Agricultural Systems 219 (2024) 104011

Contents lists available at ScienceDirect

Agricultural Systems

journal homepage: www.elsevier.com/locate/agsy

Land access and feeding strategies in post-Soviet livestock husbandry: Evidence from a rangeland system in Kazakhstan

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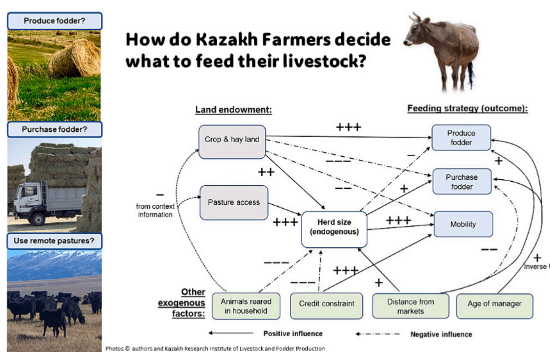
HIGHLIGHTS

- Globally, livestock systems are intensifying, with implications for production efficiency and environmental impact.
- Using surveys, we evaluate the importance of pastures, arable land and fodder markets for livestock feeding in Kazakhstan.
- We then investigate the factors influencing the choice of feeding strategy, and variation in these across holding size.
- Larger producers are more dependent on pastures, whilst intensification is limited by access to arable land and credit.
- Pasture-based production is the main pathway to growth where structural constraints to fodder availability are high.

GRAPHICAL ABSTRACT



ARTICLE INFO

Editor: Paul Crosson

Keywords:
Livestock
Intensification
Pastoralism
Land tenure
Kazakhstan

ABSTRACT

CONTEXT: Feeding strategy is a major dimension of intensification and largely determines the environmental and economic impacts of livestock production systems, in particular concerning land use competition, greenhouse gas emissions and rural livelihoods. Literature suggests that a key driver of intensification is increasing population density – associated with decreased labor costs, shifts in demand and institutional and political change; whilst at the household level farmer education and market access are also important. However, the topic has not been addressed in the rangelands of post-Soviet Eurasia, where vast underused pasture resources may be reclaimed, but improved feeding is also a key aim of agricultural policy.

OBJECTIVES: We aim to firstly describe the extent to which land users in an extensive rangeland system in Kazakhstan exploit pastures, arable land or markets to feed their animals, and secondly to explore the determinants of these decisions.

METHODS: We identify three potential strategies: self-production of roughage or concentrate, purchase of these inputs, or expansion of pasture use through mobile pastoralism. We then investigate the determinants of these feeding strategies and their interactions, including variables capturing farm and farmer characteristics, access to

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https://doi.org/10.1016/j.agsy.2024.104011
Received 14 December 2023; Received in revised form 17 May 2024; Accepted 20 May 2024
Available online 4 June 2024

land and other assets and outcomes of post-independence reforms. We examine the factors determining the three feeding strategies using a farm survey dataset from south-eastern Kazakhstan to estimate a simultaneous equation system, considering herd size as an endogenous variable.
RESULTS AND CONCLUSIONS: Herd size combined with access to land for fodder production largely determines how producers feed their livestock. Barriers to the substitution of pasture for purchased or self-produced fodder include cropland access, distance from markets, and credit availability, so that use of remote and seasonal pastures is the major feeding strategy employed by larger producers. Access to both arable land and pasture is dependent on land reform outcomes, which constrain farmers' livestock feeding decisions today. Other factors such as farmer education, human population density and household labor are less important.
SIGNIFICANCE: Grazing expansion strategies employed by farmers studied here differ from those based on external input use observed in many regions of the world. Instead, they reflect the continuing importance of pastoral resources in rangeland environments implying important trade-offs to intensification which merit further study.

1. Introduction

With growing consumer demand, livestock production in many low and middle income countries has increased in recent years, implying complex trade-offs for production decisions at farm-level (Salmon et al., 2018). For example, provision of high quality fodder commonly increases labor productivity of livestock owners and lowers greenhouse gas (GHG) emissions per unit of livestock output (Herrero et al., 2013). At the same time, supplementary fodder grown on cropland competes with land use for direct human nutrition or biodiversity protection (Mottet et al., 2017; Van Zanten et al., 2016), and systems with more stall feeding are susceptible to disease (Gilbert et al., 2021). Moreover, while many observers criticize extensive, i.e. highly pasture-based grazing systems for their excessive GHG emissions (Hayek et al., 2021), some experts call for more nuanced assessment of these systems in places where feed-food competition is low and where human livelihoods are highly dependent on them (Houzer and Scoones, 2021).

Understanding the factors influencing feeding strategy is critically important in order to ascertain circumstances under which intensification based on increased fodder provision may be unlikely or even inappropriate; identify constraints affecting farmer decisions and adapt government policy accordingly (Godde et al., 2018). Statistical analyses exploring the determinants of livestock intensification in developing countries (Baltenweck et al., 2003, 2004; Bernués and Herrero, 2008; Staal et al., 2002) and the theories underpinning it (Boserup, 1965; McIntire et al., 1992) suggest that a fundamental factor is increasing population density – associated with decreased labor costs, shifts in demand and institutional and political change; whilst at the household level farmer education and market access are also commonly associated with feeding intensification (Baltenweck et al., 2003).

However, the above-cited literature is mainly based on studies from developing countries in Africa, Latin America and South Asia. Little is known about the former Soviet Union, where commercial private livestock production has existed only since the 1990s and the role of the state and land tenure relations continue to undergo rapid change. In this study, we seek to identify the determinants of different land use and feeding strategies in Kazakhstan - a country with the fifth largest pasture resources on earth and a history of extensive pastoralism, dependent on livestock mobility to exploit vegetation variation in space and time (Ferret, 2014; Kerven et al., 2021). As a hydrocarbons producer, agriculture represents only 9% of Kazakhstan's emissions, but the country's livestock (including 8.5 million cattle and 22 million small stock) directly produce 62% of this in the form of enteric fermentation and manure-related emissions (UNFCCC, 2021). Livestock contributed 44% of agricultural GDP in 2021, with beef and cow's milk making up over 60% of the total value of raw livestock product in 2022 (FAOSTAT, 2022).

We define strategies providing more fodder per animal as more *intensive* and more pasture-dependent feeding strategies as *extensive*. We do not address livestock density on pastures but instead consider more mobile strategies to be more extensive. We recognize the heterogeneity of fodder by separating it into different types: self-produced and purchased, roughage and concentrate.

Using original farm survey data, we estimate a simultaneous equation system, modelling a number of pasture use and feeding outcomes. Our so-called conditional mixed process (cmp) model (Roodman, 2011) allows for censored dependent variables such as fodder quantities, where zero observations carry meaningful information. It also allows to set up a recursive system with separate equations for those explanatory variables of the main equation which are "endogenous" (affected by, as well as affecting certain outcomes). Here the endogenous variable is herd size, for which we analyze both the farm-exogenous determinants and the effects on feeding outcomes and mobility. Thus, controlling for herd size in the model allows us to investigate the effects of the exogenous factors, such as crop land endowments and market access, on fodder consumption and mobility. Holding herd size constant, a positive effect of an exogenous factor on fodder use implies the factor *increases the feeding intensity*, while a positive effect on mobility means it leads to *more extensive* husbandry. Our fine-grained model quantifies two types of effects of exogenous determinants on feeding outcomes: "structural", which trace the direct effects on endogenous herd size and feeding outcomes, and "reduced-form", which are net effects of the exogenous factors on feeding outcomes (see section 3.7 for a formal exposition).

Whilst many studies employ binary outcome variables (such as use of concentrate feed) as measures of farming intensity (e.g. Bernués and Herrero, 2008), we use detailed continuous measures of livestock mobility and feeding, which have very different determinants. We focus on the role of post-Soviet reforms, which have resulted in patterns of farm structure, land access and herd size which are likely to influence feeding decisions (Kvartiuk and Petrick, 2021). Using indicators of these restructuring outcomes, such as cropland allocation and unique data on rights to pasture use, we explore the chains of causality underlying different feeding strategies. Our specific research questions are thus as follows:

a) What are the determinants of land use and feeding strategies among livestock owners in Kazakhstan?
b) Among these determinants, what is the specific role of recent reform outcomes concerning land access and farm restructuring?

Next, we provide a brief review of the literature and context that motivate our model specification, then moving on to a detailed exposition of methods and results.

2. Drivers of livestock feeding strategies

2.1. Livestock sector intensification over time

Conceptualizing livestock development in land abundant environments, Binswanger and McIntire (1987) argue that population growth and external trade reduce the incentives for transhumance among herders, promoting sedentary agriculture and the emergence of individualized land rights, as well as input and output markets. In earlier stages of intensification, agro-ecological conditions and availability of production factors such as land are crucial, but these later give way to costs of land access, proximity to input and output markets as well as storage and transport infrastructure, which are key to commercial success (Robinson et al., 2011). However, in some arid systems, intensification through increased fodder provision is challenging due to low and variable rainfall, unclear property regulations and remoteness (Steinfeld et al., 2006). Land may be abundant, but if crop production is risky or impossible and fodder unavailable or expensive then returns on inputs and labor may be low (Lele and Stone, 1989). In such areas producers may expand into new areas (if these exist) or intensify through increases in stocking rates on pasture (Godde et al., 2018).

Historically characterized by transhumant livestock systems, Kazakhstan is an interesting case of population sedentarization followed by several waves of intensification during the 20th century under the paradigm of a socialist industrialization of the countryside (Ferret, 2018; Giese, 1983). Then, after independence in 1991, the sector suffered almost total collapse with the loss of about two thirds of animals. Following the breakdown of large livestock producing enterprises, most livestock are now held in small individual farms and rural households (Robinson, 2020; Robinson et al., 2021b). Households typically have privately owned kitchen gardens (small land plots for food production close to their homes) and a few livestock but are not eligible to lease state lands for farming purposes. To acquire this right, producers must register as 'farmers', which are generally larger holdings, although most are smaller than 'enterprises' which are the much larger private successors to state and collective farms (Robinson, 2020).

Current policy again promotes livestock intensification through both greater use of inputs and numbers of livestock as a pathway for diversifying the economy away from oil and gas revenues (Government of Kazakhstan, 2018; Petrick et al., 2018). Recovery from the collapse of state-supported migratory systems has been slow, with livestock expansion back into remote pastures (outside daily grazing radius of settlements) occurring in some areas but not in others (Dara et al., 2020; Kerven et al., 2016b). Implications of re-expansion for vegetation and wildlife are likely to be mixed: moderate grazing controls fire and is essential for many steppe-dwelling species (Kamp et al., 2015), but may also be associated with increased human presence and competition with wild ungulates (Baumann et al., 2020; Khanyari et al., 2022).

2.2. Current constraints and drivers of feeding strategies in Kazakhstan

2.2.1. Agro-ecological conditions and cropping potential

Kazakhstan's climate is largely arid and extremely continental, so feed cost and availability are major impediments to intensification (Broka et al., 2016; Kerven et al., 2021). Whilst 8% of the country is covered by arable land, the vast majority is rainfed and located in the north of the country where it is dependent on low and variable precipitation, making production in some areas economically risky (Dara et al., 2018). Farmers wishing to intensify will thus be constrained by climatic conditions, soil quality and water availability, or have to rely on supplementary feed imported from abroad.

2.2.2. Pasture availability

Natural conditions may favor expansion into rangelands. These cover 90% of Kazakhstan's usable agricultural land and offer a range of ecological conditions over the year (Alimaev, 2003; Zhambakin, 1995). Yet just under 50% of usable pasture area is formally allocated to users, with the rest held in the state reserve (Broka et al., 2016; Issayeva and Bakhralinova, 2020). Even when leased, the Government of Kazakhstan (2018) argues that many pastures are under-stocked or abandoned. Thus, although nationally livestock numbers are expanding fast, grazing pressure is regionally and locally uneven and there may be room for sustainable expansion into underused areas (Hankerson et al., 2019; Kolluru et al., 2023).

2.2.3. Land tenure and access

Kitchen gardens are owned outright by both households and farms, but formal titles over additional agricultural lands are available to registered farms only. Some of these lands were distributed as shares to former collective or state farm workers for permanent use in the 1990s, but land remained state-owned and these agreements were subsequently converted to 49-year leaseholds from the state, which now remain the dominant form of land title. Land privatization is possible following the 2003 Land Code, but the process is expensive and currently subject to a moratorium until 2026. New state leaseholds must be accessed through competition or auction. State control of these transactions is bureaucratic and has inhibited the emergence of dynamic land markets or use of land as collateral (Kvartiuk and Petrick, 2021). On winter, spring and autumn pastures these 49-year leaseholds from the state are the major form of property right. However, on summer pastures a number of other arrangements are also available (Kerven et al., 2016a; Robinson et al., 2021b). These include short term contracts with the forestry department and informal agreements with district authorities for state reserve lands (lands as-yet unallocated for 49-year lease). The former are obtained through individual application and common in high pastures where much of the pastureland is state forest; the latter are negotiated directly with local mayors and although use should be free of charge (Government of Kazakhstan, 2003), payment is sometimes required. All livestock owners, including households, have legal access to common pastures around the villages in which they are resident whilst some also sublease, although this is technically illegal. One of the three study districts has also allocated additional grazing lands for common use in summer areas, although these are mostly used by farms rather than households (Robinson et al., 2021a, 2021b).

2.2.4. Subsidies and credit

Successive state programs have promoted the intensification of beef production systems, providing subsidies and credits for fodder production, finishing and genetic improvements (Government of Kazakhstan, 2017; Petrick et al., 2018). These mostly went to enterprises or to the largest individual farms, but bypassed the majority of livestock owners (Petrick et al., 2017; Robinson et al., 2021b).

2.3. Determinants of feeding outcomes and associated hypotheses

Here, we introduce those factors potentially determining how livestock are fed in Kazakhstan and the mechanisms by which they are likely to act upon the more fodder-reliant or pasture-based outcomes which we explore in this study.

Higher precipitation combined with lower temperatures results in more water availability on pastures located at higher altitudes. Producers based in these areas may be more mobile thanks to proximity of high-quality summer pastures. On the other hand, precipitation at high altitude settlements also favor higher pasture yield near the home base and so may decrease the need to move elsewhere. We predict that, in line with Boserup (1965), improved access to input markets and possibly labor close to urban centers will result in higher feeding intensity. Concerning mobility, two contradictory hypotheses appear possible: either those nearer to cities will need to move further to reach pastures or they may move less as fodder markets are available.

Access to more crop and hayland will allow farmers to produce more fodder and keep more animals and we suppose that those well-endowed with land will accordingly purchase less fodder and engage less in mobility. A lack of financial liquidity will have the opposite effects. In addition, we hypothesize that more household labor will make possible both self-production of fodder and mobility, but its effect on fodder purchases will depend on whether households are purchasing this input with the objective of growth and commercialization (requiring labor) or because they have no other options. Studies by Baltenweck et al. (2003) and Bernués and Herrero (2008) suggest that farmer education level is a key determinant of agricultural intensification. As agricultural entrepreneurship and intensification have been associated both with farmers of intermediate age (Weiss, 1999) and with younger farmers (Bernués and Herrero, 2008), we allow for non-linear effects below.

Regarding restructuring, we would expect farms and in particular those who had worked on a state farm to produce more and purchase less fodder than households and those who did not work on state farms, through better access to land. We expect to see the same pattern regarding mobility, as farms have both better access to pastures and more animals. Farms, more commercially oriented than households, may exhibit higher purchases of concentrate. More recently established farms are the least likely to have benefited from land reform because at later dates land became available only through application or auction, thus we expect that younger farms will be more pasture oriented, less likely to produce their own fodder and more likely to purchase it.

We assume that larger herds reduce the mobility cost per animal and moving them becomes economically more attractive. In this case, holding the land endowment and other input availability constant, larger herds will be associated with reduced fodder production, especially where producers have access to good winter pastures. Such a relationship may not hold for concentrate or even some roughage purchases if they are not direct substitutes for pasture. For example, herd size may have a positive effect on fodder purchases if these are used for fattening.

The above cover many of the determinants found to be significant in other studies (Baltenweck et al., 2003; Godde et al., 2018). Others include cost of intensification technology; costs of pasture use; access to off-farm incomes; farmer time preference and risk perception (Godde et al., 2018; Pagiola and Holden, 2001). These were not measured in our study but may also contribute to decisions made by farmers.

3. Methods and data

3.1. Livestock production at the study site

Our study site includes three districts in Almaty province (see Fig. 1 and Robinson et al., 2021b for details). The region includes a range of environmental conditions for fodder production. Settlements in Enbekshikazakh district are below 800 m above sea level and precipitation is below 400 mm, but irrigation is possible in many areas. Meanwhile, most settlements in Kegen and Raiymbek districts are over 1500 m and characterized by colder and wetter conditions, although warmer irrigated valleys also exist in Raiymbek. Most livestock producers keep multiple species of stock, which include cattle, horses and small stock (sheep and goats), which typically move to the summer pastures together. The site hosts a vertical transhumance regime between alpine summer pastures and winter pastures in snow free areas, with settlements in between. All species of stock engage in migrations; some are driven over great distances and can theoretically be kept on pasture all year around (Ferret, 2018). In Enbekshikazakh district the local government has allocated part of the pastures in state reserve for common use.

In addition to agro-ecological diversity, settlements are located along a transect between 100 km and 300 km towards the east from Almaty, with reasonable access to abattoirs and markets in Enbekshikazakh district (closest to Almaty) and poor access in Raiymbek, which is located on the Chinese border and lacks even a local market. Input and output markets are thus likely to be important constraints.

Both livestock and human population densities in Almaty province have risen strongly in recent years (supplementary material, Figs. A1 & A2). But rural human population growth close to the city contrasts with losses in more remote areas. Growing populations combined with rising output prices and increasing urban demand for quality produce may favor intensification, but associated increases in labor opportunity cost may work in the opposite direction. The ratio between wages and land rents is difficult to observe because there is no rental market and leasehold costs are set by the State. Wages at the time of our study were over 35% higher in Enbekshikazakh than in Raiymbek.

3.2. Farm survey

In June 2018, we surveyed 50 households and 200 farms selected through a two-stage sampling process, with first sub-district, then farmers and households sampled at random using existing lists for farmers and random visits for households (see Robinson et al., 2021b for details). Households and farms are taken from different sampling frames, but exhibit similar shaped livestock ownership distributions, although the mean for households is lower (supplementary material, Fig. A3). We assume that drivers of feeding strategies are likely to affect

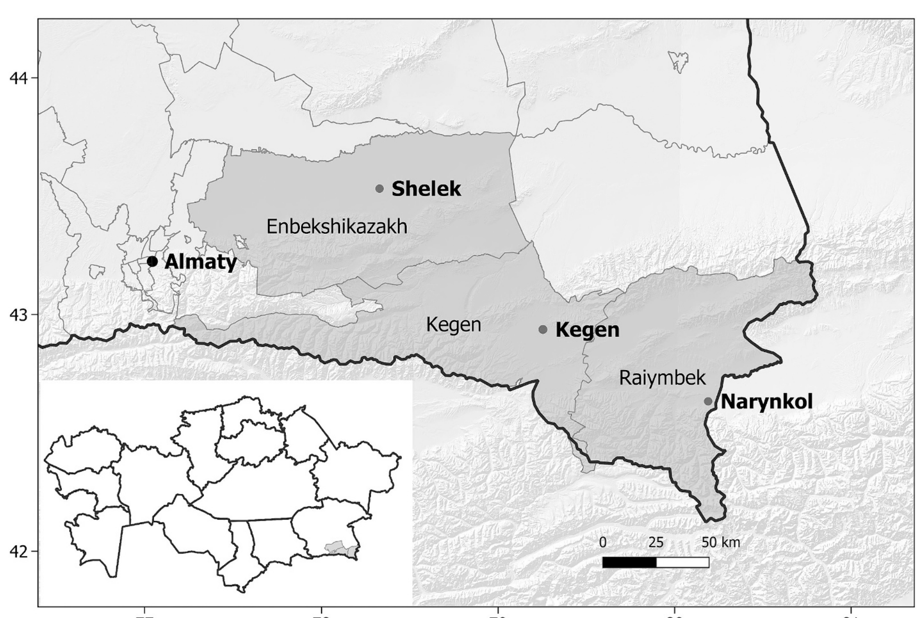

Fig. 1. Study site.
(Source: authors.)

households and farmers in similar ways and we thus group both together for the purposes of our analysis. The key outcome variables used in this study are listed in Table 1. Potential determinants (our explanatory variables) are listed in Table 2 and the descriptive statistics for these summarize the key ecological and socio-economic characteristics of the study site and sample.

3.3. Herd size as an endogenous variable

In Kazakhstan, use of remote pastures involves fixed costs and will be more cost effective for larger herds (Kerven et al., 2004; Kerven et al., 2006; Mirzabaev et al., 2016). However, feeding strategies also determine the potential for herd growth, whilst other determinants may exert their influence primarily through herd size as well. For this reason, we consider livestock numbers to be an endogenous variable, and design the empirical model accordingly, so that livestock is both a determinant in our seven feeding strategy equations, and an outcome variable in its own equation (see below). Livestock numbers exhibit a strong log-normal distribution and thus are log transformed in both cases.

We hypothesize that pasture access is the major determinant of livestock number and that this factor can be used as an instrument to mitigate the endogeneity of livestock ownership. We assume that pasture access is what allows livestock numbers to expand, resulting in turn in the feeding intensity outcomes observed. This statement is subject to a number of caveats, which are: (i) livestock ownership itself, linked strongly to the wealth and status of the applicant, may have played a role in negotiations for pasture resources (Crewett, 2011); (ii) although many pasture access arrangements are long term enough to be considered exogenous, others may be arranged at short notice and thus be at least partially endogenous; (iii) the impact of access arrangements on outcome variables may not always occur through livestock number – as a small herder can overcome this constraint by adding their livestock to a larger herd. However, in most cases, pasture access will logically precede stocking decisions and producers with theoretical access to large quantities of pasture cannot use them productively without having the livestock numbers required to cover herding and movement costs.

Table 1
Descriptive statistics for outcome indicators (feeding strategy and the endogenous variable herd size) used in paired equation models.

	Pooled sample ($n = 250$)				
Variable	Mean	Median	Min	Max	Number of censored records (with values at which censored)
Fodder availability					
Self-produced roughage (kg)	20,889	10,500	0	450,000	52 (0)
Self-produced concentrate (kg)	2284	0	0	200,000	195 (0)
Purchased roughage (kg)	18,493	0	0	1,860,000	129 (0)
Purchased concentrate (kg)	2347	775	0	50,000	77 (0)
Mobility indicators					
Share of mobile cattle in total (0–1)	0.59	0.85	0	1	87(0), 111(1)
Months spent on off-village pasture	5.35	5	0	12	83(0), 66 (12)
Maximum distance moved in the year (km)	28.9	15	0	200	87(0)
Endogenous livestock unit variable					
Livestock unit	277.4	123	7	4825	uncensored

Source: authors based on survey data collected in June 2018; fodder and mobility data refer to previous 12 months. Note: Roughage is defined as the sum of all hays (annual and perennial), silage and crop residues. Concentrates include grains, roots and combined feeds.

Table 2
Descriptive statistics for determinants of feeding strategy and herd size used in paired equation models.

	Pooled sample N = 250			
Variable	Mean or %	Median	Min	Max
Natural conditions				
Average annual precipitation[a]	384	379	325	440
Distance to markets and population density				
Distance from Almaty, km	205	233	104	291
Number of households in sub-district	1169	835	283	6162
Endowment with production factors				
Livestock unit	277.4	123	7	4825
Pasture access category[b]	4.21	4.00	1	9
Cropland (including kitchen gardens) area (ha)	8.8	1	0	300
Hayfields Area (ha)	12.4	4	0	300
Credit constrained (0/1)	0.63	1	0	1
Socioeconomic characteristics of household				
Total household members	2.5	2	1	15
Categorical education index (0–2)	1.1	1	0	2
Primary education (%)	6			
Secondary education (%)	74			
Higher education (%)	20			
Age of manager (years)	54.9	55	23	86
Farm restructuring experience				
Household (1) or commercial farm (0)	0.20	0	0	1
Worked on state farm (0/1)	0.49	0	0	1
Years since farm establishment	20.3	22	0	30
District indicators				
Enbekshikazakh district (0/1)	0.20	0	0	1
Kegen district (0/1)	0.21	0	0	1
Raiymbek district (0/1)	0.59	1	0	1

Source: authors based on survey data collected in June 2018; land use data refer to previous 12 months; [a]Precipitation is highly correlated with altitude, which ranges from 500 m to 2100 m, with a mean of 1500 m. It is negatively related to mean annual temperature, which ranges from 2 to 10 °C. [b]See Table 3.

3.4. Measuring feeding outcomes

Under rising demand for animal products, livestock farmers may simultaneously pursue various combinations of the following feeding strategies:

1. Provide additional fodder based on the crop and hay land available to them.
2. Provide additional fodder through purchases.
3. Expand into new grazing areas abandoned or underused since the Soviet period, measured through indicators of livestock mobility.

The fodder strategies also differ in terms of the *quality* of fodder provided. Roughage is defined as the sum of all hays (natural hay and cultivated hays such as lucerne), silage and crop residues. Concentrates include grains, roots and combined feeds.

We produced a set of seven outcome indicators covering these strategies as follows (see Table 1 for descriptive statistics):

Strategy 1: Fodder production using own land: We use the quantities (weights in kg) of fodder provided to livestock over one year, looking at self-produced roughage and concentrates separately. We use metrics of fodder provision for the entire herd, not per head of livestock, using the latter instead as a determinant (see empirical model). These variables are censored at zero, with a large proportion of respondents producing zero concentrate in particular, whilst others produce large amounts. For this reason, the data were log transformed before statistical analysis; with addition of a constant of 1 beforehand, so that zeros are transformed to a value of 0 in the logged data.[1]

Strategy 2: Fodder purchase. As above, we produced variables for annual weights of roughage and concentrate separately. As for fodder production, these variables are measured in kilograms, censored at zero and were log transformed for the analysis.

Strategy 3. Pasture use. We measured extensive feeding strategies using three mobility indicators. The first of these is the *number of months livestock are kept on off-village pastures*, a variable censored at zero and 12 with zero indicating residence in villages all year around and 12 indicating use of several off-village locations or permanent residence at an outlying base. The *length in kilometers of the maximum move* is censored at zero only. A long move may reflect the ability of the herder to move their animals or the distance they live from pastures. The *proportion of mobile cattle in the total cattle herd*, censored at 0 and 1, reflects the fact that producers may own some sedentary and some mobile animals. Of these values most are zero or one, only 52 values fall between the two. Unlike other species, all our respondents own cattle and variability of movement is likely to be greatest within this species, as some dairy animals may be kept back at home. Thus, we use this variable to capture variation in mobility of this part of the overall livestock herd.[2] Together, these indicators cover a number of different aspects or dimensions of mobility (supplementary material, Fig. A4).

3.5. Measuring the determinants of feeding outcomes

Concerning natural conditions, data for precipitation, temperature were extracted from the 1 km resolution 'bio' variables of the WorldClim dataset (Hijmans et al., 2005).[3] Altitude was sourced from the 90 m SRTM digital elevation model.[4] Raster data were obtained using Google Earth Engine and values extracted at points corresponding to the interviewees' home village or winter farm base. Of these indicators, precipitation, which affects pasture quality and rainfed crop production and has extremely strong relationships with temperature (negative) and altitude (positive),[5] was selected for modelling (Table 2). Districts were included as dummy variables.

Access to markets was represented through distance from Almaty, measured as the crow flies from place of interview. Population density was measured at the sub-district level, taken from (Kazakhstan State Statistical Agency, 2011).

We measure herd size in livestock units (LU).[6] Land endowments in logs were split into cropland (area of arable land available to the household, including kitchen gardens) and hayland (area of meadow for cutting of natural hay).

We analyze producers' access to funding using a method that directly elicits individual borrowing status from the respondents (Boucher et al., 2009; Petrick et al., 2017). We consider a farm or household to be credit constrained if the owner applied for a loan and was rejected or would have liked to borrow more at the going interest rate than he/she actually obtained. We also classified farmers as rationed if they refrained from borrowing because they feared the risk of defaulting on the loan or regarded the application procedures as too complicated (risk rationing and transaction cost rationing).

Household labor resources are measured as number of resident adults working on the farm or household. Education is represented as an index indicating the level of schooling of the farm manager. The age of the manager in years is also included.

We include three indicators of farm restructuring. Firstly, legal status of the farming entity, either registered farm (eligible for farmland leases) or a livestock-holding household (ineligible), is recorded in a binary variable. A second binary variable records whether the farm or household head worked on former state farm and was thus a possible recipient of land shares in the 1990s. More recently registered farms are the least likely to have benefited from land reform because at later dates land became available only through application or auction. Thus, a third (continuous) variable measures the number of years since farm establishment of the farm.

3.6. Measuring pasture access

Because many pasture users lack written contracts, or lease a small area but use much more, they are unable to provide accurate information on the area of pasture which they use. Thus, the number of different pasture areas used over the year is likely to be more informative. In addition, there are several forms of pastoral land tenure, some of which are more secure and long term than others (see section 2.2). We devised a discrete index assumed to be equally spaced, which combines the number of different pastures used over the year with the type of access arrangement. The index gives higher scores to areas accessed through individual and long-term arrangements (see Table 3). The 49-year government lease is the longest term and most secure arrangement available, as formal contracts are provided. Individually accessed state reserve and forest lands score higher than reserve lands allocated for common use, which are small and shared with other users. Sublease from another farmer is technically illegal and thus insecure - but potentially exclusive. It thus scores higher than village pastures, available as a common resource to all residents. Although access is theoretically secure and subject to few

[1] We model feeding and mobility outcomes as censored tobit regressions (Roodman, 2011, p. 163). This is a parsimonious way of modelling the hurdle and the metric outcome simultaneously (Wooldridge, 2020, p. 571). The range of the outcomes is often quite large, from near zero to several hundreds of thousands (Table 1), and approximates a log-normal distribution.

[2] We did consider the idea that the proportion of cattle in the herd might be important in relation to feed intensification, as most fodder is provided to cattle. However, the proportion of cattle is an intensification *outcome* as much as it is a *predictor* of feeding intensity or pasture use. We used this variable as an outcome in some exploratory multiple regressions using the same predictors as those of our simultaneous equations, and found it to be negatively influenced by total stock ownership, precipitation, working on state farm and distance. So those with smaller herds, living in areas with lower precipitation close to Almaty are more likely to specialise in cattle. This makes sense as these are all aspects of stock production in Enbekshikazakh, closer to Almaty with less pasture availability and more possibility to sell milk. It is notable that crop and hayland access are not directly important here. We did not include this analysis in our equation pairs as this outcome added too much complexity adding in effect an additional endogenous variable to the mix.

[3] https://www.worldclim.org/data/index.html.

[4] https://srtm.csi.cgiar.org

[5] The variables precipitation, temperature, altitude and distance have correlation coefficients of above 0.7 for all combinations except precipitation and distance. In multiple regressions, the inclusion of all of them results in variance inflation factors (VIF) of over 200 in some cases, whilst anything less than ten is considered problematic (Myers, 1990). The most orthogonal combination is that of precipitation and distance which, when the others are omitted, produce VIF values of <3 and an average of 1.53 in multiple regressions. For this reason, temperature and altitude are not included in our analysis.

[6] Based on Kazakhstani sheep units (sheep & goat = 1 LU, horse = 5 LU, cattle = 5 LU).

Table 3
Indicator of pasture access employed as an instrument in paired equation models.

Pasture access category	Score	Frequency	Percent of sample (N = 250)
Village pasture only	1	82	32.8
Subleases from leaseholding farmer	2	22	8.8
No 49 year lease, but accesses one other area of state-owned off-village pasture (off-village common lands)	3	20	8
No 49 year lease, but accesses one other area of state-owned off-village pasture (forest department lands, individual contract)	4	19	7.6
No 49 year lease, but accesses one other area of state-owned off-village pasture (reserve lands, individual arrangement)	5	4	1.6
One 49 year government leasehold	6	41	16.4
No 49 year government lease, but accesses at least *two* other areas of state-owned off-village pasture	7	3	1.2
One 49 year government lease plus at least one other arrangements for use of state pastures	8	28	11.2
Two government 49 year leases	9	31	12.4
Total		**250**	**100**

Source: authors based on survey data collected in June 2018; pasture access data refers to previous 12 months.

transaction costs, these areas are often highly stocked and used by those unable to send their animals to more productive seasonal pastures (Alimaev, 2003; Alimaev et al., 2008).

3.7. Simultaneous equation model

In specifying the quantitative model, the two major challenges to consider were the censoring of outcome variables and the endogeneity of herd size. We address these challenges by using recursive multi-equation conditional mixed process modelling (cmp) (Petrick and Götz, 2019; Roodman, 2011). These models allow for inclusion of equations with different outcome distributions, provided that they involve a linear function and that the error terms across equations follow a joint normal distribution.

For each of our feeding outcomes, we construct a paired equation model including the main eq. (1) in which livestock unit is a predictor variable for the feeding indicator of interest; and a second eq. (2) in which it is the outcome variable. In this second equation the other predictors are identical to those in the main equation, with the addition of an exogenous variable pasture access. Following an econometric approach, we assume this "instrument" to affect the main outcome through livestock only. The main outcome equations were modelled as censored variables whilst livestock was modelled as an uncensored continuous variable as there are no zero values (Table 1). For notational simplicity, the equations below show an equation pair for those variables which are left-censored only.

$$\boldsymbol{y} = \begin{cases} 0 \text{ if } \boldsymbol{y}_i^* \leq 0 \\ \boldsymbol{\alpha} l_i + \boldsymbol{x}_i' \boldsymbol{\beta}_a + \boldsymbol{\epsilon}_{ai} \text{ if } \boldsymbol{y}_i^* > 0 \end{cases} \quad (1)$$

$$l = \boldsymbol{x}_i' \boldsymbol{\beta}_b + \theta \pi_i + \boldsymbol{\epsilon}_{bi} \quad (2)$$

with $\epsilon = (\boldsymbol{\epsilon}_{ai}, \boldsymbol{\epsilon}_{bi})' \sim N(0, \Sigma)$.

$\boldsymbol{y}$ is a vector of four feeding and three mobility outcome indicators (Table 1) and $\boldsymbol{y}^*$ the vector of partly latent index variables for the outcome indicators; l is the logged number of livestock units entering each of the equations; x_i is a vector of determinants which is the same in all outcome equations and $\boldsymbol{x}_i$ the matrix of determinants across equations, π is the instrument pasture access. $\boldsymbol{\beta}$ is the matrix of parameters for the determinants $\boldsymbol{x}_i$; $\boldsymbol{\alpha}$ and θ are other parameters to be estimated and ϵ is the equation-specific error term.

Estimation was carried out using the cmp routine (Roodman, 2011) in Stata 16 which maximizes the joint likelihood function of each equation pair, assuming that the error terms follow a joint normal distribution.

We present both the structural and reduced form equation results. The structural form solves the two eqs. (1) and (2) simultaneously. It produces coefficients representing the *direct* effects of each determinant on the outcome (i.e. separated from effects mediated through livestock unit).[7] The reduced form finds the combined effects of livestock unit and the exogenous determinants by substituting the livestock equation instead of livestock itself in the main intensity outcome equation. Thus, this form gives the net estimates for each determinant, but the contribution of herd size to those effects is unseen. Large differences in coefficient estimates for reduced and structural forms thus indicate that the effects concerned are strongly mediated through livestock number.

Inserting (2) into (1) yields:

$$\boldsymbol{y} = \begin{cases} 0 \text{ if } \boldsymbol{y}_i^* \leq 0 \\ \boldsymbol{\alpha} \beta_b x_i + \theta \pi_i + \boldsymbol{x}_i' \boldsymbol{\beta}_a + \epsilon_{ci} \text{ if } \boldsymbol{y}_i^* > 0 \end{cases}, \quad (3)$$

so that the reduced-form marginal effects of a single independent variable z on any outcome y can be calculated as:

$$\frac{\partial y}{\partial z} = \alpha \beta_b + \beta_a \quad (4)$$

Here, α is the coefficient for the effect of livestock in the main outcome eq. (1), β_b is the coefficient for the variable z in the livestock eq. (2) and β_a is the coefficient for variable z in the main outcome eq. (1). These are the effects we present in the columns with reduced form effects in Table 5 and Table 6 below, also providing *P*-values calculated using the delta method.

4. Results

Fig. 2 summarizes the structural relationships between our determinants, the endogenous factor of herd size, and the feeding outcomes according to eqs. (1) and (2). Estimation results for eq. (2) are presented in Table 4, showing the effects of the independent variables on herd size. Table 5 and Table 6 display the direct impacts of those same variables on the feeding and mobility outcomes according to eq. (1), i.e. their structural effects, and the net (reduced form) effects according to eq. (4).

Fig. 2 illustrates the strong effects of *land endowment* on herd size and feeding strategies. Access to crop and hay land allows farmers to produce more fodder and keep larger herds. For a given herd size, better access to crop and hay land increases feeding intensity via own fodder production, but reduces purchased fodder input and mobility. The net effects of land access are positive on fodder production and negative on purchases, too (see the reduced form effects in Table 5). As larger herds are also more mobile, the overall net effect of land access on mobility is not statistically significantly different from zero.

The marginal effects of *herd size* on fodder use imply the following average intensity levels: at sample means, adding one LU to the herd leads the farmer to purchase additional 219 kg of roughage and 18 kg of concentrate per holding and year, while self-produced roughage decreases by 111 kg.[8]

[7] We also estimated a system of all feeding strategy equations plus the herd size equation simultaneously using cmp, which provided results broadly similar to the pairs of equations.

[8] If herd size or another determinant enter the outcome equation (1) in logs, the estimated coefficients in Table 5 have the interpretation of an elasticity $\beta = \frac{\partial y}{\partial x} \frac{x}{y}$, so that the marginal effect at sample means $\bar{x}$ and $\bar{y}$ taken from Tables 1 and 2 is $\frac{\partial y}{\partial x} = \beta \frac{\bar{y}}{\bar{x}}$

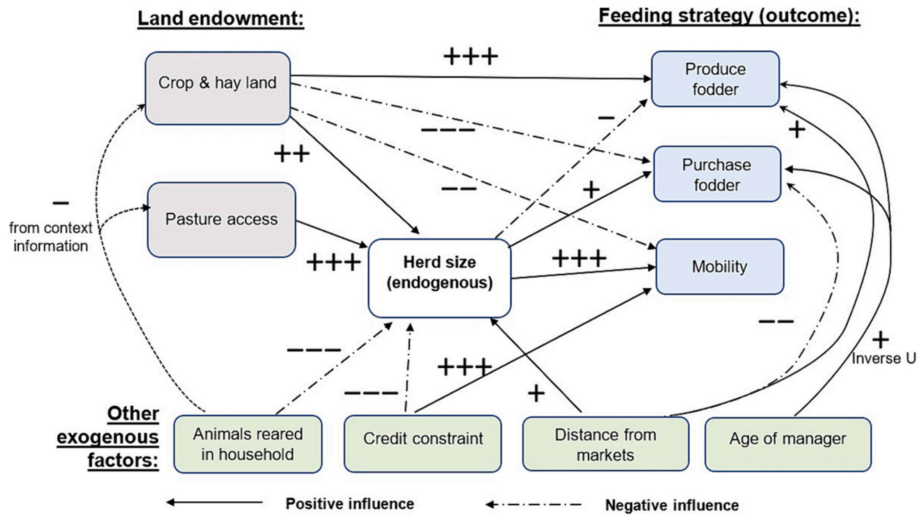

Fig. 2. Structural determinants of feeding outcomes.

Notes: The number of plus (+) or minus (−) indicates the sign and significance level of the coefficient in the model equations (+++ or — = $p < 0.01$, ++ or – = $p < 0.05$, + or - = $p < 0.1$). Land resources for own cultivation as well as fodder production and fodder purchase strategies were visually aggregated into one category each.

(Source: authors.)

Table 4

Results of the livestock (herd size) equation in paired equation models.

Determinants	Coefficient		P > |z|
Average annual precipitation	> − 0.01		0.932
Distance from Almaty, km	<0.01		0.186
Number of households in sub-district	> − 0.01		0.101
Pasture access category[a]	0.10	***	<0.001
Log of cropland area (ha)	0.14	**	0.011
Log of hayfields area (ha)	0.14	***	0.005
Credit constrained (0/1)	−0.32	***	0.005
Total household members	0.02		0.713
Categorical education index (0–2)	0.08		0.469
Age of manager (years)	0.02		0.493
Square of age of manager	> − 0.01		0.623
Household (1) or commercial farm (0)	−0.64	***	0.001
Worked on state farm (0/1)	−0.19		0.129
Years since farm establishment	> − 0.01		0.433
District (Kegen)	0.06		0.9
District (Raiymbek)	−0.87		0.19
Constant	3.71		0.013

Dependent variable is livestock units per farm in logs. ***$p < 0.01$, **$p < 0.05$, *$p < 0.1$; [a] See Table 3.

Herd size being held equal, *credit constrained* producers are more mobile, so that a lack of financial liquidity makes livestock production more extensive. For example, credit constrained farmers' share of mobile cattle in their total herd is 43%-points higher than for unconstrained farmers, and they move about 28 km further away on average (Table 6). But as farmers with credit access keep less animals, the overall effect of credit on mobility is neutral.

Household *labor availability* does not affect any of the feeding strategies examined, nor does it exhibit a relationship with livestock number. Education is not significant in any of the regressions, except for a weak relationship with share of mobile livestock in its reduced form equation. At the same time, mid-age farmers are more active in fodder production or purchase than older or younger farmers.

Distance from markets compels farmers to produce more fodder themselves. Fodder purchases appear to be lower in Raiymbek than in Enbekshikazakh reflecting the remoteness of the former district. Distance is also an important negative determinant for both concentrate production and purchase.

Households keep significantly fewer livestock (Table 4) and produce less roughage than commercial farms (Table 5). Controlling for herd size, households are associated with higher values of mobility indicators than farms. Having worked on a state farm is not related to any feeding or mobility indicators, while farms established earlier display slightly less pronounced mobility patterns.

Precipitation has no significant effect on any of our feeding outcomes, or on livestock ownership. Also, *settlement size* was not significant in any of the fodder equations, but is negatively related to share of mobile livestock and maximum distance of movement, suggesting more mobile strategies in sparsely populated areas, as expected.

Maximum distance moved is lower in both Kegen and Raiymbek than in Enbekshikazakh, suggesting that those in the latter district move further to reach distant pastures.[9] But in the structural form of the equation these relationships disappear, suggesting that they may be consequences of differences in herd size. Other mobility indicators are not higher in Enbekshikazakh.

Table 4 demonstrates that *pasture access* is indeed a strong determinant of herd size, together with land endowment and credit access. There are no relationships between livestock numbers and farmer characteristics, market access or natural conditions. Although average numbers of livestock per farm or household are far higher in Kegen than in the other two districts,[10] this effect is not evident in the multiple regression, perhaps because it is represented by hay and pastureland, whose area is correspondingly very high in Kegen.

5. Discussion

At our Kazakhstani study site, land access largely determines how producers feed their livestock. This access has been dependent on land reform and farm restructuring processes, which constrain farmers' livestock feeding decisions today. As arable land was privatized first, this quickly became a scarce resource in our study area. Pastures were allocated much later, and in many cases to people who became specialized livestock producers only in recent years, by which time little arable land was left (illustrated in the negative relationship between age

[9] Mean maximum movement in Enbekshikazakh at 47 km is around double that of the other two districts, but there is no difference in medians.

[10] Mean livestock unit ownership is 630 in Kegen, 356 in Enbekshikazakh and 221 in Raiymbek.

Table 5
Results of the fodder use equations in paired equation models (structural and reduced forms).

	Log self-produced roughage						Log self-produced concentrate						Log purchased roughage						Log purchased concentrate					
	Structural			Reduced			Structural			Reduced			Structural			Reduced			Structural			Reduced		
	Coeff.		P	Coeff.		P	Coeff.		P	Coeff.		P	Coeff.		P	Coeff.		P	Coeff.		P	Coeff.		P
Log of livestock unit	−1.47	*	0.093	–		–	−0.59		0.855	–		–	3.28	*	0.091	–		–	2.11	*	0.066	–		–
Average annual precipitation	<0.01		0.608	<0.01		0.539	<0.01		0.892	<0.01		0.889	−0.03		0.341	−0.03		0.331	<0.01		0.975	> – 0.01		0.999
Distance from Almaty, km	0.01		0.467	<0.01		0.794	0.10	**	0.044	0.09	*	0.055	0.05		0.205	0.06	*	0.079	−0.05	**	0.014	−0.04	**	0.032
Number of households in sub-district	> – 0.01		0.217	> – 0.01		0.384	<0.01		0.647	<0.01		0.579	<0.01		0.212	<0.01		0.492	> – 0.01		0.696	> – 0.01		0.292
Log of cropland area (ha)	0.99	***	<0.001	0.79	***	<0.001	5.31	***	<0.001	5.23	***	<0.001	−2.93	***	<0.001	−2.48	***	<0.001	−1.69	***	<0.001	−1.41	***	<0.001
Log of hayfields area (ha)	2.06	***	<0.001	1.84	***	<0.001	0.22		0.788	0.14		0.813	−2.90	***	<0.001	−2.42	***	<0.001	−0.65	**	0.042	−0.35		0.160
Credit constrained (0/1)	−0.75		0.213	−0.28		0.557	0.10		0.962	0.29		0.868	0.67		0.582	−0.38		0.722	0.94		0.212	0.27		0.671
Total household members	−0.10		0.487	−0.13		0.352	0.14		0.747	0.12		0.769	−0.21		0.615	−0.14		0.749	−0.31		0.291	−0.27		0.277
Categorical education index (0–2)	−0.01		0.982	−0.13		0.774	−2.61		0.160	−2.66		0.156	0.34		0.765	0.61		0.581	0.63		0.355	0.80		0.222
Age of manager (years)	0.22	*	0.094	0.20		0.113	−0.56		0.261	−0.57		0.251	0.15		0.565	0.21		0.394	0.26		0.117	0.30	*	0.066
Square of age of manager (years)	> – 0.01		0.151	> – 0.01		0.166	<0.01		0.279	<0.01		0.270	> – 0.01		0.562	> – 0.01		0.427	> – 0.01	*	0.095	> – 0.01	*	0.057
Household (1) or farm (0)	−3.29	***	0.003	−2.34	***	0.007	−2.45		0.586	−2.07		0.536	2.00		0.379	−0.11		0.946	2.30		0.111	0.95		0.372
Worked on state farm (0/1)	−0.16		0.781	0.12		0.820	1.43		0.519	1.54		0.485	−0.94		0.455	−1.56		0.189	−0.21		0.782	−0.61		0.409
Years since establishment	> – 0.01		0.962	0.01		0.810	0.05		0.724	0.06		0.697	0.14		0.112	0.11		0.192	−0.06		0.276	−0.08		0.128
District (Kegen)	−1.59		0.415	−1.68		0.326	−4.02		0.576	−4.05		0.571	−1.00		0.822	−0.80		0.859	1.49		0.559	1.62		0.531
District (Raiymbek)	−0.06		0.980	1.21		0.576	−13.51		0.121	−13.00		0.148	−7.89		0.211	−10.73	*	0.080	7.84	**	0.038	6.01	*	0.095
Pasture access category[a]	–		–	−0.14	*	0.074	–		–	−0.06		0.855	–		–	0.32	*	0.082	–		–	0.21	*	0.058
Constant	1.12		0.880	−4.34		0.478	−8.39		0.781	−10.59		0.681	−6.74		0.704	5.42		0.738	−3.00		0.767	4.83		0.602

*** $p < 0.01$, ** $p < 0.05$, * $p < 0.1$; [a]See Table 3.

Table 6
Results of the livestock mobility equations in paired equation models (structural and reduced forms).

	Share of mobile cattle						Months on off-village pasture						Maximum distance moved					
	Structural			Reduced			Structural			Reduced			Structural			Reduced		
	Coeff.		P	Coeff.		P	Coeff.		P	Coeff.		P	Coeff.		P	Coeff.		P
Log of livestock unit	1.42	***	<0.001	–		–	14.46	***	<0.001	–		–	96.12	***	<0.001	–		–
Average annual precipitation	> – 0.01		0.742	> – 0.01		0.217	−0.02		0.700	−0.02		0.210	−0.17		0.596	−0.20		0.260
Distance from Almaty, km	> – 0.01		0.594	<0.01	**	0.047	−0.03		0.524	0.04	**	0.042	0.11		0.79	0.56	**	0.011
Number of households in sub-district	<0.01		0.389	> – 0.01	**	0.023	<0.01		0.184	> – 0.01		0.728	> – 0.01		0.694	−0.01	***	<0.001
Log of cropland area (ha)	−0.16	*	0.076	0.03		0.130	−2.02	**	0.022	−0.07		0.783	−11.76	**	0.046	1.22		0.599
Log of hayfields area (ha)	−0.21	**	0.023	> – 0.01		0.941	−1.87	**	0.028	0.22		0.337	−15.42	**	0.014	−1.53		0.501
Credit constrained (0/1)	0.43	**	0.015	−0.02		0.699	5.71	***	0.001	1.09	*	0.087	28.31	**	0.028	−2.42		0.704
Total household members	−0.04		0.640	> – 0.01		0.653	−0.08		0.922	0.24		0.163	−3.02		0.537	−0.91		0.669
Categorical education index (0–2)	−0.02		0.923	0.10	*	0.068	−0.96		0.534	0.21		0.698	−6.38		0.612	1.44		0.803
Age of manager (years)	> – 0.01		0.918	0.02		0.219	−0.08		0.809	0.17		0.313	−0.80		0.807	0.87		0.674
Square of age of manager (years)	> – 0.01		0.950	> – 0.01		0.215	<0.01		0.920	> – 0.01		0.353	<0.01		0.894	> – 0.01		0.689
Household (1) or farm (0)	0.80	***	0.018	−0.12		0.284	7.74	**	0.018	−1.58		0.141	56.75	**	0.034	−5.20		0.661
Worked on state farm (0/1)	0.19		0.308	−0.08		0.232	2.31		0.193	−0.42		0.527	17.78		0.202	−0.39		0.958
Years since establishment	<0.01		0.946	−0.01	**	0.022	0.05		0.747	−0.07		0.148	−0.80		0.473	−1.61	***	0.005
District (Kegen)	−0.31		0.643	−0.22		0.342	−2.73		0.664	−1.84		0.444	−68.56		0.158	−62.68	**	0.019
District (Raiymbek)	0.72		0.463	−0.52		0.124	7.74		0.402	−4.83		0.127	−25.42		0.725	−108.97	***	0.004
Pasture access category[a]	–		–	0.14	***	<0.001	–		–	1.43	***	<0.001	–		–	9.48	***	<0.001
Constant	−5.43		0.020	−0.15		0.863	−56.62		0.012	−2.90		0.739	−320.44		0.063	36.57		0.711

*** $p < 0.01$, ** $p < 0.05$, * $p < 0.1$; [a]See Table 3.

of farm and mobility indicators in reduced form equations). Moreover, the overall availability of cropland in the region combined with the difficulty in acquiring it mean that above a certain size farmers will always become more mobile, leading to an inverse relationship between fodder provision and mobility.

The relationships between land endowments and fodder provision strategies are evident in both structural and reduced form equations. For example, according to our estimates, expanding cropland access for farmers by 1% would increase the amount of self-produced concentrate by 5.2% and reduce the purchase of it by 1.4%, while slightly expanding herd size on average across our sample population. Increasing access to hayland by 1% will increase roughage self-production by 1.8% and reduce roughage purchases by 2.4% (Table 5). At sample means, easing the cropland constraint by one hectare increases the production of concentrate by 1327 kg and reduces the purchase of it by 368 kg per year on average. One additional hectare of hayland leads to 3203 kg more of self-produced roughage and 3729 kg of it purchased less per year. But note that a majority of farmers neither self-produces any concentrate nor purchases roughage (Table 1).

The substitution between pasture and self-produced fodder is not as evident as it first appears: some studies find that cultivated land areas are only weakly related to intensification of feeding strategy due to substitutability of purchased and farm-grown fodder (Staal et al., 2002). Clearly in the rangeland system we study, substitution is more difficult – and distance from Almaty is an important predictor of concentrate purchase. Thus, at large holdings and far from markets, it may be cheaper to use pastures than either fodder procurement strategy. Baltenweck et al. (2003) suggested that the positive relationship between land size and concentrate provision found in their multi-country study was counter-intuitive. In our study, the separation into different land use types and fodder sources made interpretation easier, as it was possible to isolate the positive impact of holding cropland on self-production of concentrate.

As expected, we also find that credit constraints determine many feeding decisions. Credit constrained farmers' share of mobile cattle in their total herd is 43%-points higher than for unconstrained farmers, and they move about 28 km further away on average (Table 6). In the regression of self-produced roughage, we observe a weakly significant negative effect of the credit constraint (Table 5) which also suggests that mobility may thus be compensating for a constraint on fodder, even though this was not detected directly in the other fodder equations. Our credit variable indicates an unmet, excess credit demand, hence covers both availability and demand, which are quite different types of constraints; the first related to credit suppliers and government policy and the second to perception of risks and opportunities among farmers. Apparently the current credit subsidy policy did little to alleviate these constraints, probably reflecting barriers to achieving returns on investments in intensification in more remote or pastoral environments (Godde et al., 2018). For example, specialization requires investment in more vulnerable breeds and reduces multi-functionality of livestock, which both increase risk and create barriers to adoption of intensification technologies (Paul et al., 2020). Surveys show that perceived credit default risks are quite important in Kazakhstan. Farmers doubt they can generate a sufficiently large and stable revenue stream to service a loan, due to uncertain fodder supply and fragmented value chains (Petrick et al., 2017; Robinson, 2020).

Other factors found to be important in the literature were not significant in our study. These include farmer education level, human population density and household labor availability (Baltenweck et al., 2003; Bernués and Herrero, 2008). These findings may reflect the socialist educational legacy and a relatively high ratio of labor resources to livestock, implying low labor productivity in animal husbandry. When presented with a list of potential constraints to growth, a relatively small proportion of survey respondents (6% of households and 9% of farms) selected labor as one of these. We conclude that labor is not a limiting factor for livestock intensification, which may reflect the availability of redundant labor at our study site.

Easing constraints to land and credit access would likely spur further herd growth. But that does not mean that large farms will emulate the feedlot model found in many Western countries. Our results rather show that at larger herd sizes, use of remote and seasonal pastures is the major feeding strategy employed by producers for all species of livestock. After the slump during the first decade after independence (Fig. A1), farmers in the rangeland system we study are once again making more productive use of the country's pasture resources, exploiting pasture heterogeneity to increase forage intake over the year.

Hence, despite the emphasis by policymakers on intensive fattening systems (in particular for cattle), grazing remains a key resource for all types of livestock production at scale, at least in south-eastern parts of the country where heterogeneity of landscapes and vegetation is high. This pattern differs from the general trend of intensification based on external input use observed in many regions of the world (Davis et al., 2015). This tendency is notably absent in developing and arid regions of the world where growth in livestock production has been achieved through increasing animal density on pastures rather than through efficiency gains (Godde et al., 2018), implying important trade-offs to intensification which remain poorly understood (Behnke, 2008; Reid et al., 2014).

One issue in Kazakhstan which affects cattle in particular is the high sensitivity of intensive fattening operations to feed prices (FAO Investment Centre (2010)). Having said this, whilst few farmers are able to fatten animals themselves and even fewer sell directly to industrial feedlots, some stock are fattened by intermediaries after sale (Robinson et al., 2021b). A more complete assessment of feeding systems would take into account the entire value chain and the consumers.

Better land and credit access would allow farmers to increase the size of their herds, which is the key driver of livestock mobility, but our results raise further policy issues and research questions. Constraints on land access are difficult to tackle without deeper changes to Kazakhstan's dysfunctional land markets. Current arrangements hamper the ability of producers to obtain new land, transfer it to others or even to give it back to the state for redistribution (Kvartiuk and Petrick, 2021). In our study area, arable land and conditions for crop production are also physically limiting. Yet on pastures also, lease markets function poorly and there is little provision for common property management suitable for smallholders to access pasturelands outside villages (Robinson et al., 2021a, 2021b). Policymakers should focus on more appropriate grazing rights systems on public and private land, including forms of tenure such as common property which facilitate access for smallholders, more flexible leasehold markets and corridors for livestock migration. These will also be of increasing importance in coming years as livestock mobility is an important adaptive response to climate change (Turner and Schlecht, 2019).

6. Conclusions

Overall, this study suggests that farmers are realizing economic benefits from livestock expansion via productive use of grazing land, an abundant resource in Kazakhstan. Improved pasture access will further stimulate herd growth and reduce demand for fodder grown on arable land. Such a strategy contrasts with livestock intensification via increased external input use and/or crop-livestock interaction observed in many low and middle income countries (Salmon et al., 2018), and it runs counter to a recent global trend of grassland contraction (Godde et al., 2018). Expansion into previously undergrazed areas involves its own specific trade-offs though. For example, extensive systems have high net GHG emissions per unit of product (Garnett et al., 2017; Gerber et al., 2013; Herrero et al., 2013), but can reduce fires and promote biodiversity (Kamp et al., 2016; Kamp et al., 2015). The environmental and economic benefits of expansion will be limited if they remain confined to the largest operations, leaving the bulk of producers close to settlements where pressure on pastoral resources is high and labor productivity is low. These are topics for further research.

CRediT authorship contribution statement

Sarah Robinson: Writing – original draft, Investigation, Formal analysis. **Martin Petrick:** Writing – review & editing, Supervision, Methodology, Formal analysis, Conceptualization.

Declaration of competing interest

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

Data availability

Data will be made available on request.

Acknowledgements

This study draws on outputs of the project "Revitalising animal husbandry in Central Asia: A five-country analysis (ANICANET)" (www.iamo.de/anicanet), funded by the German Federal Ministry of Education and Research (Bundesministerium für Bildung und Forschung), [grant number 01DK17031]. Part of the work was supported by the German Academic Exchange Service (DAAD) from funds of the Federal Ministry for Economic Cooperation (Bundesministerium für Wirtschaftliche Zusammenarbeit und Entwicklung), SDGnexus Network [grant number 57526248], program "exceed – Hochschulexzellenz in der Entwicklungszusammenarbeit." In addition to our funders, we would like to thank BISAM in Almaty and in particular Serik Jaxylykov for managing the survey and supervising enumerators, Nozila Mukhamedova who supported piloting, and all co-supervisors and enumerators who participated. We acknowledge Eduard Bukin's assistance in providing maps of district boundaries for Fig. 1. We would also like to thank our four anonymous reviewers who greatly contributed to improving the manuscript.

Appendix A. Supplementary data

Supplementary data to this article can be found online at https://doi.org/10.1016/j.agsy.2024.104011.

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