Quantitative Analysis of the Relationship Between Mining and Livestock Sectors in Mongolia

Master's Thesis

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Abstract

Discoveries and exploitation of mineral resources can increase economic growth and generate employment in developing countries. However, while the benefits of non-renewable resource extraction accrue mostly to owners of capital, the negative externalities on the environment can be disproportionately borne by people living in rural areas, such as nomadic pastoralists in Mongolia. This research uses panel data by soums (counties) in Mongolia to analyse the relationship between mining and livestock sectors. The study finds evidence that increase in mining is associated with higher mortality of livestock, indicating negative environmental externalities. More mining is also associated with more sales, or consumption of livestock, pointing to the positive effect of improved markets for herders.

I. Introduction

Nomadic (or pastoral) livestock herding has been the mainstay of the Mongolian economy since the ancient times. Although in present days it has declined in importance, its contribution to the economy is still significant. In 2010, livestock herding accounted for 23% of the national output of the country and has been the source of income for 34% of the population (Government of Mongolia, UNDP and SIDA, 2011).

The rapid increase in the prices of mineral commodities on the world markets during 2002-2008 led to a considerable increase in exploration and extraction of minerals in Mongolia. Known reserves of gold, copper, coal, iron ore and rare earths have been complemented by recent discoveries of major mineral deposits. In addition to formal, licensed mining, informal mining activity has sprang up throughout the territory. The rapid increase in both the volume and prices of minerals has accelerated economic growth, increasing incomes and jobs.

However, concerns about the negative social and environmental impacts of mining are increasingly voiced in Mongolia (Government of Mongolia, UNDP and SIDA, 2011). Mining, due to its capital-intensive nature, tends to generate disproportionately more income for capital-owners, rather than wage-earners. Mining booms may generate jobs indirectly, by raising incomes and increasing demand, but in poor countries mining often operates as an enclave sector, with limited linkages with the rest of the economy and limited job creation (Hailu et al, 2011). Therefore, economies with heavy reliance on mining industries tend to have higher inequalities. Mineral extraction processes also generate significant environmental externalities. In the case of Mongolia, herders have benefited relatively little from the mining boom, while bearing the brunt of the negative environmental impacts of mining on pastures, water and, consequently, on human and livestock health.

This research seeks to examine some of the environmental and social effects of mining on the livestock sector using administrative data collected by government agencies in Mongolia. Specifically, it examines two hypotheses: whether there is an association between mining and livestock mortality, and whether there is an association between mining and consumption of livestock.

The rest of this paper is organized as follows. Section II provides a review of the literature on the environmental and economic impacts of mining, as well as the organization of pastoral livestock systems. Section III proposes a working model and introduces the hypotheses. Section IV describes the data. Section V specifies the model and discusses the results. Section VI discusses the limitations of the study, and Section VII concludes.

II. Literature review

Economic Impacts of Mining

The main framework to analyse the impact of mining comes from Corden and Neary (1982) who examined the effects of oil booms on non-oil exporting sectors of economies (summarized in Hailu et al, 2011). The model identifies three main effects: 1) the spending effect; 2) the relative price effect; and 3) the resource movement effect. First, the boom in the resource sector creates a spending effect by raising the income level, the demand for tradable and non-tradable goods, and the prices of non-tradable goods. Second, the boom in the resource sector has a relative price effect. In a small open economy with flexible exchange rates the booming resource sector will lead to appreciation of currency, thereby reducing the relative prices of imported goods and domestically, the price of exported goods. Third, the boom of the resource sector creates a resource movement effect, since it competes with other sectors for inputs, such as labor and capital. The latter effect, the resource movement effect can also be extended beyond capital and labour, to land and water as inputs of production.

Mongolia is experiencing a prolonged mining boom since 2002, temporarily dampened in 2009 by the global recession. During 2002-2008, a period of rapidly growth in the prices of mineral commodities in international markets, Mongolia's GDP growth averaged 6.8 percent compared with 2.4 percent in 1995-2001, when commodity prices declined. During 2002-2008, the share of minerals in its exports has increased tremendously, from 57% to 85% (National Statistical Office of Mongolia, various).

While there are no systematic studies analyzing the impact of mining on agricultural production, the increase in prices of agricultural food products, which are predominantly traded domestically, points to possible spending and relative price effects from the mining boom.

Environmental Impacts of Mining

Mining generates significant externalities by affecting the environment through soil and water, although the specific impacts depend on the type of mineral and method of extraction (Earle and Robert, 1996). Mineral extraction requires a removal of large amounts of solid waste because the content of the mineral within the earth is usually small relative to the surrounding earth and rock mass. Therefore, one of the major impacts of mining is large-scale changes in the landscape, making the land unusable for farming, herding or residential purposes. Forests and other vegetation are removed in the process. In open-pit mining, large holes and heaps of earth are created. In underground mining, deep shafts can lead to *subsidization*, a process where the earth layers above the mine subside, or fall, into the shaft. With appropriate reclamation, most of these problems can be adequately addressed. But many developing countries with weak environmental regulation face these problems to a greater extent (Warhurst, 1998).

The amount of solid waste in surface mining can be two to ten times the volume of crude ore (U.S. Department of Interior, 1992, cited in Dudka and Adriano, 1997). For example, uranium is found typically with concentration of 0.05%, copper 0.5-1%, and iron 60-70%, signifying that 40-99.5% of total material removed is thrown out as solid waste (Barbour, 1994). Heaps of soil and waste generated in the mineral extraction process are broadly classified into *overburden* (earth overlaying the mineral deposit), *tailings* and *leach*. Each of these types of waste is generated at successive stages of mineral extraction and affects the environment differently. For example, the removed overburden is usually large in volume, but contains little to no mineral. After the mine closure, the overburden may be restored through the process known as reclamation, but even then, the changed soil structure is less able to support vegetation (Warhurst, 1998). Tailings are the solid waste generated in the process of separating crude ore from earth and rock, which contain higher amount of mineral residue. Leach is the waste generated in the phase of further refining the crude ore and contains high amount of heavy metals. Tailings and leach affect the environment by polluting water sources and areas in the vicinity with heavy metals and chemicals during rains, floods, and dust blows (Barbour, 1994; Dudka and Adriano, 1997).

Mineral extraction also has major environmental effects through water pollution. Water that infiltrates mines needs to be periodically drained. Such mine water contains higher amounts of minerals and toxins, both from the mineral deposit itself, as well as from chemicals used in the process of separating mineral from earth. For example, coal mining water discharges have high content of TSS (Total Suspended Sediment), hardness, and heavy metals, contaminating nearby water bodies. A particularly serious cause of water pollution is Acid Mine Drainage, which is generated when minerals with high sulfur content are extracted (Tiwary, 2000). Large amount of water is used up in the mineral extraction process, thereby reducing the availability of surface or underground water, which is a serious issue in arid and semi-arid regions.

Toxins such as mercury and cyanide used in the process of gold purification are known to find their way into rivers and affect fish and other aquatic life, as well humans and animals using river water for drinking. This is a serious problem in informal, small-scale gold mining operations in developing countries. Hilson (2002) provides an overview of the general trend in the use of mercury in mining, which has vastly increased in recent decades compared with pre-

1970s, and cites a number of studies in the Brazilian Amazon, Tanzania, Bolivia, and China showing the evidence of high concentrations of mercury in mining areas, aquatic life and human bodies.

Given the dependence of pastoral livestock herding on the environment, it is particularly susceptible to the environmental impacts of mining. In the context of Mongolia, the impact of mining on the environment is exhibited primarily through: 1) reducing the land available for pasture[1]; 2) pollution or drying of rivers due to mining water discharge and alteration of river beds; and 3) dust blows generated by wind, as well as transportation of large volumes of mineral ore by unpaved roads. A number of studies warn about the negative impacts of mining on the environment in Mongolia, but a few of them quantify this impact. A study by Stubblefield et al (2005) represents a first serious undertaking to assess the impact of mining on river pollution. This study was carried in 2001-2003 on central Mongolian rivers - tributaries to the River Selenge, which forms the single largest inflow into the Lake Baikal in Russia. Comparing Total Suspended Sediment (TSS) and Total Phosphorus (TP) load in rivers downstream of mining areas with rivers not affected by mining, the study finds that the concentration of TSS and TP downstream of mining areas is higher by several orders of magnitude.

Pastoral Livestock Systems

Pastoralists are herders of livestock, who usually live in arid and semi-arid lands unsuitable for crop-farming. Some pastoralists lead a nomadic or semi-nomadic way of life, necessitated by foraging of livestock over large distances, while others combine livestock

[1] Given that Mongolia is one of the most sparsely populated countries in the world, it might seem that mining covers too small of an area to be a significant factor in reducing pastures. However, mining effects are not confined to the immediate mining site. In addition, the arid climate and sparseness of vegetation in the Mongolian grasslands means that larger spaces are required to support a given number of livestock, compared with non-arid locations.

herding with some crop farming and live in permanent or semi-permanent settlements. Pastoralists usually use common pastures managed through systems of social and kin relations. In pastoral livestock systems, herds are dependent on periodic weather events and periods of sparse vegetation (Fratkin and Mearns, 2003).

Early studies on pastoral livestock systems focused on the problems of overgrazing and irrationality of pastoralists. The collective irrationality of pastoralists, which leads to overuse of the grassland and the subsequent collapse of it, was vividly epitomized by Hardin's popularization of the "tragedy of the commons" (Hardin, 1968).

Studies in the environmental field predominantly focus on interrelationship between livestock and carrying capacity of pastures supporting this livestock. In the 1990s, the understanding of carrying capacity as a fixed measure has been replaced to a concept of carrying capacity as a dynamic concept that changes over time and over space (Rasmussen et al, 1999). The effects of droughts and other adverse weather conditions on the carrying capacity of pastures and the pastoral livestock systems are now studied from the dynamic perspective (Hess et al, 2005; Richardson et al, 2010). Another set of studies focus on analyzing the effects of weather on livestock systems (Lybbert et al, 2004) model the livestock mortality on the rain conditions, as well as the presence of common or idiosyncratic shocks, using panel data on cattle in Ethiopia. Researchers at the Meteorological institute of Mongolia used time series weather data to analyze the effect of weather on livestock mortality (Natsagdorj and Dulamsuren, 2009).

Concurrently, in economics and social studies, the criticism of irrationality of pastoralists has become increasingly replaced by views of rationality and adaptive strategies of pastoralists in the face of risks from environmental and weather factors (Livingstone, 1991; Warren, 1995). Recent studies focused on different strategies of pastoralists to overcome the risks, including: 1) diversification, 2) exchange and credit, 3) mobility, and 4) storage, or accumulation of large herds (Halstead and O'Shea, 1989; Naess and Bårdsen, 2010; Nozieres et al, 2011).

In the 1990s, Ostrom and other researchers have developed a framework for analyzing collective management of common-pool resources. In the common-pool resources framework, the “tragedy of the commons” need not necessarily be the outcome. The framework provides for a possibility of sustainable collective use of a common resource in the long term, subject to a system of formal or informal rules within a society, and a relative stability or “closedness” of society. Much evidence of sustainable, long-term use of a common-pool resource is found in both traditional and modern societies. This recent literature, therefore, has challenged the collective irrationality of traditional societies, including pastoralist societies (Ostrom, 1990, 2009; Ostrom et al, 1994; Swaney, 1990; Walker and Gardner, 1992).

From the perspective of the common-property resource framework, opening of a new mine may undermine existing long-term rules that govern the use of common resources, pasture and water, throwing the pasture management system into disequilibrium. This disequilibrium may lead to unsustainable use of the remaining pasture land, thereby increasing the mortality of livestock over time.

Key Characteristics of Mongolia’s Livestock Sector

These key characteristics of pastoral livestock systems – susceptibility to weather conditions and informal institutions governing the use land – are present in the Mongolian livestock sector.

The arid and highly continental climate of Mongolia with high summer and low winter temperatures result in periodic occurences of dzud[2], a natural disaster. In the past two decades, the country has experienced two occurences of dzud, both of which resulted in substantial losses of livestock and some losses of human life. The first of these disasters continued for two consecutive years, 1999-2000 and 2000-2001, killing about 10% and 20% of the total stock of livestock, respectively (United Nations and the Government of Mongolia, February - May 2010). The second dzud of 2009-2010 resulted in losses of about 19% of total livestock herd (United Nations Development Programme, 2010). In addition to major dzuds covering most of the territory, there are also frequent localized, milder dzuds.

In terms of land rights, most land with the exception of urban land is *de jure* property of the state, but is *de facto* owned and used by herders. However, the law prescribes that owners and users of land are entitled only to the proceeds on its surface, such as pastures and forests, but not entitled to the proceeds underground, such as minerals (Parliament of Mongolia, 2002). Therefore, in case of a discovery of a mineral deposit, the rights of the state supersede the rights of *de facto* owner (the herder). In recent years, mechanisms have been put in place to consult with elected local councils upon new license issues, but in they have done little to slow down the expansion of mining.

Due to the sparse vegetation in much of Mongolia, herders use the customary practices of seasonal pasture rotation. Herders distinguish four types of pastures: 1) winter pastures in shielded locations to protect from cold wind, 2) spring / fall pastures with high yield of vegetation, 3) summer pastures located close to water sources and 4) reserve pastures used in case of natural disaster, *dzud*. Winter and spring/ fall pastures are used as *de facto* private

[2] In its simplest form, *dzud* can be translated as a "slow natural disaster resulting from a combination of drought in the summer followed by extreme cold in the winter."

property, belonging to individual households or a few related households, whereas summer and *otor* (reserve) pastures are used as common property. In the summer, herder households together with their livestock congregate near water sources, such as rivers, lakes and wells. In a typical river valley, there are 50-150 herder households that use the summer pasture during three summer months. Informal collective institutions of herders regulate the use of these pastures. However, in the 1990s, these institutions have been affected by the transition from a centrally planned economy to the market economy, which illustrates the vulnerability of these institutions to various shocks and stresses (Fernandez-Gimenez, 1997; Mearns, 2004).

These two factors - the priority of legal land rights over customary land rights, and the transitory nature of informal institutions – have implications on the relationship between mining and livestock sectors.

III. Model and Hypotheses

A Model of a Pastoral Livestock System

Drawing on the previous literature on pastoral livestock systems, as well as the environmental and economic impacts of mining, I propose a simple model of a pastoral system, typical of small, stable pastoralist communities such as those in Mongolian rural soums.

The model is illustrated in Figure 1. The area within the grey panel takes a close look at "livestock", by breaking it up into several stock and flow variables. Here, the change in livestock in any given period comes from three different sources: 1) births, 2) mortality; 3) slaughtering for consumption, shown in the three boxes in the middle. The signs + and – signify that the contribution of each of these sources to the total change in livestock is either positive (increase) or negative (decline). Consumption is further subdivided into own consumption, as well as sale. Of these three sources of livestock change - births, mortality and consumption - mortality is outside of the control of a herder, births are controlled to some degree, while the main variable that can be regulated is consumption. For example, herders may choose to increase their consumption, either directly or by selling livestock, if they think they have sufficiently high level of livestock; and they may decrease their consumption if they want to raise the livestock at a higher rate.

The births and mortality of livestock are affected by weather, shown by the box with weather and the arrows to the livestock. I add to this model another exogenous factor – mining.

Mining can have both environmental and economic effects. By polluting and using up water and soil, and by reducing the physical space available for livestock, mining can increase livestock morbidity[3] and mortality. This relationship is shown by a solid line from mining to livestock mortality.

Mining can also have economic effects, that are ambiguous. On the one hand, opening of a mine in a remote area means an increase in the number of people, thus bringing closer a market to the herder. This represents a spending effect in the Cordon and Neary (1982) model of a resource-dependent economy.

On the other hand, a booming mining sector also should reduce the real price of imports (such as fuel) and reduce the real domestic prices of exportable goods[4]. If fuel prices increases faster than prices of agricultural produce, the herders' terms of trade deteriorate and they may need to reduce own consumption and increase sale in order to raise the total number of livestock. If fuel prices increase at a lower rate, the herders' terms of trade improve, so they may regulate

[3] However, only mortality is shown in the diagram for simplicity.
[4] Although nominal prices of both imports and exports may increase.

consumption and births. The economic effects of mining are shown on the diagram by dotted lines and represents a relative price effect in the Cordon and Neary model.

Finally, the resource movement effect may also be relevant in the case of mining and livestock. The competition for capital and labor between mining and livestock is likely to be insignificant in the case of Mongolia. The capital for mining tends to come from formal banking and financial system, while capital for livestock tends to come from personal savings and inter-household credit. Labour skills needed in both sectors differ substantially. Also, similar to agricultural systems in developing countries, the pastoral livestock system employs a surplus of labour, so even if movement of labour happens from livestock to mining, it is unlikely to affect the productivity or output of the livestock sector. However, the competition for land may exist, and may exhibit itself through higher livestock density, which then leads to higher livestock mortality.

Hypotheses

My hypotheses explore the relationships between mining and livestock mortality and consumption, depicted by solid and dotted arrows between mining and livestock in Figure 1.

Hypothesis 1: More mining is associated with higher mortality of livestock.

Hypothesis 2: More mining is associated with higher consumption of livestock.

For the first hypothesis, I use mortality rate and mortality levels as the dependent variable. This variable can capture both the long-term and the short-term state of the livestock.

For the second hypothesis, since the data on the consumption of livestock is not available, I will use a coefficient derived from the regressions as a proxy.

IV. Data and Descriptive Statistics

Data

For this research, I use administrative data on livestock, weather, and mining from the websites of government agencies in Mongolia[5]: the National Statistical Office, the Mineral Resource Authority, as well as the World Bank.

The unit of analysis in this study is soum, an administrative unit in Mongolia equivalent to a U.S. county. Several soums form an aimag, an administrative unit equivalent to a U.S. state. Since urban soums do not have livestock, they were excluded from the dataset. Complete or near complete data are available for 320 soums.

Livestock data. The data on livestock are collected through the annual livestock census by the National Statistical Office and cover the period 1970-2012.

The data on livestock include the stock of livestock at end-year, as well as deaths of adult livestock during each year. These data are available both in aggregate, and also broken down by types of livestock, namely: 1) large livestock, which include cattle (cows), horses, and camels; and 2) small ruminants, which include sheep and goats. The data on livestock mortality include deaths due to reasons other than contagious diseases and slaughtering for consumption. The reasons for livestock deaths include adverse weather conditions, deaths due to attack by wild animals, accidents, and other unidentified causes.

Mining data. The data on mining were obtained from the administrative records of the Mineral Resources Authority of Mongolia and cover the period 1992-2012. These are de-

[5] Accessed upon request and obtaining a username and a password.

identified data on mineral extraction licenses issued by soum, by year of issue and by expiration of the license.

The data on mining licenses were transformed to calculate the aggregates by each soum and year. Some mining licenses (16% of the total) covered territories straddling over two or more soums. For these “shared” licenses, I divided the size of the territory covered by two and allocated equal shares to the respective soums. As a result, the total mining area in some soums might differ slightly from the real mining area.

Weather data. The weather data are collected through 55 weather stations and were obtained from the World Bank. Some weather stations were in operation since 1956, while others were established later. In addition, there are windows of periods during which weather data from particular stations are not available. After eliminating weather stations with incomplete time series, I had data from 40 weather stations complete for the period of the study, 1992-2010.

Weather data include mean temperature, total precipitation, wind gusts, wind speed, and a set of other variables. To select the most relevant variables, I used the methodology developed by researchers at the Mongolian Meteorology Institute (Natsagdorj and Dulamsuren, 2009). Using this methodology, I calculated four indices: mean summer temperature, mean winter temperature, total summer precipitation, and total fall and winter snow. Winter includes December, January and February. To calculate average winter variables, January and February of each year were shifted to previous year. In order words, the average temperature of winter 2001, for example, was calculated as the average of temperatures of December 2001, January 2002 and February 2001.

Since the number of weather stations is considerably smaller than the number of soums, the units of my analysis, a method was needed to allocate soums to weather stations. Several methods can be used in this respect. The first one is to simply visually examine the location of weather stations and to manually allocate every soum to its nearest weather station. The second method involves detailed knowledge of climatic and geographic zones, so that, for instance, a weather station in the steppe area would be isolated from a soum in mountainous area. The third method is to use a mathematical methodology to identify the "areas of influence" of each weather station. GIS was used to draw Thiessen polygons[6] around each weather station to determine their territorial coverage.

The Thiessen polygons were then overlapped with soum territories and weights calculated. For instance, if Thiessen polygon of weather station no.1 covered the entirety of soum A, this weather station received a weight of 100. However, if three Thiessen polygons from weather stations 1, 2, and 3 intersected on the territory of soum B, the soum received three weights, one for each weather station, calculated by the share of each weather station's "area of influence" in that soum over the whole territory of the soum.

The selected weather variables, including means of summer and winter temperatures, total summer precipitation, and total snow in the preceding fall and winter, where then weighted by these weights to calculate the overall weather variables by soum. An example of these calculations is shown in Table 1.

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[6] Thiessen polygon is a method to divide a space into regions around given points. It uses a mathematical algorithm to define all points closest to given points and form distinct regions. I particularly thank professor Upmanu Lall at the Water Institute at Columbia University for advising me on this methodology and Jeremiah Trinidad-Christensen at the Columbia Digital Social Science Center for helping implement the Thiessen polygons on my dataset in GIS.

It can be seen from here that the weighted average, the temperature data are smoother as temperature tends to be very similar in adjacent areas. The weighted average precipitation data are less meaningful, since the snow in the east side of soum A may not be relevant for the west side of soum A. Nevertheless, on average, within a soum, averaging precipitation is still useful.

Based on the above methodology by the Institute of Meteorology, these four weather variables were then normalized around their long-term mean, using means and standard deviations since 1956.

Because higher summer temperatures (drought), as well as lower winter temperatures tend to increase mortality, a composite temperature index was calculated by subtracting the winter temperature index from the summer temperature index. The resulting temperature index indicates greater difference between summer and winter temperatures, with higher values expected to be associated with higher livestock mortality.

Similarly, less precipitation in the summer (drought) and more snow in the fall/ winter tend to increase livestock mortality. Therefore, a composite precipitation index was calculated by subtracting the total fall/winter precipitation from the total summer precipitation. Higher precipitation index would mean more humidity in the summer and less snow (less obstacles for forage) in the winter, and is expected to be associated with lower mortality.

Descriptive Statistics

The key descriptive statistics are shown in Table 2.

For each variable, the table shows the mean and median values. Since the data are panel data, the median values show those of "a typical soum in a typical year", while the mean values show the means across years and across soums.

The table also reports within groups, between groups and overall standard deviations. Large standard deviation within groups indicates that the values of the variable vary substantially within each group and over time. Large standard deviations between groups indicate that there are substantial variations between mean values of variables from one soum to another. The overall standard deviation is calculated using the pool of all values for all soums and years.

The last column reports the number of observations, where N indicates the total number of observations, n indicates the number of groups (soums) and T indicates the average number of observations per soum.

The number of livestock per soum is significant, over 100 thousand heads of livestock on average and with nearly 93 thousand heads as a median. The number of livestock differs substantially between soums and has increased considerably from the beginning of the period to the end of the period.

The mortality of livestock has a large standard deviation within soums, which indicates that mortality differs substantially from one period to another. In a typical year, typical soum, the losses of livestock are about 1.5 thousand heads of livestock, which is equal to 1.6% of the stock of livestock. However, average losses of livestock per year and per soum were equal to 6.7 thousand, constituting 6.6% of the mean stock of livestock. This indicates that in years with adverse weather conditions, mortality of livestock can increase substantially.

The distribution of the area mined is highly skewed – more than 50 percent of soums do not have any mining, but those that do, have large areas under mining. Therefore, the mining area variable was converted into logs.

The mean summer temperature is 64^{o}F, with standard deviation of 6^{o}F. The mean winter temperature is -2.4^{o}F, with standard deviation of 8^{o}F. The temperature is fairly normally distributed across soums, although in certain years it suddenly drops or increases.

The mean of total summer precipitation is 58.3 dm per season, per soum, although median soum receives only 4.1 dm of precipitation. The mean of total fall/ winter snow is 72.5 dm per season, per soum, with median value of 43.2 dm. Both precipitation and snow differ more from year to year within soums, although differences between soums are also large.

To compare key statistics for soums with and without mining, I have created a categorical variable that has a value of 0 if the soum has no mining, a value of 1 if the soum has moderate amount of mining, and a value of 2 if the soum has significant amount of mining. The cut-off point for separating between moderate and significant mining was determined as 500 hectares, close to the median mining area in the 2000s.

The examination of trends in mining and livestock (see Figure 2) shows that the area licensed to mining has rapidly increased from a negligible level in 1990 to over two million hectares by 2009 (4.94 million acres or 7,722 sq. miles, an area similar to the size of Massachusetts). Total livestock has also substantially increased in the last two decades, but became highly variable, rising rapidly in regular years and dropping precipitously in years with adverse weather conditions (dzud). However, even after the decline in 2011, the number remained substantially higher compared with the level observed in 1990, the beginning of the period examined.

V. Methods and Results

The Underlying Model

Panel data allow controlling for stable characteristics of soums over time that may affect livestock mortality levels or rates. These include, for example, geographical characteristics of soums, such as whether the soum is located in a mountainous, steppe or desert zone, or access to rivers and lakes. These characteristics may also include unobservable, slow-changing characteristics which may affect livestock mortality, such as herders' informal arrangements for using common pastures, or skills and experience of herders.

Using the panel data, I employed a fixed effects model to test my hypotheses. Specifically, model is as follows:

$$mortality\_rate_{it} = \log(mining\_area)_{i,t-1} + temp\_ind_{i,t-1} + precip\_ind_{i,t-1} + \Delta livestock_{it} + error\ term_{it} \quad \text{(A)}$$

Where the subscript *i* denotes soum, and *t* denotes year. *Mortality* is the number of losses of livestock per soum in a given year. *Livestock* is the number of livestock per soum. Livestock enters into the model as a change from the previous period, and so is denoted *Δlivestock*. *Mining* is the log of mining area. *Temp_ind* is an index denoting the difference between summer and winter temperatures. *Precip_ind* is an index denoting the difference between summer precipitation and fall/ winter precipitation. The first three variables, mining, temperature index, and precipitation index are included in the model with a one-period lag.

The log of mining area was included in the model with a one-year lag, because it takes some time for a mine to be put into operation once a license is issued. While the duration between a license and the start of a mine might differ considerably depending on the size of the operation, one year is typical of many medium-scale mines and therefore, the effect of mining was assumed to kick in after one year.

Weather indices were included with a one-year lag. A lag is necessary because it is the weather of the previous year that affects the mortality of the livestock in the subsequent year. Most losses of livestock occur during January-April because of the inability of animals to accumulate sufficient nutrition and energy during the previous year's summer, and the additional impact of snow and cold weather during the previous year's fall and previous/ current year's winter. However, weather variables for January and February were shifted forward to the previous year in order to keep winter as a single season (see the "Data" section). In other words, weather variables for the winter of December 2001-February 2002 are recorded as the winter of 2001. Thus, the use of one-year lags was necessary in order to capture the effect of weather on livestock mortality.

Main Results

The resulting model is reported in column (1) of Table 3 and has the following form:

$$\underset{}{\textit{mortality-rate-hat}_{it}} = \underset{(0.791)}{-6.184} + \underset{(0.015)}{0.032}*\log(\textit{mining\_area})_{i,t-1} + \underset{(0.132)}{2.353}*\textit{temp\_ind}_{i,t-1} - \underset{(0.002)}{0.0007}*\textit{precip\_ind}_{i,t-1} - \underset{(0.00001)}{0.0004}*\Delta \textit{livestock}_{it} \qquad \text{(B)}$$

R^2-within 0.64

The coefficient on mining is 0.032, statistically significant at the 95% confidence level. The coefficient of 0.032 indicates that one percent change in mining area is associated with only 0.03% higher mortality rate. If a soum with a typical mortality rate of 1.80% has an expansion of mining area by 30%, it will be associated with 30*0.03=0.9% higher mortality rate, bringing the overall mortality rate to 2.7%, or increasing the mortality rate of livestock by 50%.

The coefficient on the temperature index is 2.353, significant at the 99% confidence level. The standard deviation of the temperature index is 0.52. One standard deviation increase in the temperature index, or the difference between summer and winter temperatures, is associated with 1.22 percentage points higher mortality rate, equivalent to a 60% increase in the mortality rate. However, the coefficient on the precipitation index is not statistically significant, One standard deviation increase in the difference between summer and fall/winter precipitation is associated with 0.25 percentage points higher mortality rate.

Column (4) of Table 3 reports the results of the same regression done over the 2000s, to examine if the more recent period has seen changes in the association between mining and livestock mortality. The coefficient on the log of mining in the 2000s is 0.049, higher compared with the coefficient for the whole period. A hypothetical 30% increase in mining area is associated with 1.47 percentage points increase in livestock mortality, thereby increasing the mortality rate in a typical soum by 81%.

These results indicate that mining is positively and statistically significantly associated with livestock mortality, and this association has become stronger in the 2000s.

Comparison of Different Groups of Soums

Next, I also compare the results of regressions for soums with different levels of mining. These are reported in columns (2) and (3) of Table 3. The coefficients on other variables hardly change. Interestingly, the coefficient on the log of mining for soums with moderate amount of mining, reported in column (2) is higher and is significant at the 99% confidence level, while the coefficient for soums with significant amount of mining is lower than the overall average, and is not statistically significant. Similar results, but with higher coefficients, can also be seen from columns (5) and (6) of Table 3, which report the same regressions for the period 2000-2010.

Comparison of Different Types of Livestock

Since the data is available on different types of livestock, I also examine whether the regressions differ between goats, sheep, cattle, horses and camels. Table 4 presents the results of these regressions. In these regressions, the dependent variables are the mortality rates for goats, sheep, cattle, horses, and camels, respectively.

The coefficients on weather are also consistent with anecdotal evidence that goats, sheep and cattle are more susceptible to weather effects: the coefficient is 2.07 for goat mortality, 1.85 for sheep mortality, 4.18 for cattle mortality, 1.36 for horse mortality and 0.95 for camel mortality.

An interesting result is that the association between mining and the mortality rate is highest for goats, followed by sheep, but it is negative for the large livestock – cattle, horses and camels, with all coefficients being significant at the 99% confidence level. The coefficient on the log of mining for the goat mortality rate regression is 0.13. In other words, a 30% increase in area mined in a soum would be associated with 3.9 percentage points increase in goat mortality.

In comparison, one standard deviation change in the temperature index is associated with 1.07 percentage point higher mortality rate, indicating that mining could have a stronger effect on goat mortality compared with weather. This is a very large association in real terms. Considering that goats, by producing cashmere, constitute the largest source of herders' income, it is not surprising that herders as a group are strongly opposed to the expansion of mining.

However, the coefficients on the log of mining are negative for cattle, horses and camels, indicating that more mining is associated with lower mortality of these types of livestock. One possible explanation for this counterintuitive result could be the mobility of herders. Mining displaces herders either directly or indirectly. Therefore, herders from heavily mining-affected areas tend to migrate to areas less affected by mining, thereby changing the within-soum associations between mining and livestock mortality. During such permanent and long-range migrations, that herders would usually sell their small stock - goats and sheep, but would take with them the large stock - cattle, horses and camels, because they are smaller in numbers and endure long migrations better.

Mining and Market Access

Finally, I have also run the regressions on the level of mortality as the dependent variable, as opposed to the rate of mortality. These regression results are reported in Table 5. Column (1) shows the regression of mortality on the independent variables for all soums, while columns (2), (3), and (4) show the results for soums with no mining, soums with moderate amount of mining, and soums with significant amount of mining, respectively.

Here, the coefficients on the change in livestock provide an interesting insight into my second hypothesis that mining is associated with higher consumption of livestock. Since I do not have data on livestock consumption, I exploit the structural relationship between some livestock variables to test my hypothesis.

The simple model of a pastoral livestock system shown in Figure 1 shows that the change in livestock in any given year is always equal to the increase in livestock due to births, and the decrease in livestock due to mortality and consumption of livestock. The exact relationship can be expressed by the following equation[7]:

$$\Delta livestock_{t} = births_{t} - consumption_{t} - mortality_{t} \qquad \text{(C.1)}$$

Equation (C) explains why the coefficients on the change in livestock in Table 5 are negative and range between -0.56 and -0.63. The change in livestock comes from three sources: the increase due to births; the decline due to consumption, either direct consumption by the herders' households or by sale; and the decline due to mortality caused by weather and other reasons. Therefore, mortality would have an opposite sign to the change in livestock and would account only for a portion of the overall change.

Since I am interested in the consumption of livestock, I rearrange the equation (C) again to have consumption on the left side:

$$consumption_{t} = births_{t} - mortality_{t} - \Delta livestock_{t} \qquad \text{(C.2)}$$

[7] Equation (C.1) assumes no transfers of livestock between soums. Transfers of livestock may happen during years with adverse weather conditions, when herders may migrate beyond the confines of their soums with their livestock, as well as due to permanent migration, when herders might move closer to urban markets.

Dividing both sides of equation (C.2) by $\Delta livestock_t$, I have a new equation that represents the same relationships in terms of proportions:

$$\frac{consumption_t}{\Delta livestock_t} = \frac{births_t}{\Delta livestock_t} - \frac{mortality_t}{\Delta livestock_t} - \frac{\Delta livestock_t}{\Delta livestock_t}$$

which is the same as:

$$consumption\_share_t = birth\_share_t - mortality\_share_t - 1 \qquad \text{(C.3)}$$

Here, I use the term "share", rather than "rate" to distinguish the proportions over the *change* in livestock, as opposed to proportions over the beginning *level* of livestock. The consumption *share*, for example, represents the proportion of livestock consumed as a proportion of the *change* in livestock in this period, while a consumption *rate* represents the proportion of livestock consumed in the *level* of livestock at the end of the previous period.

In the regressions in Table 5, the coefficient on the change in mortality is $\frac{mortality_t}{\Delta livestock_t}$, or $mortality\_share_t$, and can be substituted into equation (C.3). In the case of soums wihout mining, the mortality share is 0.63, equal to the coefficient on the change in mining in Table 5, column (2). For soums with moderate amount of mining, the mortality share is 0.57, equal to the coefficient on the change in mining in Table 5, column (3). For soums in categories 1 and 2, the equation (C.3) now has the following form:

$$consumption\_share_{t,1} = birth\_share_{t,1} - 0.63 - 1 = births\_share_{t,1} - 1.63 \qquad \text{(C.4)}$$

$$consumption\_share_{t,2} = birth\_share_{t,2} - 0.57 - 1 = birth\_share_{t,2} - 1.57 \quad \text{(C.5)}$$

where the subscript *1* denotes soums in soums without mining and subscript *2* denotes soums with moderate amount of mining.

While I cannot observe the share of livestock births in these soums, I can assume that the birth shares are fairly constant across soums. In this case, by deducting equation (C.4) from (C.5) and assuming $birth\_share_{t,1} = birth\_share_{t,2}$, I can estimate the difference in consumption of livestock between soums in these two categories:

$$consumption\_share_{t,2} - consumption\_share_{t,1} = birth\_share_{t,2} - 1.57 - birth\_share_{t,1} + 1.63 = 0.06 \quad \text{(C.6)}$$

From equation (C.6), the consumption share of livestock is higher in soums with moderate mining compared with soums without mining by approximately 6 percentage points, indicating that soums with moderate mining have consumed relatively more of their increase in livestock compared with soums without mining. Since consumption consists both of own consumption and sale of livestock, and since own consumption shares are unlikely to vary significantly from soum to soum, the difference can be entirely attributed to the sale of livestock. This indicates that soums with moderate amount of mining have 6 percent more of their change in livestock sold, i.e., that they have better market access.

The difference between soums with no mining and significant amount of mining is more moderate, only 3 percent. This is an unexpected result. One possible explanation is that better access to markets brought by mining might also be mediated by increased concentration of herders in the area, each of whom would be trying to sell their produce. In this case, the sale, and therefore, the consumption rate of livestock would be lower.

Since in Mongolia, herders are usually located in remote locations, their ability to sell the produce is hampered by long distances and high costs of gasoline. However, opening of a new mine in a soum increases the possibilities for herders in the vicinity to sell their produce to mine workers.

This analysis is necessarily tentative as it is based on assumptions about birth rates of livestock and does not incorporate factors such as remoteness of soums, as well as dynamics of herders' migrations. Nevertheless, it provides some support to my second hypothesis that more mining is associated with higher consumption of livestock.

VI. Limitations

This study has several important limitations.

First, the use of soum-level data may be too large, since the effects of mining on livestock mortality may be localized in the immediate vicinity of a mine.

Another limitation is that the study does not take into account spatial autocorrelation. Mining carried near the border of a soum may have a large effect on the mortality of livestock in the neighbouring soum. In addition, the environmental effects of mining, such as water pollution and drying up of rivers are transported along rivers. Therefore, the effects of mining carried out in upstream soums are likely to spread outside of the soum, toward those soums that are located downstream.

Another important limitation is that the study does not take into account the dynamics, particularly the migration of herders and their livestock. The census of Mongolia's population in 2010 has shown substantial internal migration of people, which resulted in increase in population density in central soums close to urban areas and major transportation networks, and a decline in population density in outlying soums. However, if the increase of mining results in the exit of a large number of people and livestock from a soum, within-soum analysis will not discern the relationship.

The use of administrative data on mining also presents challenges. As mentioned earlier, there is a considerable amount of informal mining activity in Mongolia which is, by definition, not registered. To some extent, since informal mining tends to occur on or near sites of formally licensed mining, the official data on mining captures the spread of informal mining to some extent, but not fully.

VII. Conclusions

I sought to examine some of the environmental and social impacts of mining, by examining the relationship between mining and livestock sectors in Mongolia. Two major channels of relationships were identified: 1) through the environmental impact, such as water pollution, soil degradation and reduction of space; and 2) through the economic impact, by improving herders' opportunities to market their produce, but also by changing relative prices in the economy.

The available data permitted to examine the direct, environmental impact by examining the association between mining and livestock mortality. The results indicate that mining is indeed associated with non-negligible increases in mortality, but this association paradoxically becomes smaller as mining in a soum increases. Mining has strong and positive association with the mortality of small ruminant livestock - goats and sheep. A puzzling result was a negative association between mining and the mortality of large livestock - cattle, horses, and camels. These surprising results may be attributed to one the main limitations of the study, in that it does not take into account the spatial movements of herders and their livestock.

Tentative results based on assumptions and indirect derivation of consumption of livestock point to a positive association between mining and improved market access for herders. However, due to data limitations, this study does not incorporate relative price levels and differences in distances from urban markets, something that can be analyzed in another study.

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Annexes: Tables and Figures

Table 1. Conversion of weather station-based weather variables to soum-based weather variables

		Weight (1)	Mean summer temperature, F (2)	Weighted mean summer temperature (1)x(2)
Soum A	Weather station 1	100%	55	55
Overall - Soum A				**55**
Soum B	Weather station 1	20%	55	11
	Weather station 2	30%	52	15.6
	Weather station 3	50%	56	28
Overall - Soum B				**54.6**

Table 2. Summary of key statistics, by soum

Variable	Mean	Median		Std. Dev.	Observations	
Livestock						
Livestock at end-year, heads	100,870	92,907	overall	53,064	N	4,466
			between	44,924	n	319
			within	28,346	T	14
Mortality during the year, heads	6,652	1,485	overall	14,143	N	4,466
			between	4,032	n	319
			within	13,557	T	14
Mining						
Area mined, hectares	659	0	overall	5,550	N	4,466
			between	3,499	n	319
			within	4,312	T	14
Weather						
Mean summer temperature, F	64.0	64.3	overall	6.0	N	4,457
			between	4.7	n	319
			within	3.7	T-bar	14
Mean winter temperature, F	-2.4	-0.8	overall	8.0	N	4,457
			between	6.7	n	319
			within	4.4	T-bar	14
Total summer precipitation, dm	58.3	4.1	overall	160.8	N	4,457
			between	21.8	n	319
			within	159.4	T-bar	14
Total fall/ winter snow, dm	72.5	43.2	overall	85.8	N	4,457
			between	47.8	n	319
			within	71.3	T-bar	14

Note: urban areas are excluded.

Table 3. Mortality rate regressions covering the entire period and the 2000s

	1992-2010			2000-2010		
VARIABLES	(1) Mortality rate in all soums	(2) Mortality rate in soums with moderate mining	(3) Mortality rate in soums with significant mining	(4) Mortality rate in all soums	(5) Mortality rate in soums with moderate mining	(6) Mortality rate in soums with significant mining
Log of mining area$_{t-1}$	0.032**	0.071***	0.008	0.049*	0.076*	0.021
	(0.015)	(0.022)	(0.021)	(0.028)	(0.039)	(0.041)
Temperature index$_{t-1}$	2.353***	2.373***	2.371***	2.190***	2.807***	2.791***
	(0.132)	(0.287)	(0.255)	(0.199)	(0.489)	(0.324)
Precipitation index$_{t-1}$	-0.0007	-0.002	0.0001	0.002	0.005	0.007**
	(0.002)	(0.004)	(0.003)	(0.002)	(0.004)	(0.003)
Change in livestock	-0.0004***	-0.0004***	-0.0004***	-0.0004***	-0.0004***	-0.0004***
	(0.00001)	(0.00002)	(0.00002)	(0.00001)	(0.00002)	(0.00003)
Constant	6.184***	7.019***	5.363***	5.259***	3.522	2.729**
	(0.791)	(2.028)	(0.972)	(0.978)	(2.411)	(1.065)
Observations	5,664	1,292	1,812	3,481	792	1,118
Number of clusters	317	72	102	317	72	102
R^2 within	0.64	0.61	0.65	0.66	0.64	0.69
R^2 between	0.23	0.21	0.17	0.23	0.10	0.01
R^2 overall	0.62	0.60	0.64	0.64	0.60	0.62
RMSE	5.52	5.51	5.05	6.33	6.39	5.67

Robust standard errors in parentheses
*** p<0.01, ** p<0.05, * p<0.1

Table 2. Regressions by type of livestock

VARIABLES	(1) Mortality rate of goats	(2) Mortality rate of sheep	(3) Mortality rate of cattle	(4) Mortality rate of horses	(5) Mortality rate of camels
Log of mining area$_{t-1}$	0.130***	0.059**	-0.256***	-0.126***	-0.071***
	(0.032)	(0.028)	(0.049)	(0.041)	(0.021)
Temperature index$_{t-1}$	2.067***	1.846***	4.183***	1.355***	0.951***
	(0.191)	(0.204)	(0.399)	(0.245)	(0.165)
Precipitation index$_{t-1}$	0.004**	0.002	-0.004	0.004	0.005**
	(0.002)	(0.002)	(0.004)	(0.003)	(0.002)
Change in livestock	-0.0004***	-0.0004***	-0.0005***	-0.0004***	-0.0001***
	(0.00001)	(0.00001)	(0.00002)	(0.00002)	(0.00001)
Constant	4.630***	5.109***	9.615***	4.008***	0.273
	(0.968)	(1.007)	(1.685)	(1.201)	(0.865)
Observations	3,479	3,478	3,477	3,475	3,109
Number of clusters	317	317	317	317	309
R^2 within	0.66	0.63	0.57	0.52	0.24
R^2 between	0.075	0.20	0.30	0.12	0.00
R^2 overall	0.62	0.60	0.54	0.48	0.13
RMSE	6.27	6.66	11.04	8.18	4.81

Robust standard errors in parentheses
*** p<0.01, ** p<0.05, * p<0.1

Table 3. Mortality level regressions

VARIABLES	(1) Mortality in all soums	(2) Mortality in soums with no mining	(3) Mortality in soums with moderate mining	(4) Mortality in soums with significant mining
Log of mining area$_{t-1}$	111.8***		161.4***	160.6***
	(19.49)		(41.03)	(57.73)
Temperature index$_{t-1}$	2,165***	1,180***	2,208***	2,168***
	(141.3)	(286.7)	(409.5)	(438.4)
Precipitation index$_{t-1}$	18.88***	32.34***	19.56***	22.76***
	(2.084)	(3.847)	(3.831)	(3.636)
Change in livestock	-0.577***	-0.631***	-0.569***	-0.599***
	(0.0144)	(0.0191)	(0.0282)	(0.0307)
Constant	-1,071	-5,932***	-3,407	-2,782*
	(936.1)	(1,668)	(2,059)	(1,429)
Observations	5,664	1,571	792	1,118
R-squared	0.767	0.822	0.767	0.787
Number of clusters	317	143	72	102
R^2 within	0.767	0.822	0.767	0.787
R^2 between	0.0441	0.0132	0.00575	0.0341
R^2 overall	0.497	0.483	0.486	0.531
RMSE	5930	6949	5993	6524

Robust standard errors in parentheses
*** p<0.01, ** p<0.05, * p<0.1

Figure 1. A simple model of a pastoral livestock system

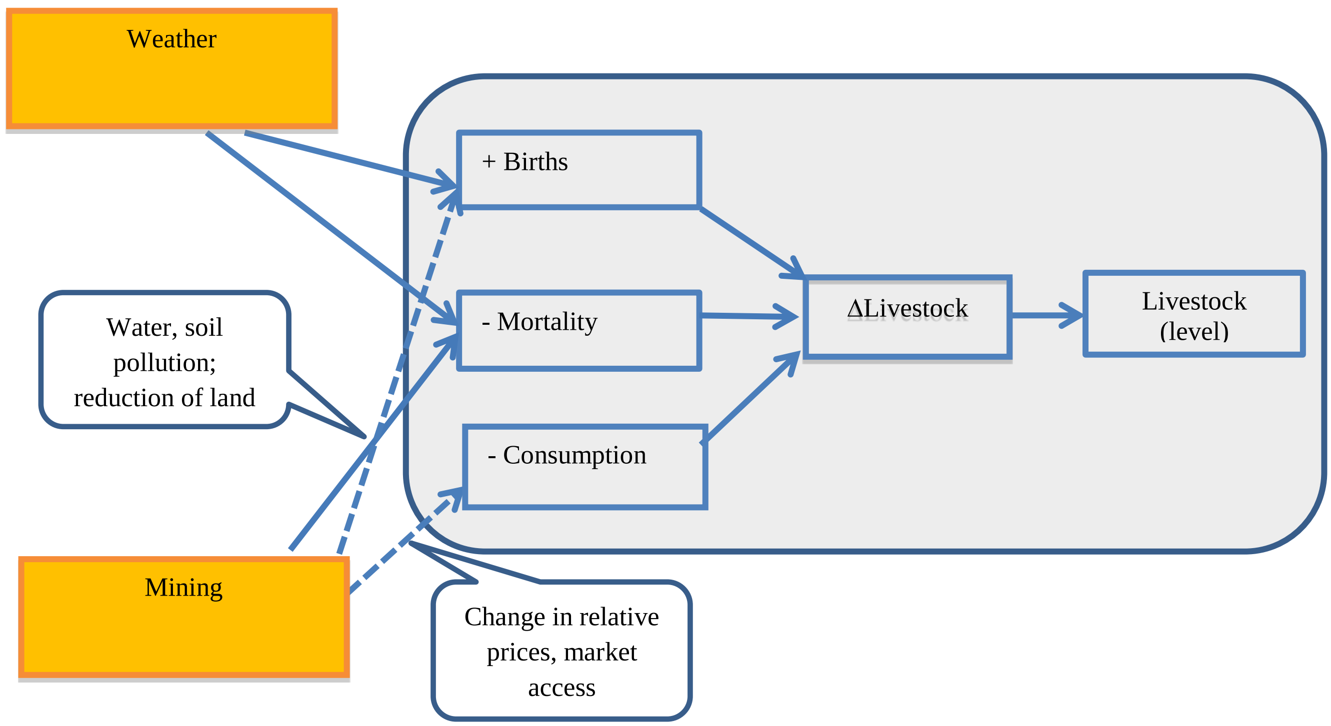
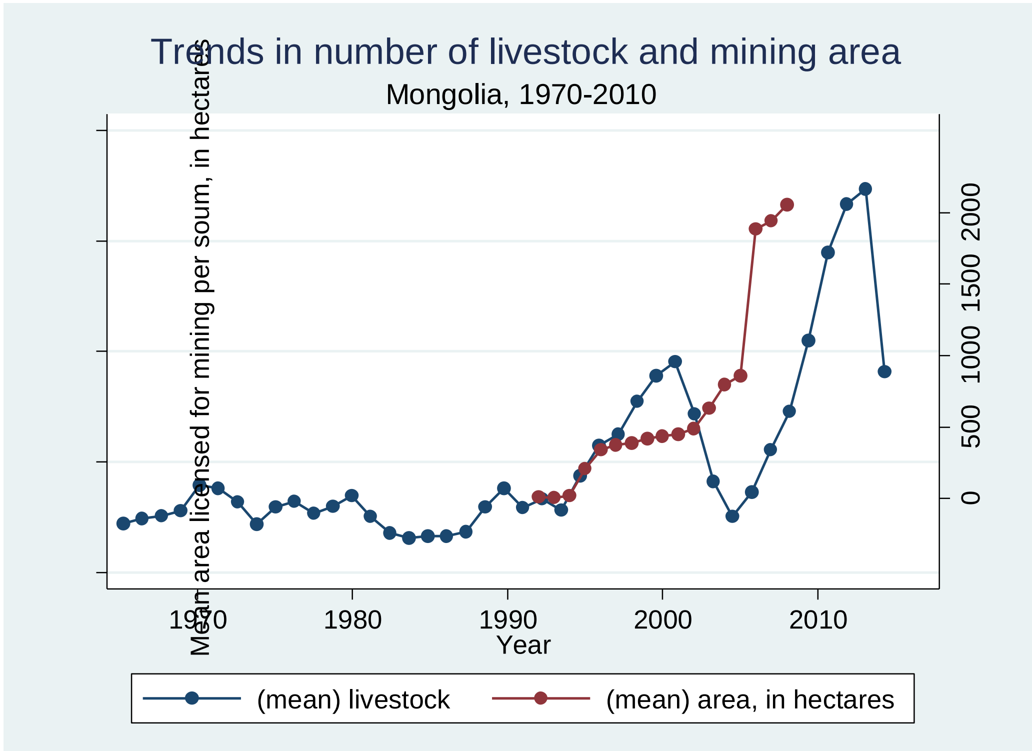


Figure 2.



Source: Livestock data – National Statistical Office; Mining data – Mineral Resources Authority