full extent. While households grazing on low productivity grassland prefer to purchase forage as supplement rather than selling them directly. Dependence on local grassland decreases passively and the pressure is shifted to grassland far away. In spatial scale, NPP mainly impacts on local herders' grazing activities rather than those far away. Herders depend on natural grassland to a great extent for grazing livelihood and their livelihoods are quite vulnerable compared to other agricultural livelihoods and require more support from organizations and governments.

A non-linear relationship was found between stocking rate and local grassland dependence. Dependence increases first when stocking rate increases. After stocking rate reaches certain level, if stocking rate keeps increasing, local grassland dependence does not change much. The more stocking rate increases, the much stocking rate impacts on household local grassland dependence for grazing. The relationship in first stage might be due to the marginal effects of livestock number when households start increasing livestock number from a low level. And then households tend to depend on local grassland rather than purchasing forage from markets. The number of laborers in a household is negatively related to dependence in neighbouring space units. Perhaps households are motivated to purchase forage when neighbors have more laborers. While laborers in a household were found positively related to local dependence. One possible reason is more laborers in a household means higher ability to harvest fodder and feeding livestock or laborers in a household doesn't completely devoted to grazing livelihood.

This study fills the gap that little work has be done on local grassland dependence, especially examining the local grassland dependence from the perspective of metabolic energy instead of livelihood income share. In chapter 3, I examine herders local grassland dependence for grazing livelihood with OLS model, fixed effect model, mixed effect model and double hurdle model. Fixed effect model and mixed effect model allow to examine grassland dependence with the consideration of time series. Double hurdle model takes the effect of a large amounts of zeroes in dependent variable into account, so we can look at whether households completely depend on local grassland and how they make use of grassland if herders started to purchase forage from markets. In chapter 4, I incorporate spatial effects to fixed effect and random effect model to examine how individual and environmental factors effects on local and neighbouring grassland dependence.

5.2 Implications for future research

Current literature mostly focuses on grassland dependence from the perspective of income, including the share of grassland to household income, the rank of household income, or strategies classified by income (Babulo et al., 2008; Mazumder, 2018; Zenteno et al., 2013; Elizabeth et al., 2018; Kimengsi et al., 2019; Ofoegbu et al., 2017). While few studies examine dependence on local grassland ecosystems. Some work has been done on stocking rate decisions or grassland profitability (Kemp et al., 2011; Li and Bennett, 2019b; Romera and Doole, 2016). But no work has looked explicitly at livelihoods that rely on grassland ecosystem services or how to measure this dependence from the perspective of grassland and energy.

This thesis has some implications on future studies. Fixed effect and mixed effect model help to examine effects across time series. Spatial models help to look at spatial effects other than time effects. Double hurdle model is specialized in coping with zeroes in observations. I didn’t build double hurdle model with spatial effects or panel data, which is a constrain and a direction to be investigated in the future. Besides, further studies can be done with a panel dataset with more time series. Grassland local dependence does not indicate absolute positive or negative impacts on natural grassland. In the future, D_i can be combined with local grassland quality and productivity. Reduced local D_i transfer local ecological pressure to grassland far away. If the dependence in vulnerable grasslands decreases and transfer ecological pressure to grassland far away with extra available carrying capacity, win-win situation is settled. Therefore, future research could not only look at how herders depend on local grassland and forage from markets, but also consider where forage comes from and where forage goes to. Researchers could examine from the perspective of supply and demand by tele-coupling system.

5.3 Implications for Policy

Other than the implications to future studies, this research also brings implications on policies. As anthropogenic activities and climate change have led to grassland degradation and desertification, the Chinese government has implemented numerous policies on reducing grazing intensity, thus responding to grassland degradation. Ecological compensation subsidy policies, including forbidden grazing subsidy and grassland livestock balance subsidy, are effective overall, but they also need to be increased. Droughts drive people to purchase forage to mitigate losses, while herders may not act similarly to respond to different shocks. The government could manage differently to cope with shocks by subsidizing households, providing forage, help to sell livestock, etc. Households with limited market access tend to depend on local grassland passively, the policymakers could help herders in remote areas to sustain livelihoods by providing forage or improve market access. From chapter 4, we found NPP impacts on grazing directly and locally. Besides, NPP is found to be related with precipitation (Guo et al., 2016; Wu et al., 2011).

Policymakers should consider the dynamic of environment production on grassland management to secure livelihoods and protect grassland. In addition, the stocking rate has a non-linear relationship with grassland local dependence for grazing. Policymakers may benefit if they adjust the management by the level of stocking rate. Besides, herders are affected by factors from local and neighbouring areas. The policymakers should consider not only the effect of local environment or household characters, but also effects from neighbouring area. There is an urgent need for the government to develop effective policies that address grassland degradation while safeguarding the livelihoods of herders. It is important to understand how herders respond to policy changes and make grassland use decisions to support poverty alleviation and grassland conservation.

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Appendices

Appendix Table 1: Variable description

Variable	Description
age	Head age
sex	Head sex: 1) male 2) female
gsld_type	Grassland type: 1) meadow steppe 2) typical steppe 3) desert steppe 4) sandy steppe 5)desert
ethnic_group	0) mongol 1) han
laborers	Number of laborers in the household
under16	Number of individuals in the household 16 years old or younger
above60	Number of individuals in the household 60 years old or older
shocks_number	Number of environmental shocks (plagues of locusts, snowstorms, or drought) that household suffered in surveyed year
education	Maximum amount of education achieved by householder: 1) illiterate (no school) 2)elementary education 3) middle school 4) high school 5) college or higher
health	Reason health expenditures were large: 0) health expenditures were not large 1) shock 2) not shock

Appendix Table 2: Standard Sheep Unit conversion factors

Animal	Sheep Unit	Energy requirements used
Sheep	1	Sheep
Lamb	0.5	Sheep kids
Goat	0.8	Goat
Goat kids	0.4	Goat kids
Beef cattle	7	Cattle
Bull calf	3.5	Cattle kids
Cow	8	Dairy cow
Heifer calf	4	Dairy cow kids
Horse	7	Horse
Camel	9	Camel

(Liu et al., 2009; Rao et al., 2015; Yuan et al., 2016)

Appendix Table 3: County number ordered with county name

county_name	county_number
Chenbaerhu	1
ewenke	2
xinzuoqi	3
dongwuqi	4
xilinhaote	5
Xianghuangqi	6
Sunite left banner	7
Sunite right banner	8
siziwang	9
wushen	10
hangjin	11
etuoke	12
wulatehou	13
Alashan left banner	14
Alashan right banner	15

Appendix Table 4: PCA for asset index

Principal components/correlation			**Number of obs**	**832**
			Number of comp.	8
			Trace	8
Rotation: (unrotated = principal)			Rho	1
Component	**Eigenvalue**	**Difference**	**Proportion**	**Cumulative**
Comp1	1.98782	0.604755	0.2485	0.2485
Comp2	1.38307	0.298532	0.1729	0.4214
Comp3	1.08454	0.199546	0.1356	0.5569
Comp4	0.88499	0.0518407	0.1106	0.6676
Comp5	0.833149	0.0853488	0.1041	0.7717
Comp6	0.7478	0.111053	0.0935	0.8652
Comp7	0.636747	0.194861	0.0796	0.9448
Comp8	0.441886	.	0.0552	1

Appendix Table 5: PCA components for asset index

Variable	ln(housearea)	Shed area	Well number	passcar	moto	tractor	mower	truck_number
Comp1	0.372	0.346	0.350	0.419	0.320	0.422	0.391	0.099
Comp2	0.428	0.120	0.289	0.134	0.184	-0.520	-0.572	0.264
Comp3	-0.278	0.236	-0.402	-0.147	0.420	-0.053	0.110	0.702
Comp4	-0.206	-0.796	0.218	0.281	0.424	-0.039	0.074	0.101
Comp5	0.084	-0.207	0.444	-0.320	-0.504	0.192	0.105	0.590
Comp6	-0.055	-0.038	-0.329	0.757	-0.494	-0.067	-0.019	0.255
Comp7	-0.714	0.363	0.529	0.161	-0.051	-0.218	0.003	-0.054
Comp8	0.196	-0.020	0.004	-0.064	-0.077	-0.677	0.701	-0.042
Unexplained	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000

Appendix Table 6: Margins of dependence by levels of household's characteristics

Variables		**level**		**Margin of ln(U_i)**	U_i	D_i
Drought		0		-3.511	0.029	0.971
		1		-3.369	0.033	0.967
		2		-3.226	0.039	0.961
		3		-3.082	0.045	0.955
		4		-2.938	0.052	0.948
		5		-2.793	0.060	0.940
Asset index		-4		-3.181	0.041	0.959
		0		-3.298	0.036	0.964
		4		-3.428	0.031	0.969
		8		-3.571	0.027	0.973
		12		-3.724	0.023	0.977
		16		-3.886	0.020	0.981
Age		35		-3.234	0.038	0.962
		40		-3.265	0.037	0.963
		45		-3.297	0.036	0.964
		50		-3.328	0.035	0.965
		55		-3.359	0.034	0.966
		60		-3.391	0.033	0.967
ln(stocking rate)	-2.7	**Stocking rate**	0.07	-3.351	0.034	0.966
	-1.7		0.18	-3.341	0.034	0.966
	-0.7		0.50	-3.342	0.034	0.966
	0.3		1.35	-3.352	0.034	0.966
	1.3		3.67	-3.372	0.033	0.967
	2.3		9.97	-3.400	0.032	0.968

Amount of forbidden grazing subsidy kept in the household (thousand RMB)	0	-3.231	0.039	0.962
	10	-3.343	0.034	0.966
	20	-3.453	0.031	0.969
	30	-3.563	0.027	0.973
	40	-3.672	0.024	0.976
	50	-3.780	0.022	0.978
	60	-3.887	0.020	0.981
Amount of grass-livestock balance subsidy kept in the household (thousand RMB)	0	-3.220	0.039	0.961
	10	-3.313	0.035	0.965
	20	-3.419	0.032	0.968
	30	-3.536	0.028	0.972
	40	-3.662	0.025	0.975
	50	-3.796	0.022	0.979
	60	-3.938	0.019	0.982
Salary earned through off-farm activities (thousand RMB/year)	0	-3.286	0.036	0.964
	10	-3.379	0.033	0.967
	20	-3.474	0.030	0.970
	30	-3.568	0.027	0.973
	40	-3.664	0.025	0.975
	50	-3.759	0.022	0.978
Distance to city(km)	0	-3.119	0.043	0.957
	20	-3.193	0.040	0.960
	40	-3.267	0.037	0.963
	60	-3.341	0.034	0.966
	80	-3.414	0.032	0.968
	100	-3.487	0.030	0.970
	120	-3.560	0.027	0.973
	140	-3.633	0.025	0.975
	160	-3.705	0.024	0.976

Appendix Table 7: Summary of Household Characteristics by Dependence, Asset Index, and Time

		Dependence			Asset Index			Time	
Group number		1	2	3	1	2	3	1	2
Group		Top 20th percentile	20-80th percentile	Bottom20th percentile	Bottom 20th percentile	20-80th percentile	Top 20th Percentile	2009	2014
Range/ Mean		<-5.08	-5.08~-2.03	>-2.03	-0.38	0.38~2.23	>2.23	-3.82	-3.33
U_i		>0.01	0.01~0.13	>0.13	0.03	0.03	0.02	0.02	0.03
D_i		>0.995	0.87~0.995	<0.87	0.97	0.97	0.98	0.98	0.97
Household size	**Mean**	4.05^{c}	3.98^{c}	$3.74^{a,b}$	$3.48^{b,c}$	$4.00^{a,c}$	$4.25^{a,b}$	3.98	3.91
	Std.	1.33	1.25	1.14	0.98	1.22	1.44	1.25	1.25
Age	**Mean**	47.43	47.63	47.27	46.68	47.69	47.83	45.48^{d}	49.63
	Std.	10.61	10.66	10.25	10.78	10.56	10.35	10.50	10.22
Sex (Female-1, Male-0)	**Mean**	0.07	0.08	0.08	0.12	0.07	0.07	0.07	0.08
	Std.	0.26	0.27	0.27	0.33	0.25	0.25	0.25	0.28
Education	**Mean**	2.79	2.71^{c}	2.82^{b}	$2.56^{b,c}$	2.78^{a}	2.82^{a}	2.74	2.75
	Std.	0.84	0.82	0.81	0.72	0.82	0.89	0.78	0.86
Ethnic group (0-Mongol;1-Han)	**Mean.**	0.17^{c}	0.22^{c}	$0.32^{a,b}$	$0.30^{b,c}$	0.22^{a}	0.18^{a}	0.24	0.22
	Std.	0.38	0.41	0.47	0.46	0.42	0.39	0.42	0.42
Children (the number of children under 16yo)	**Mean**	0.61	0.60	0.52	$0.49^{b,c}$	0.59^{a}	0.66^{a}	0.58	0.59
	Std.	0.71	0.69	0.63	0.60	0.68	0.76	0.65	0.72
Elder (the number of elders above 60yo)	**Mean**	0.37	0.40	0.36	$0.30^{b,c}$	0.40^{a}	0.43^{a}	0.33^{d}	0.44
	Std.	0.67	0.68	0.68	0.61	0.69	0.69	0.63	0.71

Laborers (the number of laborers reported in the household)	**Mean**	2.62	2.53	2.56	2.27^{b,c}	2.57^{a,c}	2.77^{a,b}	2.29^{d}	2.82
	Std.	1.11	1.05	1.04	0.87	1.05	1.18	0.94	1.11
Asset index	**Mean**	1.57^{b,c}	1.04^{a}	0.97^{a}	-1.01^{b,c}	0.72^{a,c}	4.52^{a,b}	0.97^{d}	1.30
	Std.	3.06	1.99	2.45	0.57	0.71	3.00	2.30	2.38
Grassland type (1-Meadow steppe, 2-typical steppe,3-desert steppe, 4-sandy steppe ,5- desert)	**Mean**	2.73^{b,c}	3.35^{a,c}	2.92^{a,b}	3.13^{c}	3.29^{c}	2.72^{a,b}	3.14	3.15
	Std.	1.54	1.27	1.34	1.20	1.32	1.57	1.35	1.38
ln(stocking rate)	**Mean.**	0.26^{b,c}	0.01^{a,c}	-0.15^{b,a}	-0.28^{b,c}	0.04^{a,c}	0.32^{a,b}	0.03	0.04
	Std.	1.71	1.19	1.56	1.57	1.20	1.64	1.54	1.21
Stocking rate	**Mean**	1.30	1.01	0.86	1.32	1.04	1.38	1.03	1.04
Obs.		328	981	327	328	981	327	832	804
Above variables were surveyed in both years. Below are only collected in 2015.									
Health	**Mean.**	0.35	0.33	0.35	0.32	0.33	0.36	NA	0.33
	Std.	0.67	0.69	0.71	0.69	0.69	0.70	NA	0.69
Shocks	**Mean**	1.38	1.78	2.44	2.34	1.93	1.38	NA	1.87
	Std.	1.25	1.80	2.22	2.10	1.92	1.36	NA	1.87
Drought	**Mean.**	0.72	1.30	1.72	1.69	1.37	0.82	NA	1.30
	Std.	1.21	1.61	1.84	1.69	1.67	1.39	NA	0.52
Snowstorm	**Mean**	0.66	0.41	0.66	0.57	0.50	0.54	NA	3.94
	Std.	0.81	0.79	1.11	1.27	0.84	0.67	NA	0.05

Sandstorm	**Mean.**	0.26	5.03	4.05	7.19	4.06	1.14	NA	0.06
	Std.	2.18	16.11	11.02	15.67	14.26	7.88	NA	0.06
Locust	**Mean**	0.00	0.07	0.05	0.07	0.06	0.02	NA	1.64
	Std.	0.00	0.41	0.33	0.53	0.35	0.13	NA	0.89
Other disaster	**Mean.**	0.00	0.09	0.02	0.01	0.07	0.06	NA	13.50
	Std.	0.00	0.53	0.16	0.09	0.48	0.35	NA	0.35
Animal disease	**Mean**	0.08	0.05	0.07	0.05	0.05	0.10	NA	0.41
	Std.	0.27	0.34	0.40	0.45	0.30	0.38	NA	0.35
Distance to nearest city(km)	**Mean.**	52.55	59.10	54.20	68.19	56.58	48.36	NA	56.70
	Std.	56.12	39.84	40.47	46.36	38.58	51.12	NA	43.34
Distance to nearest road(km)	**Mean**	7.91	9.33	8.32	10.10	9.10	7.07	NA	8.82
	Std.	9.18	17.45	16.01	12.02	18.62	8.50	NA	15.91
Grassland Subsidy (thousand RMB)	**Mean.**	21.74	18.08	16.44	16.97	17.89	20.50	NA	18.31
	Std.	21.92	15.56	16.81	16.60	16.71	18.91	NA	17.22
Grassland Own area(mu)	**Mean**	5858	9804	6273	6244	8362	9281	8126	8211
	Std.	6161	11720	6787	6632	10121	11484	9943	9993
Livestock income (thousand RMB)	**Mean.**	164.63	128.30	114.09	72.17	114.00	223.37	82.31	131.11
	Std.	171.80	113.86	102.42	59.86	86.49	187.16	92.12	124.46
Other income (thousand RMB)	**Mean**	143.17	64.79	72.68	40.41	70.81	138.43	NA	80.63
	Std.	510.26	80.16	79.91	40.72	78.87	461.53	NA	227.68
Obs.		142	458	204	134	493	177	832	804

[a] group is significantly different from the first group at 90% confidence level
[b] group is significantly different from the second group at 90% confidence level
[c] group is significantly different from the third group at 90% confidence level
[d] group is significantly different from 2014

Appendix Table 8: Determinants of how households make use of grassland based on utilization

Variable	OLS_hh	OLS_15	FE	ME
ln(U_i)				
ln(stocking rate)	-0.107**	-0.082	-0.166***	-0.120***
ln(stocking rate)^2	0.082***	0.080***	0.039***	0.056***
Age	-0.011**	-0.013**		-0.005
Sex	0.001	0.119		0.094
Ethnic group (Mongol-0, Han-1)	0.321***	0.446***		0.441***
Laborers	-0.117***	-0.148***	-0.089**	-0.121***
Children	-0.097*	-0.134*		-0.096*
Elder	-0.032	-0.004		-0.058
Asset index	0.031	-0.001		-0.035
Max education level achieved by householder (ref:Illiterate)				
Primary school	0.193	0.251		0.117
Middle school	-0.002	-0.034		0.147
High school	-0.093	-0.147		0.094
College or higher	-0.242	-0.183		0.165
Grassland Type (ref: meadow steppe)				
Typical	2.403***	2.242***		1.707***
Desert steppe	1.259***	1.627***		1.706***
Sandy steppe	0.664**	0.233		0.082
Desert	0.384	0.275		1.032***
Shocks				
Drought		0.086**		
Snowstorm		-0.068		
Locust		-0.002		
Sandstorm		-0.022		
Other disaster		0.05		
Animal disease		0.257*		
Distance to city(km)		-0.002*		
Distance to road(km)		0.004		
Non-grassland subsidy (thousand RMB)		0.011		
Grassland subsidy (thousand RMB)		-0.008**		

Other income (thousand RMB)		0		
Health		0.076		
Panel year(2015)	0.631***		0.241***	0.318***
_cons	-4.121***	-3.157***	-3.380***	-4.262***
r2	0.359	0.419	0.144	
AIC	5806.924	2798.506	2632.738	.
BIC	5963.311	2985.79	2658.792	.
Obs.	1636	804	1362	1362

* = p<0.05; ** = p<0.01; *** = p<0.001. I include county dummy variables in both OLS models.

Appendix Table 9: Determinants of whether household start to purchase forage and how much household rely on markets

	Does the household purchase forage? (stage 1, probit)		**How much households rely on markets? (stage 2, lognormal)**	
ln(*U_i*)	i)	ii)	i)	ii)
ln(stocking rate)	-0.018	-0.038	-0.117**	-0.103***
ln(stocking rate)^2	0.041	0.037**	0.039***	0.053***
Age	-0.005	-0.003	-0.006	-0.003
Sex	0.146	-0.101	0.112	0.166
Ethnic group	0.141	0.058	0.445***	0.399***
Laborers	-0.169**	-0.062	-0.097**	-0.102***
Children	-0.151	-0.01	-0.091	-0.132***
Elder	0.033	0.01	-0.014	-0.092*
Asset index	0.045	0.053***	-0.065***	-0.054***
Education level(ref:illiterate)				
Primary school	0.492	0.277	0.145	0.026
Middle school	0.261	0.126	0.08	0.052
High school	0.18	0.039	0.122	0.112
College or higher	0.744	0.609	-0.269	-0.449
Grassland Type (ref: meadow steppe)				
Typical steppe	1.802***	1.805***	0.771***	0.694***
Desert steppe	2.454***	1.667***	0.801***	0.446***
Sandy steppe	0.474**	0.374***	-0.395**	-0.105
Desert	1.86***	1.408***	0.158	-0.047
Shocks				
Drought	0.062		0.115***	
Snowstorm	-0.132		-0.026	
Locust	-0.003		-0.001	
Sandstorm	3.381		0.017	

Other disaster	3.562		0.056	
Animal disease	0.576**		0.026	
Distance to city(km)	-0.001		-0.003***	
Distance to road(km)	0.002		0.002	
Non-grassland subsidy	0.031		-0.004	
Income from other resources (thousand RMB	-0.001*		0.001**	
Amount of forbidden grazing subsidy kept in the household (thousand RMB)	-0.002		-0.01***)	
Amount of grass-livestock balance subsidy kept in the household (thousand RMB)	0.015		-0.018***	
Health	0.07		0.078	
Panel year(2015)		0.327***		0.457***
_cons	-6.451***	-6.88***	-2.661***	-3.164***
ln(sigma)			0.050*	0.088***
AIC			2574.612	5302.076
BIC			2869.585	5512.389
Obs.	804	1636	804	1636

*** P < 0.01, ** P < 0.05, * P < 0.10

Appendix Table 10: Marginal Effects of Double Hurdle Model

Variable	**Marginal effects on ln(Utilization)**	**Implied marginal effects on dependence**	**p-value**
ln(stocking rate)	-0.111	10.485	0.090
ln(stocking rate)2	0.055	-5.63	0.009
Age	-0.008	0.75	0.244
Sex	0.169	-18.46	0.381
Ethnic group	0.458	-58.047	<0.0001
Laborers	-0.168	15.488	0.001
Children	-0.154	14.278	0.042
Elder	0.004	-0.414	0.962
Asset index	-0.034	3.363	0.177

Education level(ref:illiterate)		1	
Primary school	0.382	-46.453	0.193
Middle school	0.214	-23.863	0.475
High school	0.206	-22.888	0.515
College or higher	0.100	-10.538	0.803
Grassland Type (ref: meadow steppe)		1	
Typical steppe	2.067	-690.076	<0.0001
Desert steppe	2.192	-794.939	<0.0001
Sandy steppe	0.249	-28.218	0.393
Desert	1.485	-341.415	<0.0001
Shocks	0.131	-13.948	<0.0001
Drought	-0.088	8.378	0.156
Snowstorm	-0.002	0.209	0.760
Locust	1.683	-438.205	0.989
Sandstorm	1.806	-508.522	0.984
Other disaster	0.307	-35.925	0.082
Animal disease	-0.003	0.306	0.009
Distance to city(km)	0.003	-0.273	0.388
Distance to road(km)	0.012	-1.167	0.404
Non-grassland subsidy	0.001	-0.086	0.086
Amount of forbidden grazing subsidy kept in the household (thousand RMB)	-0.010	0.986	0.006
Amount of grass-livestock balance subsidy kept in the household (thousand RMB)	-0.008	0.818	0.299
Income from other resources (thousand RMB)	0.102	-10.778	0.162

Appendix Table 11: Determinants of Grassland Utilization in OLS and Spatial Models

	OLS	**SAR**		**SEM**	**SDM**	
Main		Fixed effect	Random effect	Fixed effect	Fixed effect	Random effect
ln_ani	-0.419***	-0.366***	-0.322***	-0.348***	-0.336***	-0.292***
ln_sr	-0.046	-0.083***	-0.069*	-0.083***	-0.083***	-0.086**
lnsr2	0.025***	0.027***	0.025***	0.031***	0.038***	0.039***
laborers	-0.007	0.01	-0.012	-0.001	-0.017	-0.024
lnnpp	0.035**	-0.135***	0.01	-0.141***	-0.186***	-0.008
_cons	-0.509		0.253			0.224

Spatial						
rho		0.032	0.425***		0.068	0.469***
lambda				0.178***		
Variance						
sigma2_e		0.170***	0.354***	0.168***	0.161***	0.333***
lgt_theta			-0.564***			-0.592***
Spatially lag term						
ln_ani					-0.125	-0.027
ln_sr					-0.013	0.048
lnsr2					-0.031**	-0.030**
laborers					0.163***	0.069
lnnpp					-0.029	0.026
aic	3385.812	1037.815	2756.724	1030.202	997.015	2732.201
bic	3415.027	1071.898	2800.545	1064.286	1055.443	2800.367
N	962	962	962	962	962	962

Appendix Table 12: Marginal effects of SDM model on ln(Utilization)

	Direct effect	**Indirect effect**	**Total effect**
ln_ani	-0.336***	-0.150	-0.486***
ln_sr	-0.085***	-0.021	-0.106
lnsr2	0.038***	-0.031**	0.007
laborers	-0.015	0.175***	0.160***
lnnpp	-0.186***	-0.044	-0.231***