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EFFECTS OF PROPERTY RIGHTS ON ECONOMIC BEHAVIOUR OF PASTORAL SOCIETIES IN NORTHERN KENYA: *ANALYSIS of AND TEST FOR RES NULLIUS VERSUS RES COMMUNES.*

By

Wellington M. Mulinge

A thesis submitted to the Faculty of Graduate Studies and Research in partial fulfilment of the requirements for the degree of Master of Science.

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The undersigned certify that they have read, and recommend to the faculty of Graduate Studies and Research for acceptance, a thesis entitled "Effects of property rights on economic behavior of pastoral societies in Northern Kenya *Analysis of and test for res nullius versus res communes*" submitted by Wellington M. Mulinge in partial fulfilment of the requirements for the degree of Master of Science in Agricultural Economics.

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This thesis is dedicated to my wife, my son and my mother.

ABSTRACT

The purpose of this study was to test for the type of property rights regime operating in range resource utilization in Northern Kenya. African nomadic pastoralists have occasionally been accused of following socioeconomic and resource-use strategies that are destructive to the environment and land resource base. This paradigm is commonly referred to as the tragedy of the commons.

The problem was analysed by determining the optimization process that the pastoralists use in economic decision making through the discount factor and the theory of rational expectations. A nested model was developed to test for the presence of *res-nullius* (open access property) versus *res communes* (true common property). The data used consisted of time series livestock numbers, livestock sales (off take), livestock prices, labour costs, low income consumer price indices, interest rates and ecological indices, all from the Marsabit district, Northern Kenya.

Results obtained for Marsabit district from this study suggest that *res nullius* property rights apply in production of small ruminants (goat and sheep). However, camel and cattle production are *res communes*. This result suggests that there is a need to destock small ruminants while increasing the number of camels and cattle. Camel populations have been decreasing naturally due to fertility problems and therefore,

may not threaten environmental destruction. The problem of open access range depletion seems to apply in resource management strategies of Marsabit district as regards harvesting of forage resources through small ruminants (goats and sheep). Cattle and camel production seems to operate under res communes regime.

Traditional property rights institutions don't seem to apply today, because of external interference. Past government policies have neither helped set up new sustainable institutions nor strengthened traditional institutions.

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1.0 INTRODUCTION

A lot of attention has been given to the study of the culture of the pastoralists, especially those from the less developed countries. Memories of the 1968-73 Sahelian drought are still raw as well as the recent devastating famines in Ethiopia and Somalia. During the Sahelian drought, the UN Food and Agriculture Organization estimated that 3.5 million head of cattle as well as 100,000 to 250,000 people perished. This drought also focused the attention of the world on the process of desertification. This process is man-made (Lamprey, 1983; Ingold, 1980; Picardi and Siefert, 1976), and once triggered, it is self feeding. Desertification and overgrazing are generally recognized as serious problems in the arid and semi arid areas of the world.

Range management techniques developed in western countries have been applied but have failed miserably. There has been the unsuccessful attempts by range managers to limit stocking rates, redistribute livestock using boreholes and impose grazing systems. The high rate of failure of range development programmes to improve pastoral living standards and to protect the environment has prompted international development agencies to reduce or abandon funding of range development programmes. As of today, no one can claim to have developed a suitable and locally acceptable range management strategy (Gilles, 1987). Most range programmes have failed because range managers have, in most cases, been unable to develop grazing systems that limit access to pastures and control stocking rates.

In Kenya about 80 percent of the land is classified as Arid and Semi-Arid Land (ASAL). This area is inhabited by 20% of Kenya's human population and 50% of its livestock population (Pratt and Gwynne, 1978). International donor agencies have spent millions of dollars and anthropologists have spent uncountable person-hours in studies geared to improve livestock production, with the aim of raising pastoral living standards. However, one feature of traditional livestock management practice by pastoral communities which attracts most attention and still remains unresolved is overgrazing and environmental destruction. This feature of nomadic livestock production continues to generate interest because of the varied views expressed by both antagonists and protagonists of indigenous traditional livestock management practices.

The debate revolves around those who support and appreciate the nomadic adaptation and those who view it as primitive and inefficient, both economically and ecologically. One school of thought (Lamprey, 1983; Igold, 1980; Picardi and Siefert, 1976) argues that pastoral nomadism involves Garrett

Hardin's open access[1] condition whereby, livestock accumulation leads to overgrazing, environmental degradation, loss of livestock and famine. Supporters of nomadic pastoralism, on the other hand maintain that pastoral nomadism is environmentally sound, with *res communes* features and that disruption of the normal system (true common property[2]) has caused environmental degradation (Hogg, 1987; Sinclair and Fryxell, 1985; Swift, 1977).

These interventions on the nomadic pastoral economy are ill conceived developments of the past, which has encouraged settlement, cultivation and annexing areas previously used by pastoralists as dry season grazing zones. This development is a result of a government policy which emphasizes settlement in interests of national unity, and agriculture to increase food production rather than pastoral nomadism (Hogg, 1987). Donor agencies require that people settle for ease of aid administration and funding of future development projects. Connected to this activity is the imposition of land tenure and production strategies, alien to and incompatible with the pastoral production system (Horowitz and Little, 1987;

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1 No defined group of owners or users and the benefits derived from the resource are free for all on a first come first served basis (ownership through capture).

2 A group of users and owners exit with well defined rules of resource use which includes exclusion of non members.

Sandford, 1983; Swift, 1977; Hjort, 1990)[3]. These arguments for or against pastoral nomadism have resource management and control as their fulcrum.

1.1 Objectives of the study

The central purpose of this study is to test the property rights regime in Northern Kenya and propose policies that can be used to enhance pastoral production and improve living standards of the pastoral peoples. Policies that encourage innovation and generation of superior socio-economic institutions acceptable to the pastoralist and compatible with the traditional pastoral system will be sought.

An optimization model is also developed to test and analyze the range property rights regime. The following hypothesis are tested in this paper:

1.2 Hypothesis

Property rights in Northern Kenya are attenuated, leading to inefficiency from and the pastoral production system that exhibits *res nullius* characteristics.

For the above hypothesis to be validated for econometric

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[3] An example is the per head of cattle tax imposed to reduce livestock numbers through getting rid of unproductive animals.

tests, a parameter which implies this hypothesis has to be identified and the underlying relationships defined. This parameter is the discount rate and its relationship to property rights is discussed in Chapter four.

1.3 Justification

Most range programmes have failed because range managers have been unable to develop grazing systems that are compatible with the pastoral socio-economic system. The key to sustainable development and management of rangelands lies in the certain understanding of the nature of property rights and how pastoralists respond to them.

The UNESCO Man and Biosphere project (MAB) (Lusingi, 1984) established in Marsabit district divided the constraints to use of rangelands in to four categories:

1. lack of sufficient number of water points;
2. lack of public security;
3. lack of a sufficiently secure land tenure system; and
4. lack of grazing control.

Water points can be developed to redistribute grazing animals and balance forage utilization. However, successful management of arid lands require control grazing of domestic animals by limiting stocking rates and development of rotational grazing.

Pastoralists often keep unproductive animals over and above their subsistence level. Accumulation of these herds leads to range deterioration; moreover, the impact of recurrent drought is more severe than if there were some control on herd expansion. The economic implication is that rangeland productivity will decline with time as the range becomes more arid. If the problem continues unabated, desert conditions will result, small islands of desert will merge to become large deserts, human suffering in these areas and the number of families requiring famine relief on permanent basis will increase. Expanding deserts will accelerate global climatic change. The Government of Kenya recognizes the need to develop arid lands and manage them in a manner which can help to provide national income, employment and food self sufficiency goals as spelled in its sessional paper no. 1 of 1986 on economic management and renewed growth. The same paper emphasises the need to develop a land policy[4].

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[4] "There has not been a major review of land policy since independence. The existing situation combines colonial land tenure laws with recent practice in a complex pattern that makes it difficult to operate a land policy". (sessional paper no.1 1986 pg. 90).

1.4 Thesis organization

This thesis is organized into seven chapters and one appendix. The study begins with an introductory chapter, followed by a brief historical background describing the area of the study, land, people and cultural socio-economy. Chapter three contains an explanation of the economic theory of property rights. Chapter four contains a conceptualization of the economic arguments behind property rights issues and how they relate to resource management. A pastoral production function is specified showing the relationship between output (livestock products) and inputs (livestock capital, human labour and forage resources. The quadratic function is selected for analysis because it is flexible and easy to manipulate when deriving Euler equations for estimation. An optimization problem is posed using the profit function to help derive a nested model whose parametric estimations would help in testing the proposed hypothesis. Chapter five contains an explanation the econometric estimation procedures, and concludes with a brief explanation of data requirements for this kind of study, data sources and data collection methodology. Chapter six contains the empirical results of the study and their policy implications. The paper ends with discussions and concluding remarks in chapter seven.

2.0 THE SETTING

2.1 Project area

The study area is located in Marsabit District, Eastern Province, Northern Kenya. Marsabit District is the largest District in Kenya and consists of five administrative divisions. It borders Ethiopia to the North, Lake Turkana to the West, Wajir and Garissa Districts to the East, and Isiolo and Samburu Districts to the South. The pastoral tribes native to Marsabit district are the Gabbra inhabiting the north western region, the Boran inhabiting the central marsabit, Burji on the central division, Rendille, Ariaal and Samburu on the south western region.

The area of the district is 72,732 km^2 and is composed of lowlands and several high mountains: Mt. Kulal, the Hurri Hills, Mt. Marsabit, Ndoto Ranges and Mt. Nyiru. The high elevation areas receive more rainfall than the lowlands, thus Mt. Marsabit receives more than 700 mm of rainfall whereas Korr receives about 188 mm of rainfall. Moreover, the rainfall in the highlands is more prolonged and reliable than the lowlands (IPAL, Technical Report No. A-6, 1984). The rainfall is bimodal with annual rainfall divided between two major rainy seasons. The long wet season starts in March/April and lasts till May while the short rains start in October and last for two months. About 2-5% of the district can be used for agricultural purposes (Range Management Handbook, 1991).

2.2 Traditional pastoralism, culture and resource management

Pastoral migrations have developed over a long time as strategies for efficient harvesting and conservation of the available range forage and water resources. Cultural and social functions have been tailored to enforce these strategies. Movements are often motivated by ritual requirements, which can occur once per year, or at intervals of four times per year and for up to fourteen times per annum. Examples of these are:

(i) The Gabbra tribe jila-journey of the Galbo phratry in 1986; Galbo phratry is a migration which comprises 140 households and thousands of livestock. Like other migrations such as Gaar phratry, these migrations are aimed at performing pilgrimage rituals in the holy sites of Gabbra Malbe. These pilgrimages are determined by solar and lunar cycles of their calender.

(ii) The Rendille tribe circumcisions, unlike the Gabbra individual or small group circumcisions, are performed communally. Circumcision sites are determined by the availability of pasture and water. Level ground is preferred for ease of settlement.

(iii) The Rendille Gaalgulamme ("camel stampede") (Schee (1991)); At this ceremony, the Rendille form a giant ring of houses in a clockwise order depending on seniority starting from west. All camels are present in this ceremony, because some of the rituals involve driving camels.

(iv) Lunar and solar calender movements: Sorio and almondo festivals; The Rendille tribe's calender differs from both the Muslim and the Gregorian calenders. This calender has a sequence of twelve months each of which has a name but they do not refer to this cycle as a year. This calender determines performance of Sorio and Almodo. There are four Sorio sacrificial ceremonies in the Rendille culture. Three are performed in the Rendille months of Sondeer I, Sondeer II and Daga (these ceremonies are also common in Gabbra, Sakuye and Garre). The fourth Sorio festival has some links with the Muslim rituals. Sorio affects grazing management because, herds acquire cyclic movements to and from settlements during these periods. The effects of these festivals on pasture management may not be obvious to an outsider.

The Almodo ceremonies mark the solar year. Marking the solar year ceremonies are also common to other pastoral tribes in Northern Kenya like Gabbra, Somali and Sekuye. The Rendille shave their heads during the Almodo. The rule is that the settlements should not move on while the scalps of men are still bare. One should wait for periods between weeks or months before moving on, depending on water availability. Schee (1991) reports that the full effect of the Almodo on livestock is weaker than that of Sorio festivals.

(v) Response to ecological constraints. Satellite camps (forr) are temporary camps for herdsmen (Morans or warriors) and livestock. These camps can be located as far as 100 to 200 km away from the main camps when harsh conditions necessitate it. These movements may be opportunistic in nature, in that one goes wherever conditions are best. There is a tendency for individuals to move to higher ground or to neighbouring districts in the dry season. Other motives involve moving closer to markets and infrastructure.

(vii) Semi-permanent camps or main camps (goob), are settlements for women, children and elders. In the view of an outsider, the Rendille tribe seems to have concentrated in small clusters around Kargi and Korr settlements. There are two groups of the Rendille, the "white Rendille" and the Ariaal. It is the former group that is accused of staying clustered around these centres, because they tend to live near the settlements. The Ariaal stay further away from market centres. However a census conducted by Gunther Schee (Range Management Handbook, Vol. 2, 1 1991) revealed that although the "white" Rendille tended to cluster near towns, they covered longer distances once they moved. The Ariaal on the other hand tended to cover shorter distances which may be detrimental to range ecology. The further away from the major settlements the longer the lactating animals can be kept near the Goob. So the choice of location and movement of the Goob depend on pasture availability, proximity to water and urban facilities.

2.3 Modernization of pastoral resource management systems

The range management discipline has its roots in North America. It then spread to other parts of the world especially Australia. The purpose of range management is to optimize returns from rangelands through ecological manipulation. Range science is also committed to sustainable production through environmental protection and productivity improvement of the range resources. The range management approach is well suited for social and ecological conditions of North America were it originated. In North America, pasture lands are either privately owned or state property. This pattern is in contrast to rangelands in Northern Kenya, where traditional pastoralism is the major economic activity. Neither the state nor individuals have traditionally owned rangelands. Pastures tend to belong to large groups of pastoralists who, although they habitually use the rangeland, do not normally have exclusive property rights. This feature of rangelands in Northern Kenya has made it difficult if not impossible for North American range management strategies to be adopted. Lack of well defined property rights make it very difficult for range assistants with North American training to devise appropriate and effective grazing plans. This circumstance led some scholars to believe that privatization is the precondition for protection and improvement of the arid and semi arid lands Hopcraft, 1981).

Numerous attempts have been made to privatize rangelands in Kenya but with little success. First came the private ranches, company ranches, co-operative ranches closely followed by group ranches. Later on, block ranches were introduced in the drier parts of Kenya. Some ranches have been very successful, but the general trend has been that of one failure after another[1]. Establishment of these ranches required subsidies, special loans from the government, and often necessitated forceful displacement of the resident pastoral groups. This method of establishing rangelands was possible during the colonial periods. In the

[1] It is important to note that some of the ranches failed because of management problems rather than on technical or economic grounds.

world today, such a move would raise concern from both local and international human rights groups. The use of government funds to displace its citizens would not be politically palatable, not to mention the hostilities that the disposed groups would direct to the favoured few. Dividing extensive pastoral lands into small privately owned plots may not be feasible. The cost of land adjudication and boundary enforcement is likely to exceed the benefits that can be derived from private ownership (Runge, 1981). In most cases, creation of a large number of ranches may increase overgrazing and range deterioration, hence reduced livestock productivity[2]. Small ranches do not leave room for the flexibility required by pastoralists to exploit the range resource. Pasture production depends on rainfall which is sparsely distributed. To tap the pastures produced after rains, a pastoralist has to be mobile. This mobility is reduced if land is demarcated.

Agriculture on Mt. Marsabit was established in the 1920s (District handover reports, 1920-1963). This reduced cereal inputs to the district. However it was observed that

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[2] Some cases where the management of small private ranches have been successful have been reported. Gunther Schee, Range management handbook, Kenya. The owners of these small ranches continue to have access to the common grazing lands for most of the year and graze their animals in their private land only after the common pool grazing has been exhausted.

mountain pastoralists were more vulnerable to drought than other nomadic pastoralists. The 1940s famine forced the colonial government to distribute famine relief to the settlers. The oldest farming areas of Marsabit are the Marsabit township and Dakabaricha which were used since colonial times. The dry season grazing area is continually being opened for cultivation by people forced out of nomadic pastoralism after losing viable herds of the Borana, Gabra, Rendille and Samburu nomadic pastoral systems. Other settlers include the early Burji who migrated from Ethiopia, recent (1980s) Ethiopian refugees and people from high populated areas like Meru. Such areas are: Hula Hula, Songa, Nasikakwe, Kituruni, Manyatta, Gabra Scheme and Marsabit Refugee rehabilitation centre. The opened area is then subdivided into 1-2 ha. to about 10 ha. and even over 50 ha. (District Development Plan 1989-93).

2.4 Erosion of traditional systems of range resource management

In the pre-colonial era the members of the Karnath clan were recognized as the secular clan or tribal leaders of the Rendille tribe. This clan was the largest of all the clans in the tribe. Within this clan, only members of a particular lineage (yaf hi karnath delo) assumed leadership.

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Implementation of decisions by these leaders was reinforced by a curse. Administrative duties were easy because all households moved together in a bloc. The colonial authorities, however, changed this form of leadership by appointing headmen who were initially unpaid. These unpaid headmen were incorporated on the colonial government's pay roll and additional sub headmen added into the government's chain of command. The headmen's authority rested on the local government official, the District Commissioner. The new system was authoritarian and the headmen were judged by the taxes they collected. The power of the headmen soon replaced the powers of the karnath, as well as their judicial and welfare functions. This situation diluted the cohesiveness of the Rendille pastoral group and increased the power of the camp leaders (jaldab).

After independence, the new government inherited the old headman system, and even attempted to increase their numbers for effective administration. These chiefs are looked upon by Rendilles to solve serious disputes, maintain law and order and to seek famine relief in drought years. The camp leader makes decisions related to camp movement, while the satellite camp (forr) movement decisions are made by the herdsmen (Moran). Effective enforcement of efficient range use would require increased co-ordinated strategies among the fragmented camps, the administration and members of other pastoral groups.

Little (1983) studied the effects of disruption of the Il Chamus indigenous mechanism of grazing control called the Olokeri. Little's study suggested that the system was becoming ineffective in regulating grazing, because local elders (who have been controlling the system) were continuously losing power. Out-migrations and increased non-pastoral activities deprived the Olokeri of its vital regulation enforcement resource.

2.5 Traditional water-use rights and rangeland use

Digging a well gives exclusive rights of ownership to a pastoralist over the water (et wor leh). The deeper the well the more difficult it becomes to dig. Therefore, the pastoralist may seek help from other individuals (thothi wor islehuto), usually from the same camp. The helping pastoralists also acquire use rights by virtue of their help. A system is established where small stock are watered after every four days, and cattle after every two days. The co-owners are assigned a day each to water their animals. In situations where an individual temporarily abandons his well, siltation may occur. Another pastoralist may be granted water use rights if he requests the well owner and on the condition that he cleans the well.

Public water systems, such as bore holes and dams, are developed by the Ministry of Water Development. Dams and water pans are free to all pastoralists and to a lesser extent bore hole water. Bore holes are administered by the chief, with the assistance of a committee. He may also delegate powers to water technicians (IPAL technical report, A-6). Development of these wells naturally affects distribution of livestock. Areas which were only available to certain individuals due to their traditional water rights, now become accessible to other pastoralists. The result is that man made deserts around these bore holes develop due to increased grazing pressure.

2.6 Land use innovations in Northern Kenya (grazing block ranches)

A grazing block is communal grazing land that has been defined by physical boundaries and developed for use by livestock and wildlife. The average area of a block is 500,000 ha. Development is carried by provision of watering points, infrastructure, extension services, and recommendations on carrying capacities and grazing systems. These block ranches were developed in areas without land adjudication and official registration. The aim of developing these ranches was to increase, stabilize and manage water storage potential in a manner that would increase forage use and stabilize livestock production at the optimum level. This idea was aimed at conserving the rangeland to maintain sustained yields and improve the already denuded areas.

The local district officer and chiefs (headmen) were to organize a grazing block management committee to formulate seasonal and long term grazing plans. The district officer, local chief and block manager were the chairman, vice chairman and secretary of the committee respectively. It was hoped that this committee would effectively implement grazing plans, but as it turned out, they were unable to effect livestock control and exclude other pastoralists from poorly developed areas.

2.6 Factors affecting land resource utilization in Northern Kenya

Research scientists perceive that at least five factors affect resource utilization in Northern Kenya; land tenure, population growth and influx, population density and distribution, climatic conditions (rainfall intensity and distribution), and life style/culture. Each is serious in its own right. The rangelands in the North, apart from where people have settled in the wet or dry season areas and issued with title deeds, are held in trust by the state rather than by the pastoralists. This means that local herdsmen don't have a clearly defined legal claim on the land, and the government can appropriate land for its own use at will. Examples of such cases are the Bura and Hola irrigation schemes, annexation of the Marsabit Forest and National Parks, the Kulal Forest, the Hurri Hills and the Nyiru Forest. To the south west of Marsabit, there are occasional frictions between Turkana, Samburu, and Rendille herdsmen over grazing land. On Mount Marsabit there disputes between Rendille and Boran on land, whereas on the lowlands, north west of Marsabit, there are disputes between Rendille and Gabbra over land use rights. These disputes have often led to bloody raids by one community against another and subsequent retaliation by the victims of the attack.

The displacement of nomadic pastoralists from their prime dry season grazing areas is increasing and the effects of such changes is to constrict the pastoralists' territory. This reduction of free range area has resulted in overuse of certain range areas, reduction in productivity as a result of accelerated desertification and aggravation of tensions among herdsmen themselves, and conflict between herdsmen and farmers which can result in violence and loss of life (Little 1987).

The Northern Kenya arid rangelands suffer from periodic droughts, which appear to occur more frequently in recent times. The impact of drought is far more severe than it was formerly. The increase in both human and livestock population may be elevating this problem. When these droughts occur, they claim the lives of large numbers of livestock and wildlife. The resilience of the rangelands production system to recover from drought seems to be declining with each drought. This phenomena is evident from the number of destitute families which is increasing after each drought. Destitute families are those which lose all their livestock, or the animals left may be too few to support nomadic pastoralism. These families become reliant upon famine relief. Provision of famine relief has become a permanent feature of the economy of Marsabit District (District Development Reports 1969 to 1991). Current opinion is that, developmental and environmental programmes should be aimed at strengthening the pastoral livestock sector base. This option would improve the welfare of the pastoralists. Once the pastoral economic base is firmly established the surplus product from the range resources would be available to the wider economy. Stressing commercial goals may not meet the developmental aspirations and welfare of the pastoral communities. The UNESCO Man and Biosphere project (MAB) established in the project area divided the constraints to use of rangelands in the following four categories: lack of sufficient number of water points, lack of public security, lack of a sufficiently secure land tenure system and lack of grazing control. The last two constraints are closely related to property rights, which we will now turn to for most of the remaining part of this thesis.

Another factor accelerating deterioration of arid lands is the increasing human population. The arid land human population which has doubled in the last 25 years and is expected to double again in the next 10 years (District Development Report 1989). Pastoral population growth is reinforced by the influx of surplus population from the high potential areas. The rising human population has resulted in increased demand upon rangeland resources. Particularly significant is the additional requirement of woody vegetation for building and for fuel, leading to felling of large tracts of woody vegetation. Pastoral people in Northern Kenya use large quantities of woody material for construction of night enclosures (boma). These bomas keep animals together at night and prevent loss by predation and stock theft. These bomas are built at both permanent and temporary camps (IPAL UNESCO Technical Report No. A - 6 1984). The permanent bomas are occupied for longer time periods than the temporary bomas (satellite camps) before new camps are constructed. The former also move shorter distances as compared to the latter. The movements are necessary to avoid the accumulation of ticks and parasites. Before the pastoralists move, the old boma is burned down, so new material is required to construct a new boma. This practice has a great impact on the woody vegetation because a shrub in the arid area takes a long time to grow and recruitment of new seedlings is low.

Also contributing to the deterioration of rangelands in the Arid North is the settlement pattern (distribution of human population). The traditional practice of the pastoral nomads was to disperse during the wet season, from dry season grazing areas[3] and permanent watering points. However today there is an increase in sedentarization of formerly nomadic people on these more productive lands. Humans and livestock are now tending to concentrate around springs, wells, and boreholes. These concentrations are followed by shops, schools, medical centres, and famine relief programmes. They, thus, become a nucleus of overgrazed and overused land which spreads in widening circles of man-made deserts.

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[3] These areas remain somehow green when all other areas are almost devoid of vegetation, because the probably have high water table and the soils are more fertile.

2.7 Socio-economic value of livestock

Pastoralists who keep camels prize them more than cattle although they have low commercial value. Camels are kept for both baggage transportation and for milk production. Camels continue to produce milk even after other livestock have dried especially during drought. Animals are occasionally sold or slaughtered for meat especially when they are injured. Sometimes, camels are exported to the Persian Gulf for slaughter. Camel numbers have declined and this is probably due to fertility problems. Calving is biennial and calves sexually mature after three years.

Sheep and goats are the major source of meat and skins for both pastoralists and agricultural communities as well as a currency for barter trade. Sheep are often exported to Arabic countries for mutton and lamb during religious festivals. Goat meat is a delicacy in major towns and among the pastoral communities. There is therefore a substantial demand for both sheep and goat products. The indigenous ewe is very fertile, with sexual maturity occurring at approximately one year of age. Unless interrupted by pregnancy, oestrum (heat) occurs every 14-19 days and the gestation period is 140-160 days. Goats like sheep are very prolific. Sexual maturity occurs approximately four to five months of age. Oestrum in goats occurs every 18-21 days and the gestation period is 147 days. Twin lambs and kids are not uncommon.

Pastoralists primarily keep cattle for milk and blood production. The average gestation period is 283 days. The calving rate ranges between 50 to 80 percent. Calf mortality lies between 5 to 15 percent. Pastoralists can loose 40 percent or more of their cattle herds during drought years. Cattle are mainly found in wetter parts of Marsabit District such as the central division (Mt.Marsabit, Mt. Kulal, areas surrounding Moyale and Loiyangalani and the Ndoto ranges). In drier parts of Marsabit (80% of the district) camels supplement or replace cattle for milk production. In most cases, cattle are a sign of wealth among the Borana and Samburu tribes. The Rendille and Gabbra value highly the camel and the number of camels one owns may be a reflection of a pastoralist's status in the community[4].

The pastoral economy is complex and has developed over the years to protect pastoralists from adverse effects of weather and other natural hazards like diseases. It is increasingly becoming apparent that the traditional pastoral socio-economic institutions cannot sustain pastoralists, under the new environmental, social-economic and cultural

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4 These comments are based on the authors personal communication with pastoralists.

institution systems. Under-development symptoms such as severe hunger, poverty and human misery have been prevalent among pastoralists.

In the next chapter the manner in which property rights can affect resource use is discussed. Defining the proper property rights institutions can improve rangeland resource use efficiency, hence help to improve the pastoralists' living standard. Improved efficiency in resource use can raise rangeland productivity levels and promote economic growth.

3.0 THE THEORY OF PROPERTY RIGHTS

3.1 The economic concept of property rights

Pareto efficiency is achieved when all potential gains from trade in all sectors of a perfect economy are exhausted. Certain institutional conditions must be satisfied for a Pareto efficient equilibrium to be achieved. The necessary conditions for Pareto efficiency are also the marginal conditions for efficient trade. The institutional arrangements that facilitate perfect competition, also encourage the achievement of Pareto efficiency. Property rights play a key role in resource allocation and efficient functioning of markets.

A property is said to be a bundle of rights to control[1]. This bundle consists of strands which can be distributed among the state, owners, users, credit, taxation, workers and other economic agents (Ciriacy-Wantrup and Bishop, 1975). The characteristics of an efficient and adequate set of property rights are[2] (Randall, 1975 and

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[1] Bromley defines a right as the capacity to call upon the collective to stand behind one's claim to a benefit stream.

[2] Bromley uses "fundamental legal relations" concerning rights and property as recognized by (Hohfeld, W.N., 1913: Source; Bromley). The terms used are: Right vs Duty, Privilege vs No right for static correlate; and Power vs Liability, Immunity vs No power for dynamic correlate.

1978) as follows:

(a) Ownership is a legal device that assigns the right to use. Ownership depends on various restrictions of resource use. The two polar ends of ownership restrictions are: The exclusive ownership (private property), which caries with it the right to use and to determine who uses; and the *res nullius* (no-body's property), which carries the right to use but not the right to exclude others.

(b) Specification of rights helps in resolving conflicting interests. Well specified rights determines the rights that dominate in case of a dispute.

(c) Transferability requires that rights associated with ownership must be transferable. This enables owners of the rights to relinquish them at will whenever another individual makes an offer to acquire the rights.

(d) Effective enforcement involves the discovery of violators, their apprehension and imposition of the appropriate punishment.

Property rights which exhibit all these characters are said to be nonattenuated property rights, and they ensure Pareto efficiency. Property rights operate within resource management regimes (Bromley, 1989a). A resource management regime is a structure of rights and duties characterising the relationship of individuals to one another with respect to a particular resource. There are four types of resource management regimes:

(i) State Property Regime (*res publicae*) occurs when the state acquires the ownership and control rights over resource use. Individuals or groups may be able to use the resource by seeking the state's consent.

(ii) Private Property Regimes arise when the individual (or group) owner has the right to make management and investment decisions regarding a certain resource with full knowledge that good stewardship will return private rewards. Private property is suitable so long as it satisfies the following assumptions; production decisions are geared to produce goods valued by society, absence of externalities and it induces industry.

(iii) Common Property Regimes (res communes)[3] are situations whereby the management group has the right to exclude non-members, and non members have duty to abide by the exclusion. Individual owners have both rights and duties regarding use rates and conservation of the resource.

(iv) Open Access Regimes or Non-Property (res nullius) are situations where, no defined group of users or owners exist and the benefits from the resources are free for all.

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[3] Ciriacy-Wantrup and Bishop, 1975. Clarified the confusion created by Garret Hardin's article on common property regimes, by differentiating res communes from res nullius.

Individuals are said to have a privilege but no right with respect to use and conservation of the resource. An open access results from the absence or breakdown of the institution concerning management and control of the resource[4].

3.2 Property rights institutions, Pareto efficiency and range resource management

In this section, the property rights institution is evaluated on the basis of whether they facilitate the achievement of the Pareto-efficiency criterion. A social institution, for this matter a property rights institution, has two basic aspects (Summers and Keller, 1927)[5], the *purpose* and the *structure* of property rights. Our concern is how the structure of the property rights institution as a limiting factor can influence a nomadic pastoralist's resource management and conservation decisions. The basis of this evaluation will depend on the nature of property rights. The relations used are; indefiniteness, instability

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[4] One would be right to refer this as the real case for Hardin's tragedy of the commons.

[5] Adopted from Ciriacy-Wantrup, Resource Conservation Economics and Policies 1968, pp. 140.

and imbalance of property rights[6].

(a) Indefiniteness of property rights exist when resources have to be captured or secured as possession in legal terms before being reduced to property. Such resources are referred to as fugitive resources. Fugitive resources must be captured through use. The range forage on the pastoral grazing lands in Northern Kenya is increasingly becoming a natural resource which has indefinite property rights and fugitive characteristics, as the traditional land use institutions are altered. Every user tries to protect himself against other agents by grazing as much forage as possible, by increasing his livestock numbers as fast as possible. Resource tenure[7] is not defined, therefore those who benefit from the grazing resources are the ones who get there "fastest with the mostest". This behaviour leads to great uncertainty problems, deferred grazing is discouraged because others may graze the deferred land in the meantime.

Resource economists suggest that resource depletion and environmental quality degradation are typically attributed to the lack of well defined property rights for many natural

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[6] Based on Ciriacy-Wantrup discussions on the effects of property rights on resource conservation. Resource Conservation and Policies, 1968, chapter 10, pp. 141.

[7] Tenure here refers to all strands of the bundle of property rights.

and environmental resources. Garret Hardin's expression "tragedy of commons" in his article in Science (1968) was an attempt to describe so-called common property (in reality, open access regimes):

"Therein the tragedy." Each man is locked into a system that compels him to increase his herd without limit - in a world that is limited. Ruin is the destination toward which men rush, each pursuing his own best interest in a society that believes in the commons (Hardin 1968, p. 1, 244).

As indicated earlier in this paper, land in the Northern Kenya region is held in trust by county council (local government). The county council does not define clearly who is to use the rangeland and how the rangeland is to be conserved, although user rights are assumed to be vested on the tribal or pastoral groups that already roam the land. Such tribes or pastoral groups do not have any legal right to exclude others from using the land. This case is well demonstrated by the annexing of Mount Marsabit, a prime dry season grazing area by cultivators, government agencies and other institutions without compensation to pastoralists. Land acquisition for ranching in Baragoi and Isiolo is another example of this problem. Wanton destruction of woody vegetation around permanent settlement is another example of indefiniteness of property rights. If a pastoralist does not cut a tree near the settlement for firewood or to repair his fence, someone else will cut it and reduce it to his possession through capture.

Remedies to counter the problem of indefiniteness of property rights are as follows:

(1) Control over resource use may be defined through law and government regulations in such a way that the need for capture disappears. In the USA the Taylor Grazing Act of 1934 provided law and administrative basis for the control of grazing land. Conservation was achieved through the removal of public domain, establishment of grazing districts, creation of a coordinating unit to monitor, enforce the rules and issue grazing permits to users. The open access common grazing range present two sets of regulatory problems which involve economic efficiency.

(i) Maintaining stocking rates at the desired level. Solutions to this problem require definition of the desired stocking density; this calls for economic information on costs, prices, biological data on range pastures and growth rates to determine the optimal livestock numbers and pasture biomass and their efficient trajectory over time. The amount of pasture that can be harvested depends on the number of animal units, location of the pasture and season. Thus restrictions on the number of animal units and prescribed grazing can protect rangelands overuse.

(ii) The problem that concerns us is the economic efficiency in harvesting range pastures. Employment of excessive and redundant privately owned capital (livestock herds) to harvest fugitive pastures in the commonly owned rangelands, may lead to inefficiencies in rangeland use. Inefficiencies also arise due to concentration of livestock on areas of higher productivity. These tendencies call for regulatory measures because they lead to rent dissipation of the communally owned rangeland as compared to the rent appropriated with prescribed grazing. Penalizing the pastoralists who keep herds past their economic performance can reduce this problem.

(2) Instead of making private tenure more definite, control of resource use may be vested in the government or a monopolistic firm can be appointed to act on behalf of the government. This particular idea may not be acceptable in the present world, where private enterprise is favoured and monopolies opposed.

(b) Instability of property rights (insecure) property rights results due to the following reasons:

(i) If the user has doubts of the renewal of his lease;

(ii) High discount rates due to the risks of drought and famine; and

(iii) Political change which can bring about stringent government regulation and confiscatory taxes.

Rigidity of property rights is associated with the problem of poor or slow adaptation of property rights structure to changes in the society. Rigidity of property rights cause stresses which are unfavourable for efficient resource use and conservation.

Stability of property rights refer to the expectations that whatever land use rights individuals hold to land and its use will be secure and dependable over time. If the user of such a resource feels that the property rights he holds are insecure, this individual will tend to maximize short term benefits at the expense of the conservation of the resource. However, if property rights are secure (stable), this will act as an incentive for resource conservation. Security consists of two main facets: Physical security; and Tenure security.

Physical security is concerned with "protection against physical uncertainty", that is, against variability over time of the amount of land available for grazing under the right due to land annexation by outsiders (cultivators, government and influential people). Tenure security is concerned with the "protection against variability over time of the amount of land available for pastoral use due to lawful acts of other individuals or groups, private or public."

The pastoralist's concern with security of land use rights problems is reflected in both physical and tenure security. Pastoralists are not certain that the physical land available to them will be secure. Pastoralists from other tribal groups can force their way into the territory of another group. Wet season grazing areas are being converted into private property and there are no guarantees that the government will not annex some land without compensation. A herd owner in Northern Kenya has unrestrained right of access to forage on the common grazing land. So long as maximum sustainable stocking rate is not exceeded, no overgrazing occurs. Tenure rights are however insecure because there is distinct possibility that collective grazing will lead to overgrazing of land. This instinct is enhanced because each pastoralist has unrestrained right to increase the number of livestock in his herd, and has no liability whatsoever to other pastoralists for any adverse effects on forage availability which may result due to his grazing activities. Flexibility of land use rights on the other hand refer to the case of transferability of land use rights between uses and users. There are no markets for land use rights or permits in Northern Kenya. Since pastoralists have no legal basis to claim land, they cannot transfer their use rights to other pastoralists or cultivators. One has a right to use land when he physically owns a herd on the public land. The possibility of introducing tradeable grazing rights permits could be explored. This absence of grazing permit exchange is probably an example of a missing market.

(c) Imbalance deals with the equity and externality implications of property rights. Property rights are said to be imbalanced if they lead to revenue and cost distributions such that, members of the social group involved don't take into account all the costs and revenues. Under such conditions, agents will be interested in their private revenues (benefits) and private costs, rather than those of the society.

The remedies for reduction of the imbalance of property rights are;

(i) Disparity between private and social costs and benefits can be reduced through perfecting existing legal instruments and by devising others.

(ii) A second way is to prohibit use of the resources exhibiting imbalance of benefit and costs through zoning and nuisance abatement ordinances and full cost accounting.

(iii) Lastly, one could make regulations enhancing treatment of damage done or range rehabilitation.

3.3 Defining Property Rights in Northern Kenya.

The problem of overgrazing (browsing) land due to non exclusiveness is likely to persist due to economic, cultural, traditional and the basic nature of the arid rangelands. The following illustration using oysters and salmon will help illustrate the problem of Northern Kenya rangelands. Oysters are sedentary and grow to maturity while attached to a particular rock bed so it is easier to define exclusive rights to such a resource. This situation can be likened to high potential rangelands, where a pastoralist can cost effectively fence off parcels of land to exclude other pastoralists from grazing his/her pasture. That is, the benefits of excluding other pastoralist more than offsets the costs of the exclusion exercise.

On the other hand salmon fishes are highly mobile and require both sea and fresh water rivers to complete their life cycle. It is therefore very difficult to define exclusive rights on highly mobile fish like salmon. Ownership of salmon is established through the rule of capture unlike ownership of farm livestock or privately owned oysters. Grass on an extensive hard to monitor rangeland is likely to develop fugitive characteristics like the salmon. Improvement of policing and involving the local pastoralists in conservation planning can reduce the rule of capture in forage resources. The cost of defining and enforcing the exclusive property rights may be way higher than the benefits that may be attained. In cases where this cost is very high, it might be more feasible to wait for scarcity to drive prices high enough for attainment of favourable cost benefit ratios. When exclusion is feasible, specification of exclusive property rights as described in the previous sections is a political decision that should be resolved.

3.4 Identifying factors for analysing property rights problems.

Formulation of sound range management policies and property rights institutions require good knowledge of the right economic relationships underlying rangeland use. This knowledge is acquired through analysis of models that describe these relationships. In the next chapter, these models will be described along with parameters that can be used to test the hypotheses identified above.

4.0. ANALYTICAL METHODS APPLIED IN COMMON PROPERTY RESOURCES

4.1. The Gordon model adapted for rangeland

The resource management problems involving common property regimes have in the past been analysed using a static economic model such as the one developed by H. Scott Gordon (1954) for the open access fishery. Gordon's model portrays the long run operational results of various levels of input (effort) and output (fish). In the fishery case, users are rewarded for increasing fish stocks. The Gordon model can be modified for rangeland use. In our case the control variable would be livestock numbers (stocking rate) expressed in terms of Tropical Livestock Unit (TLU) and livestock output (animal products) expressed in money terms of annual yield (milk, meat, blood etc). Unlike the fishery case, large stocks of livestock have an overall negative environmental and economic impact on the rangeland. The relationship between the costs, yield and livestock numbers is portrayed in Figure 1.

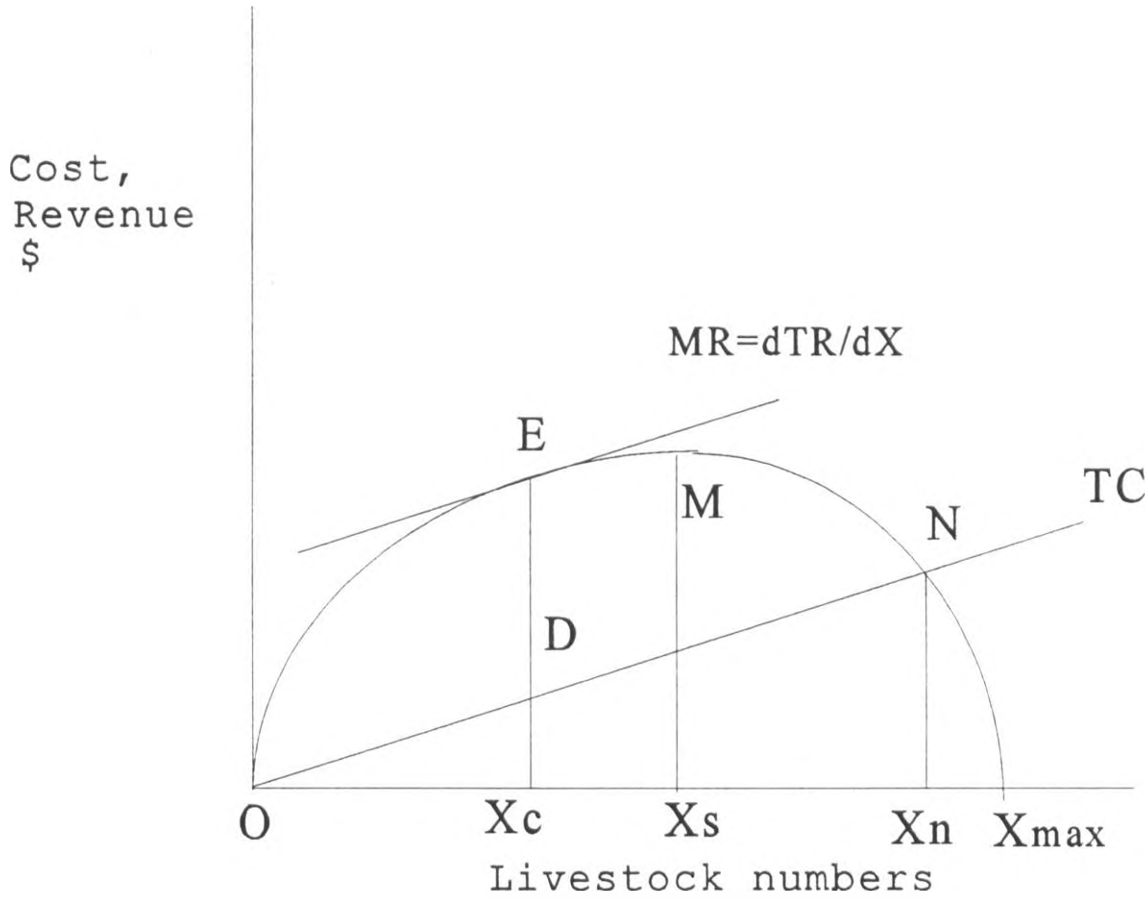

Figure 1. Open access rangeland; annual costs, yield and livestock numbers.

In figure 1, the yield curve is the locus of sustainable yields expressed in money terms, at various stocking rates. The typical bell shaped yield curve is due to the biological characteristics of the relationship between stocking rate and forage production. When stocking rates are low, average animal production per livestock unit will be very high because there is little competition for the forage resources. However, total annual production will be low because only a few animals are put into production. When pastoralists increase the number of animals and hence stocking rates, annual animal production will rise initially, because of increased number of productive animals, but this increase will be at a declining rate. The decreasing rate of total annual output is attributed to the decrease in average output as competition for grass by animals increases. The rise in annual output will eventually fall because forage intake will decline as the rate of regeneration is exceeded. Animals will start to lose weight as they move longer distances to find food hence, overall productivity declines both in total terms and per animal terms. In figure 1, this point is OXs. The maximum sustainable yield is M, which will be achieved by maintaining stocking rates at OXs. Extra animals beyond OXs will result in overgrazing, and subsequent range deterioration. This phenomenon is what is referred to as overgrazing in a biological sense.

The costs of producing animal products are: herding inputs (the opportunity cost of labour etc), veterinary charges, and watering fees. The total cost of herding is assumed to be directly proportional to the number of livestock herded. The total cost curve is thus a straight line through the origin. The difference between the total revenue curve and the total cost curve at any stocking rate, is the economic rent. The most economically efficient stocking rate is the one where the economic rent is maximum. This stocking rate is at OXc, where the marginal cost (slope at D) is equal the marginal revenue (slope at E). The value of animal products here is EXc, while the cost is DXc. As long as economic rent exists, more animals will be added to the rangeland through additions to the existing herds and entry of more pastoralists. However, when the stocking level OXn is exceeded, economic rent will be dissipated and there will be no further inducement to enter or increase the number of livestock. What this model predicts is that, if the rangeland is not restricted, livestock numbers will inevitably be driven to point Xn, here the rents related to the range resources are completely dissipated. This citation will be a classic case of *res nullius*.

Economic theory through the marginal rule tells us that it is irrational for a single-owner pastoralist to expand his livestock numbers beyond OXc where marginal cost is greater than marginal revenue. Operating beyond OXc is not Pareto efficient, and may be said to be overgrazing in an economic sense. An intelligent pastoralist will realize the irrationality of expanding livestock numbers beyond OXs, where biological overgrazing will occur. Not all open access resources will be over exploited beyond OXs, occasionally, costs may be prohibitive cutting through point M, thus no increase in livestock numbers beyond OXs would be economically possible.

Elinor Olstrom (1990) has argued that there are situations when the commons work. The agents involved have through time developed and perfected a wide variety of their own agreements, enforced by many mechanisms. Outsiders may not perceive these arrangements, and they may erroneously conclude that enforcement is absent, since a central governing body is absent. The Alanya fishermen of Turkey and the Swiss Alps herdsmen are cited as examples. A restricted grazing resource (*res communes* or the true common property) will operate between OXc and OXs, whereas a true *res nullius* will operate at point OXn.

The classical symetrically shaped curve may not apply in cases where rangelands are fragile due to low and erratic rainfall. The author would suspect that such regions would deteriorate very fast at high stocking rates. This means that the upper tail of the bell curve would be sharper or decline faster than the classical case as shown in Figure 2. This implies that the difference between the *res nullius* and *res communes* stocking rate levels is small. Thus rejection or acceptance of either case revolves around a more narrow margin than in the classical case.

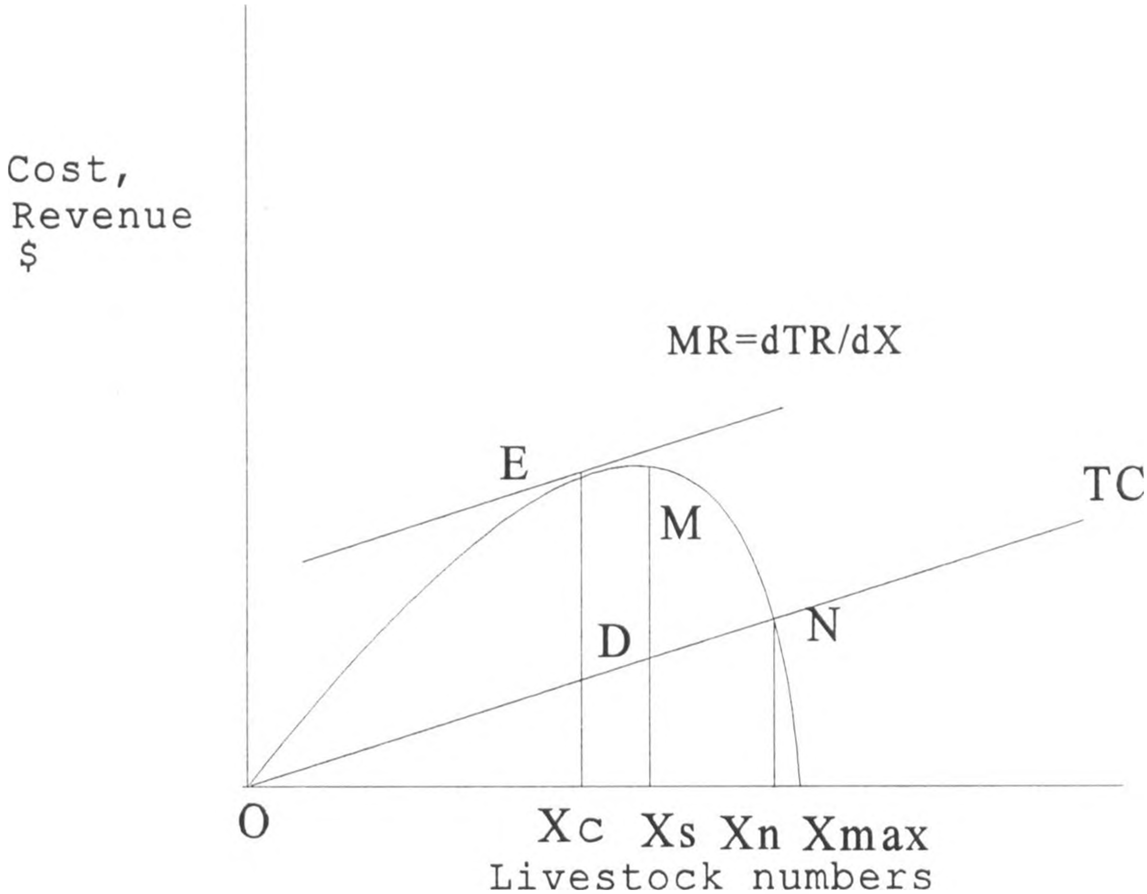

Figure 2. Open access rangeland; annual costs, yield and livestock numbers, the case of rapid range deterioration after maximum sustainable yield is exceeded.

4.2 Demand and Supply Analysis

The problem of a so-called "common property" (open access) resource explained above can also be analyzed using the marginal willingness to pay curve (demand) and the marginal cost curve (supply). These demand and supply diagrams are adopted from the Haveman's (1973) static "common property" model (Figure 1). This model is presented in Figure 3.

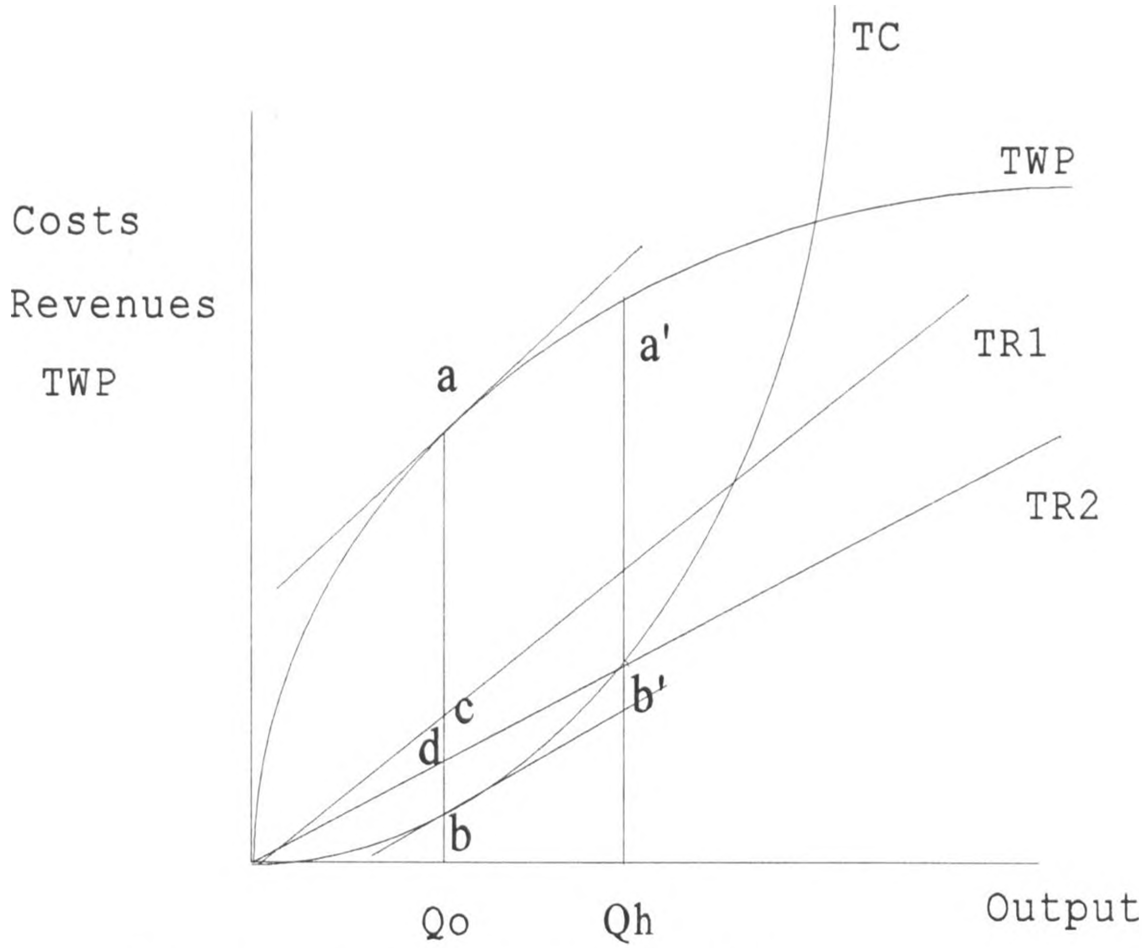

Figure 3. Haveman's model

The total willingness to pay (TWP) is equal to the total revenue (TR) plus consumer surplus. The bio economic equillibrium (b') is the point where total revenue (TR) equals total cost (TC). At point b', the economic rent is zero corresponding to the open access production Qh. The sole owner or group of owners (true common property) will operate at Qo, where economic rent is maximum. The marginal willingness to pay, marginal cost, average cost and marginal revenue curves are derived[1] from the corresponding Haveman's total willingness to pay, total cost and total revenue curves. These curves are presented in Figure 4

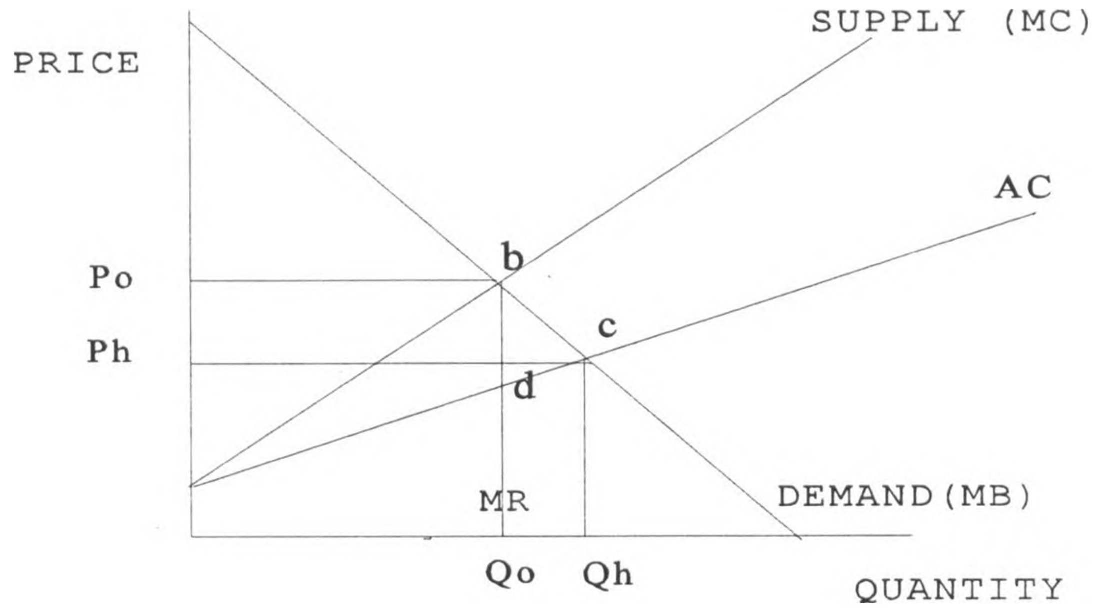

Figure 4. Demand, supply, average cost and marginal revenue curves.

The Pareto efficient pastoral production system will operate at the intersection of demand curve and the supply curve, where marginal benefits equals, marginal costs, equals price Po. At this point, output Qo is the socially optimal

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[1] Using the first derivatives.

output. The economic rent which is equal to Qo multiplied by (Po minus average cost), is maximum. This situation can be likened to the *res communes* case of true common property. The open access case occurs where average cost (AC) is equal to marginal benefit (MWP=MB) equal to price Ph. At this point, economic rents are dissipated and the output is Qh. The economic rent which is equal to Qh multiplied by (Ph minus average cost) is equal to zero. This condition can be likened to the *res nullius* case of open access common property. The equilibrium rate of output under res communes case is lower than under res nullius. The price is however higher under *res communes* case than at *res nullius*. Consumer surplus under *res nullius* is greater than under res communes.

4.3 Dynamic modelling and the discount factor.

4.3.1 Static and dynamic optimization.

The static models above are limited in analyzing resource use. As optimization models, the problem is that of finding values of the endogenous variables that maximize (or minimize) a specified objective function and identifying the first order conditions that serve equilibrium. Typically, the assumption of zero discounting, constant prices, and independence of successive time periods are made.

A dynamic optimization approach is adopted as the analytical tool in this thesis. Rational expectations hypothesis is also applied to improve on the simple theory of bioeconomic equilibrium[2] used by early analysts (Conrad and Clark, 1987). In this thesis dynamic optimization and the theory of rational expectations are combined to obtain a model to test for property rights.

4.3.2 Discount factor.

The discounting technique is used to calculate the present value of a future stream of benefits from a resource like rangeland. In descrete-time model analysis, the present value of future net benefits B_t where time (t) = 0,1,2,3,....T. is calculated using the following formular:

$$B = \sum_{t=0}^{T} \frac{B_t}{(1 + \delta)^t} = \sum_{t=0}^{T} \beta^t B_t$$

Where delta (δ) is the discount rate and beta (β) is the discount factor.

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The simple theory of bionomic equilibrium assumes that fishermen or pastoralists enter or leave the "common property resource depending on whether net revenues are positive or negative. Rational expectations theory on the other hand assumes that pastoralists predict the number of pastoralists entering the "common resource" and the resulting time profiles on prices and resulting costs.

The discount factor is inversely related to the discount rate as shown in the equation below:

$$\beta = \frac{1}{(1 + \delta)}$$

From the above relationship, it is obvious that a high discount rates[3] will result in very low values of beta (approaching zero). High discount rates mean that pastoralists prefer to use rangelands now rather than concerving them for the future. On the other hand, low discount rates[4] result in discount factors that approach one. Discount factors near one mean that pastoralists give a heavy weighting to future stream of benefits rather than using the rangeland resources now, meaning that the resource will be conserved. The rate of range resource use (conservation versus depletion) depends on the particular property rights regime in place as explained above. The remaining part of this chapter contains a formulation of models can be used to test the significance of β in resource use. If $\beta = 0$, res nullius exists; if $\beta > 0$ res communes exists.

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[3] Discount rates that approach infinity.

[4] Such as zero, meaning no discounting at all.

4.4 EMPIRICAL RESEARCH MODEL

4.4.1 Pastoral production model

Consider a pastoralist facing competitive but uncertain markets. The quantity of livestock products (TPP) is a function of the total number of livestock grazed (S_t), the amount of pasture produced (X_t) and variable pastoral labour (P_{1t}). Biological capital S is the capital invested in livestock mainly small ruminants (goats and sheep), cattle and camels. TPP can be presumed to be produced via a concave production function as shown below:

$$TPP_t = f_1 S_t + f_2 X_t + f_3 P_{1t} - 0.5(f_{11} S_t^2 + f_{22} X_t^2 + f_{33} P_{1t}^2)$$

$$+ f_{12} X_t S_t + f_{13} S_t P_{1t} + f_{23} X_t P_{1t} \qquad (1)$$

The nature of the production function depends on how the output per unit area and stocking rate relationship is formulated. Stocking rate experiments conducted by Jones and Sandland (1974) indicated that gain per animal regressed against stocking rate can be fitted into a simple linear model below:

$$Gain\ /\ animal = a - bS \qquad (2)$$

Production per hectare, on the other hand, was expressed in a curvilinear model as follows:

$$Gain\ /\ hactare = aS - bS^2 \qquad (3)$$

For the purposes of our study, the curvilinear relationship which helps derive a flexible functional form such as the concave quadratic production function is more appropriate for the analytic procedures used herein.

The amount of pasture produced depends on the level of precipitation and grazing pressure. An equation of motion or difference equation that defines the change in rangeland pasture production potential from one period to the next is shown as follows:

$$X_{t+1} - X_t = gR_t - \alpha S_t \qquad 0 \leq \alpha < 1 \qquad (4)$$

Pasture standing biomass is inversely related to livestock numbers (S_t) grazed in a given area. The higher the number of livestock grazed, the more pasture that is removed, trampled or agitated. Studies conducted by McNaughton (1979) and Belsky (1986) suggest that often compensatory plant growth may occur due to herbivore grazing. This compensatory or stimulated plant growth may occur due to: increased photosynthetic rates in residual tissue; relocation of substrates from elsewhere in the plant; mechanical removal of older tissues functioning at less than maximum photosynthetic level; consequent increases light intensities upon more active underlying tissues; reduction of leave senescence (thus prolonging the active photosynthetic period of residual tissue); hormonal redistribution promoting cell division and elongation and activation of remaining meristems (thus resulting in more rapid leaf growth and promotion of tillering); enhanced soil moisture conservation due to reduced evapotranspiration surface and reduction in relative stomatal resistance; and direct effects from growth promoting substrates in ruminant saliva. Plant tissue reduction by grazing or browsing activities of animals beyond the optimum level will ultimately lead reduced plant growth. In arid areas where soils are poor and rainfall is erratic, plant growth is likely to be reduced in a more linear way than high potential areas[5].

Rainfall (R_t), on the other hand, enhances regeneration of pasture. The relationship between rainfall and herbaceous primary production has been investigated for areas south of the Sahara where rainfall is less than 700 mm. The rule of the thumb is that 1 mm of rainfall produces 2.5 kg of dry matter per hectare (Le Houe'ron and Hoste, 1977). The woody

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[5] Authors own observation and assumption.

vegetation at low rainfall conditions and at a density of 130 plants per ha may yield about 120 kg of dry matter (Bille, 1979). The difference equation above should be formulated in a state transition model which is more appropriate for grasslands that are dominated by annual plant species and characterised by low and erratic rainfall. This relationship is represented by natural growth factor **g**. The pasture or forage input is expressed in terms of rainfall received. Studies have been conducted to investigate the relationship between average rainfall and pasture production. Average rainfall is correlated with other climatic factors such as rain variability, number of rainy days, length of dry and wet seasons. Therefore adding these in a regression model may not provide extra explanatory power. For purposes of this study we use average rainfall data obtained from the Kenyan government (meteorological department) is used.

Range pasture may be considered as a linear function of average annual rainfall. However, this model does not explain satisfactorily the Sudano-Sahelian rainfall/pasture production relationship (Le' Houerou and Hoste, 1977). Le Houerou showed that a better model for this region would be a power curve, $X = aR^b$, where X is biomass production (total dry matter), R is average annual rainfall, and a and b are constants.

The Coe, Cummings and Philipson (1976) study utilized data from East, Central and Southern Africa including the study area of this report. The relationship obtained between primary production and evapotranspiration in their study was

$$Log_{10}\,NAAP = LOG_{10}\,AE(1.66 \pm 0.27) - (1.66 \pm 0.07) \qquad (5)$$

Where NAAP is net above ground primary production in grammes per metre squared per annum ($g\ m^{-2}\ a^{-1}$) (dry weight) and AE is annual actual evapotranspiration in millilitres per annum ($mm\ a^{-1}$) . Actual evapotranspiration is regarded as a simultaneous measure of water availability and solar radiation. This study therefore supports the findings of Le Houerou. Cassady (1974) conducted research on effect of rainfall, soil moisture and harvesting intensity on grass production in Kenya's arid rangeland (zones V and IV. Grass was harvested from one to eight times a year to estimate standing crop and accumulated yields under several harvesting pressure. Without harvesting, forage yields near maximum were reached in 44 days, with growth rates ranging from 32 to 68 kg/ha/day, during the first 50 to 100 days. Repeated moderate defoliation (4 to 8 times) produced yields equal to or higher than control plots. Severe harvesting reduced yields by 22 to 60 per cent, and most of the standing grass was destroyed.

The total number of livestock in the rangeland S_t is equal to the number of livestock held by individual N pastoralists in the area, thus.

$$S_t = S1_t + S2_t + S3_t + \ldots\ldots + Sn_t$$

4.4.2 Constrained pastoral production model under common property (*res communes*)

Suppose n pastoral agents own the livestock on the rangeland under true common property regimes. The problem faced by the management group (or appointees) is to choose the number of livestock units (S_t) for each period of planning horizon, to maximize the expected discounted future profits, derived from the consumption and sale of livestock and livestock products. Hence the following equation:

$$V_o = Max\ E_0 \sum \beta^t [(P (f_1 S_t + f_2 X_t + f_3 P_{1t} - 0.5 (f_{11} S_t^2 + f_{22} X_t^2$$

$$+ f_{33}^2 P_{it}^2) + f_{12} X_t S_t + f_{13} S_t P_{1t} + f_{23} X_t P_{1t}) - r_{t+1} S_t - w_t P_{1t})] \quad (6)$$

Subject to;

$$X_{t+1} - X_t = gR_t - \alpha S_t \quad (7)$$

Where V_o is the present value of profits, E is the expectations operator at time o, P is the price per unit of livestock product, C is the cost of herding inputs and β is the discount factor. The Lagrangian expression can be written in terms of a current value Hamiltonian following Conrad and Clark (1987):

$$H(S, X, R, h, \lambda_{t+1}) = E_t\ (\ \beta^t[\ P\ (\ f_1S_t + f_2X_t + f_3P_{1t} -0.5(\ f_{11}S_t^2$$

$$+ f_{22}X_t^2 + f_{33}P_{1t}^2) + f_{12}X_tS_t + f_{13}S_tP_{1t} + f_{23}X_tP_{1t}) - r_{t+1}S_t - w_tP_{1t}\ )$$

$$+ \mu_{t+1}(gR_t - \alpha S_t)\ ] \qquad (8)$$

Where $\mu_t = e^{\delta t}\ \lambda_t$. λ_t is the present-value shadow price of an additional unit of grass from the perspective of time (t) = 0 and μ_t is the current-value shadow price of an additional unit of grass from at instant time (t). The first order conditions (FOC) are as follows:

$$(i)\ E_t[\beta^t(f_1 - f_{11}S_t + f_{12}X_t + f_{13}P_{1t} - r_{t+1}) - \alpha\mu_{t+1}] = 0,$$

$$(ii)\ -E_t(\mu_{t+1} - \mu_t) = \beta^t E_t(f_2 + f_{12}S_t - f_{22}X_t + f_{23}P_{1t}),$$

$$(iii)\ E_t(f_3 + f_{13}S_t + ff_{23}X_t\ f_{33}P_{1t} - w_{t+1}) = 0,$$

$$(iv)\ E_t(X_{t+1} - X_t) = E_t(gR_t - \alpha S_t).$$

The first Lagrangian FOC is the optimality condition for the number of livestock or animal units employed. Each independent profit maximizing herd owner will add animal units to his herd until the current value of an additional animal unit equals until the current value of an additional animal unit equals the marginal cost of acquiring and keeping the animal in the herd plus the current cost of future benefits foregone if overgrazing occurs.

The second FOC describes the optimality condition of the use of the rangeland forage. This equation describes the user cost of the range resource. The third FOC indicates that the pastoral labour will be used until their marginal benefit equals its marginal cost (wage rate). The last FOC describes the equation of motion for range forage resources.

4.4.3. Constrained pastoral production model under non-property (*res nullius*)

Next, consider a case of *res nullius* (open property or no property regime). Pastoralists will not assign user costs to the degradation of range resource. Instead, their economic behaviour will be as if they consider the effects of grazing on the current and not the future profits. This high discounting rate in favour of the present would lead to pasture overgrazing, the marginal social productivity of livestock is zero and negative when the carrying capacity of the rangeland is exceeded. Overgrazing reduces forage production, and , therefore the ability of livestock to produce livestock products. A zero or negative social marginal product does not necessarily mean that the surplus livestock have no value as inventory. Speculative herdsmen may find it worthwhile accumulating animals if their value (spreading risk and future price increases) is expected to rise by more than the cost of retaining them.

However retaining these animals is expensive to the society, and results in an inefficient use of resources. Grazing that can be used to raise output and leave the rangeland resilient enough to recover from adverse effects of drought is used up. The economic behaviour of pastoralists described above will have two effects on the first order conditions. First the co-state variable μ_t will be zero for all time periods, because the discount factor β_t in the first and second FOCs becomes zero as the discount rate δ approaches infinity[6]. Second, since overgrazing through excessive overstocking S_t affects the next periods biomass stock of forage and not the current profit, the forage biomass is taken as given by pastoralists.

4.5 Formulation of the stochastic Euler equations for estimation

The strategy employed in this analysis is that the dynamic optimization problem of pastoralists as economic

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6 See section 4.2.2.

agents typically imply a set of Euler equations that must be satisfied in equilibrium. These Euler equations consequently imply series of orthogonality conditions that depend non-linearly on variables observed by econometricians and on parameters characterizing the profit function described above.

The Euler equations can be obtained for common property pastoral livestock production through a complex mathematical process. This process involves a combination of expectations theory and difference equations to obtain reduced form equations that can then be used for hypotheses testing. This process will only be discussed briefly because it is extensively discussed else where[7]. First, the herding input variable is eliminated from the first and second FOC's, using a rearranged third order condition. Using the lag operator, a time change in value for the shadow price for the first order condition similar to that of the second first order condition can be obtained. Substituting the lagged first FOC into the second FOC gives an equation consisting of the control variable, state variable and input prices. To eliminate the state variable from the new equation, the equation of motion is rearranged as follows:

$$E_t X_{t+1} = E_t(g - \alpha S_t)/L \qquad (9)$$

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[7] See for example Clark and Carlson (1988), Hansen and Sergent (1980) and Sergent (1978).

$$E_t X_{t+1} = E_t(g - \alpha S_t)/L \tag{9}$$

where L is the lag operator and pasture growth is assumed as constant g for simplicity. The right hand side of this equation of motion is used to eliminate the state variable. Then with some equation rearrangements and collection of terms, a final Euler equation for *res communes* is obtained as follows:

$$\theta_0 + \beta S_{t+1} - ((1 + (1 - \beta)\theta_1 + \beta\theta$$

$$+ S_{t-1} + \theta_3(\beta r_{t+2} - (1 + \beta) r_{t+1} + r_t)$$

$$+ \theta_4(\beta w_{t+2} - (1 + \beta) w_{t+1} + w_t) + \beta\theta_5(r_{t+2} - r_{t+1})] = \nu_t \tag{10}$$

The same procedure followed in the formulation of *res communes* Euler equation is used to derive the *res nullius* Euler equation. The only difference is that the changes to the first order conditions described in section 4.4.3 are observed. Thus, the *res nullius* Euler equation is as follows:

$$\phi_0 - \phi_1 S_t + S_{t-1} - \phi_2(r_{t+1} - r_t) - \phi_3(w_{t+1} - w_t) = \mu_t \tag{11}$$

The coefficients obtained from equation 10 and 11 are related to the production function as well as the first order conditions. The test of mathematical stability of equations 10 and 11 is tested in the Appendix.

5.0 ESTIMATION AND TESTING

The statistical properties of equations 10 and 11 require estimation based on algorithms for nonlinear-in- parameters systems (Wallis, Kenneth F. 1980). The best way to estimate Euler equations 10 and 11 is by use of instrumental variable estimation because of the error terms on independent variable data measurements. The general methods of moments is likely to be appropriate because the sample of the data used in this analysis is small (1968 to 1993) and because of potential serial correlation problems. The sample size is further reduced by lagging, leading and differencing during the analysis. These problems render the weighting matrix W_j singular as explained below.

5.1 Instrumental variable estimation

Let the Euler equations 10 and 11 from the first order conditions be simplified into the following functional form

$$E_t g(X_{t+i}, \theta_o) = 0 \qquad (12)$$

Where E_t is the expectation's operator conditioned on the pastoralists' information set $E_t I$ at period t, g is a function mapping R^k X $\dot{R}$ into $^m R$, X_{t+i} is a k dimensional vector of variables observed by pastoralists and the analyst, and θ_o is a one dimensional vector of parameters unknown to the analyst. Let

$$\nu_{t+i} = g(X_{t+i}, \theta_o) \qquad (13)$$

The ν_{t+i} constituents are assumed to have finite second moments.

$$E_t[\nu_{t+i}] = 0 \qquad (14)$$

Next a function h is defined as

$$(X_{t+i}, Z_t, \theta) = g(X_{t+i}, \theta) \otimes Z_t \qquad (15)$$

where Z_t is a q dimensional vector of instrumental variables that are in pastoralists' information set and observed by the analyst, h maps R^k X R^q X $\dot{R}$ into R , r = m.q, and ⊗ is the Kroneker product. Thus 14 and 15 imply that

$$E\,[h(X_{t+i}, Z_t, \theta)] = 0 \qquad (16)$$

where E is the unconditional expectations operator. Equation 16 represents a set of orthogonality conditions from which an estimator of θ_o can be constructed, provided that r is at least as large as the number of the unknown parameters, l. Let

$$j_o(\theta) = E[h(X_{t+i}, Z_t, \theta)] \qquad (17)$$

where $\theta \in R^1$ and the left hand side doesn't depend on t[1]. The method of moments estimator for j_o is

$$j_T(\theta) = \frac{1}{T}\sum_{t=1}^{T} E[h(X_{t+i}, Z_t, \theta)] \qquad (18)$$

and T is the sample size. Under regularity conditions $J_T \rightarrow E[j_t(\theta)]$ as T approaches ∞. Therefore, the estimator of θ is obtained by minimizing the following:

$$J_o(\theta) = \bar{j}_T(\theta)' W_T \bar{j}_T(\theta) \qquad (19)$$

where W_T is a symmetric non singular weighting matrix. This weighting matrix is easily singular for small samples. This singularity problem implies that it is not possible to calculate the inverse of W_T thus rendering the estimation unsuccessful. Different matrix forms can be specified to overcome this problem. These estimators specified to overcome singular problems are Newey and West estimators (1987), Andrew's quadratic spectral estimator (1991) and Tukey - Hanning estimator[2]. However for this particular analysis the various formulations could not work for all equations. The author therefore had to turn to the second best alternative, nonlinear least squares estimation. Instrumental variable estimation would have been more appropriate for this study had

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[1] 16. implies that j_o has a zero at $\beta = \beta_o$

[2] Citations based on Shazam version 7.0 manual.

sufficient data been available.

5.2 Least squares estimation

The θ parameters can be estimated using the nonlinear least squares estimator. Consider a nonlinear model

$$y = f(X, \theta) + e \qquad (20)$$

where y is a matrix of the dependent variable X is a matrix of independent variables, θ is matrix of unknown parameters and e is a vector of the error term such that E[e]=0, and E[ee']=σI. The nonlinear least squares estimate of β is the β which minimizes the residual sum of squares (ee'). The first order conditions for a minimum are

$$\partial(ee')/\partial(\theta) = -2\frac{\partial f(X, \theta)'}{\partial(\theta)}[y - f(X, \theta) = 0 \quad (21)$$

Let D(θ) denote the transpose matrix ∂f(X, θ)'} / ∂(θ). In this case, the first-order condition for a minimum can be written as

The approximation for f(X, θ)=y with a first order Taylor series expansion around an initial point θ_1 is given by

$$y \approx f(X, \theta) \approx f(X, \theta_1) + D(\theta_1)(\theta - \theta_1) \qquad (22)$$

from which a linear pseudo model can be constructed as

$$\overline{y} = D(\theta_1)\theta + e \qquad (23)$$

A series of n iterations using the Gauss-Newton algorithm provides estimates of θ such that

$$\theta_{n+1} = \theta_n + [D(\theta_n)'D(\theta_n)]^{-1}D(\theta_n)'[y - f(X, \theta_n)] \qquad (24)$$

When the iteration process converges $\theta_{n+1}=\theta_n$, the first order conditions for a minimum must be satisfied and the positive definiteness of $[D(\theta_n)'D(\theta_n)]^{-1}$ ensures that this is achieved. For asymptotic normality of the estimators to be ensured, it may require that $1/T[D(\theta_n)'D(\theta_n)]$ is be nonsingular in the limit as $T \rightarrow \infty$. Nonlinear least squares estimators may not be the most satisfactory method for this analysis but will have to do for the moment.

The Shazam econometrics computer programme, version 7.0. (White 1993) was used for estimation and tests in this study. The two equations (reference the equation 10 and 11) obtained from the first order conditions were evaluated as follows:

$$S_t = \beta S_{t+1}/\zeta + S_{t-1}/\zeta + \theta_0/\zeta + \theta_3(\beta r_{t+2} + (1 + \beta)r_{t+1} - r_t)/\zeta + \theta_4(\beta w_{t+2} + (1 + \beta)w_{t+1} + w_t)/\zeta + \beta\theta_5(r_{t+2} - r_{t+1})/\zeta + \nu_t/\zeta \qquad (25)$$

where the multiplication term on S_t is

$$\zeta = 1 + (1 - \beta)\theta_1 + \beta\theta_2 \quad \wedge \quad \zeta_0 = 1 + \theta_1$$

an if $\beta = 0$ (reference the res nullius formulation, equation

11).

$$S_t = \Phi_0/\zeta_0 + S_{t-1}/\zeta_0 + \Phi_2(r_{t+1} - r_t)/\zeta_0$$

$$+ \Phi_3(w_{t+1} - w_t)/\zeta_0 + \mu_t/\zeta_0 \qquad (26)$$

Suppose the random variable S ~ $N(\theta, \sigma^2)$, the complete parameter space for equation 25 is

$$\Omega = (\theta, \sigma^2); -\infty < \theta < \infty, \; 0 < \sigma^2 < \infty$$

The null and alternative hypotheses are

H_o: $\beta = 0$ For the case of *res nullius*

H_A: $\beta \neq 0$ For the case of *res communes*

The null hypothesis denotes the subsurface for the $\beta = 0$ restricted parameter[3] space ω thus

$$\omega = (\theta, \sigma^2); \beta = 0.0; -\infty < \theta < \infty, \; 0 < \sigma^2 < \infty$$

The likelihood functions values at the maximum are for the restricted model is $l(\omega)$ and $l(\Omega)$ for the unrestricted model. The likelihood ratio is

$$\lambda = \frac{l(\omega)}{l(\Omega)}$$

and the test statistic (LR) is

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[3] Sub-surface for equation 26.

$$LR = -2\lambda = -2[l(\omega) - l(\Omega)] = 2[l(\Omega) - l(\omega)]$$

is asymptotically distributed as a χ^2 random variable with 2 degrees of freedom equal to the number of hypotheses.

5.3 Data Collection

Annual data from 1968 to 1986 are used for this study. Complete time series are not available so, some of the data points had to be interpolated. Livestock numbers series were available from Kenya Rangeland Monitoring Unit for census done from 1978 to date. These data are collected from low flying craft on 5 by 5 kilometre transects. The rest of livestock number series is obtained from estimates made by the Ministry of Agriculture and Livestock Development. Data series on herding labour cost, low income price index, interest rates and price of beef and lamb are available at Kenya Bureau of Statistics, Ministry of Planning and National Planning. Livestock (camel, sheep, goat and cattle) prices and sales were obtained from the Livestock Marketing Division (LMD). These data on sales and prices was compared and supplemented by data obtained from the Veterinary Division (Kabete). Effort was made to make sure that data were collected from different sources to minimize the problem of estimation errors.

Table 1. Livestock numbers by species for Marsabit District of Kenya 1968 - 1986.

	Livestock numbers[1]		
Year	Cattle	Small ruminants	Camels
1968[2]	225000	549000	207000
1969[3]	280000	618000	320000
1970[4]	196000	509000	146000
1971	169000	472500	129690
1972[5]	142000	375000	131000
1973	85200	225000	129837
1974	75521	257813	131149
1975	94401	315750	132473
1976	104890	421000	133811
1977	116544	456241	135163

[1] Estimates based on Government of Kenya (Ministry of Agriculture and Livestock Development and Department of Resource Surveys and Remote Sensing, KREMU).

[2] Adopted from Brown 1963 estimates in Range Management Handbook, 1991.

[3] Adopted from Spinks 1964 estimates in Range Management Handbook, 1991.

[4] Adopted from Watson estimates in Range Management Handbook, 1991.

[5] Adopted from Watson estimates in Range Management Handbook, 1991.

Table 1 continued.

		Livestock numbers[6]	
Year	Cattle	Small ruminants	Camels
1978	236124	814245	103701
1979	456100	846236	38600
1980	402000	930859	38990
1981	82700	449082	39384
1982	420000	1126339	76178
1983	420000	900000	76948
1984	452000	627000	77725
1985	260000	661000	78510
1986	299000	795000	30000
1987	314000	834000	12060
1988	300000	805000	52426
1989	375000	989000	22000
1990	224681	1406791	111794
1991	354000	1007000	123675
1992	196500	779000	14560
1993	152851	804243	123675

[6] Estimates based on Government of Kenya (Ministry of Agriculture and Livestock Development and Department of Resource Surveys and Remote Sensing, KREMU).

Table 2. Livestock prices by species, monthly wage rate and low income CPI for Marsabit District of Kenya 1968 - 1980.

	Livestock prices (KSH/head)			Wage rate[1]	CPI[2]
Year	Cattle	Small ruminants	Camels		
1968	90	12	170	50	92.4
1969	100	13	190	60	92.4
1970	150	14	200	70	93.9
1971	200	15	220	81.6	100.9
1972	250	18	240	91.4	103.9
1973	275	23	260	83.4	119.5
1974	60	23	270	73.7	119
1975	120	24	280	90	118
1976	300	25	290	100	118
1977	300	27	350	120	142.8
1978	350	30	350	150	162.3
1979	370	40	350	175	177.1
1980	460	45	380	215	187.1

[1] Based on the minimum wage paid to herdsmen in the Agricultural areas.

[2] Consumer Price Index.

Table 2. Continued.

	Livestock prices (KSH/head)			wage rate[3]	CPI[4]
Year	Cattle	Small ruminants	Camels		
1981	450	50	400	220	239
1982	470	60	550	230	270.8
1983	500	70	570	250	297.9
1984	800	117.5	650	275	330.4
1985	800	225	1800	300	357.6
1986	1200	252.5	2200	340	368.6
1987	1560	227.5	2500	380	405.5
1988	2400	266.5	3000	463	452.7
1989	2500	270	2500	510	505.5
1990	3000	300	2000	570	597.2
1991	1900	320	1800	647.8	600
1992	1608	190.5	2028	688	640
1993	8000	1200	10000	902	740.83

A close look at the livestock numbers show huge drops around 1972/73, 1980/81, 1985/86 and 1992/93 periods because of the effects of drought around those years. The data presented in Tables 1 and 2 were used to run regressions in

[3] Based on the minimum wage paid to herdsmen in the Agricultural areas.

[4] Consumer Price Index.

around 1972/73, 1980/81, 1985/86 and 1992/93 periods because of the effects of drought around those years. The data presented in Tables 1 and 2 were used to run regressions in the analysis and the results are reported in the next chapter.

6.0. EMPIRICAL RESULTS

This chapter contains the results of the regression analysis on equations 25 and 26 for each livestock group (small ruminants, cattle and camels). The analysis was carried using different livestock classes because each class has a unique socio economic value, hence different management regimes are likely to be used on the different classes of livestock. Sheep and goats were grouped in one category because they have similar socio economic values. Also data on sheep and goats are normally reported as one group. The results for the different classes are reported in Tables 3 to 8.

6.1 Cattle results and tests

The low income Consumer Price Index (CPI) was used as a proxy for the opportunity cost for cattle herding labour because it produced better results than herding labour cost. The low income CPI is an indicator used to measure the price variations for the low income earners in urban centres who earn less than 2,000 Kenya Shillings. These are labourers, living nannies, watchmen/ security guards etc. Cattle herders in Marsabit district live in the higher agricultural producing areas, and are likely to be in a better position to move to these urban areas in search of the low income jobs, than camel herdsmen. Hence, the low income CPI in cattle analysis only is used.

The regression model parameter estimation procedures used time series data and lagged independent variables of livestock numbers, wages and prices. Auto correlation was present and the data were transformed to allow for first order autogression results contained in Table 3. Furthermore θ_2 was set to one in order to overcome a problem of identification.

Table 3. Parameter estimates using CPI as a labour proxy in the unrestricted model for cattle

PARAMETER	coefficient	standard error	t-ratio
β	1.0242	.11053	9.2668
θ_0	-.69172	1.5875	-.43573
θ_1	49.203	218.15	.22555
θ_3	-.603E-03	.327E-03	-1.8402
θ_4	.459E-01	.253E-01	1.8143
θ_5	-.197E-01	.244E-01	-.8088
ρ	-.56474	.16688	-3.384
R^2 value	.6022		
Durbin-Watson	2.4567		

The parameter estimates for β, θ_3, θ_4 and ρ were significant. The R^2 value (60.22%) was better than that of the previous model estimates where auto correlation and identification problems existed. The Durbin-Watson indicates that auto correlation was eliminated. As indicated above $\theta2$ was eliminated from the analysis by restricting it to one due to an identification[1] problem. This identification problem was similar in subsequent estimations for the other animal classes as well.

Table 4. Likelihood ratio tests of res nullius, res communes on cattle.

PARAMETER RESTRICTION	res communes	res nullius
Log likelihood value	-51.869	-55.425
Log likelihood value	-46.848	-54.840
Calculated χ^2 VALUE	7.1123	
Calculated χ^2 VALUE	15.983	
DEGREES OF FREEDOM	2	
CRITICAL χ^2 VALUES		
.500 Upper tail area	1.386	
.100 Upper tail area	4.605	
.050 Upper tail area	5.991	

[1] Similar problem to that encountered by Clark and Carlson (1990) in estimating a similar model.

Likelihood ratio test results (Table 4) indicate that the the null hypothesis be rejected and the alternative hypothesis accepted; that is, cattle production exhibit *res communes* characteristics at $\alpha = 0.05$ upper tail area.

6.2 Small ruminant (sheep and goats) results and tests

The significant parameter estimate was ρ (Table 6). All the other parameter estimates were not significant for small ruminants. The R^2 value (64.32%) was high in line with the large volume of trade in small ruminants. The Durbin-Watson statistic indicate that the auto regressive parameter ρ solved auto correlation. These results are presented in the Table 6 below:

Table 5. Parameter estimates for unrestricted model of the small ruminant.

PARAMETER	coefficient	standard error	t-ratio
β	.22490	.2027	1.1095
θ_0	.147E+07	.903E+07	.16287
θ_1	.929E+07	.570E+08	.16287
θ_3	.118E+06	.723E+06	-.16287
θ_4	-20057	.123E+06	.16287
θ_5	18280	.112E+06	.16287
ρ	.89108	.851E+01	10.475
R^2 value	.6432		
Durbin-Watson	2.26646		

Likelihood ratio test results (Table 7) indicate that the null hypothesis be accepted and the alternative hypothesis rejected; that is, small ruminant production exhibit *res nullius* characteristics at $\alpha = 0.05$ upper tail area.

Table 6. Likelihood ratio tests of res nullius, res communes on small ruminants.

DISCOUNT FACTOR VALUE	res communes	res nullius
Log likelihood value	-65.758	-66.103
Calculated χ^2 VALUE	.6916285	
DEGREES OF FREEDOM	2	
CRITICAL χ^2 VALUES		
.500 Upper tail area	1.386	
.100 Upper tail area	4.605	
.050 Upper tail area	5.991	

6.3 Camel results and tests

The beta and rho parameter estimates (Table 8) were significant for camels. The rest of parameters were not significant. The Durbin-Watson statistic was high enough to eliminate auto correlation concerns.

Table 7. Parameter estimates for the unrestricted camel model.

PARAMETER	coefficient	standard error	t-ratio
β	.78080	.14324	5.4511
θ_0	9200.7	.105E+06	.873E-01
θ_1	32806	.375E+06	.874E-01
θ_3	.72042	7.8563	.917E-01
θ_4	-.82711	8.5803	.964E-01
θ_5	.34847	3.5009	.995E-01
ρ	.81475	.10883	7.4867
R^2 value	.6871		
Durbin-Watson	2.1257		

Likelihood ratio test results (Table 9) indicate that the null hypothesis be rejected and the alternative hypothesis accepted; that is, camel production exhibit *res communes* characteristics at α = .500 upper tail area.

Table 8. Likelihood ratio tests of res nullius, res communes on camel.

DISCOUNT FACTOR VALUE	res communes	res nullius
Log likelihood value	-19.937	-22.918
Calculated χ^2 VALUE	5.962168	
DEGREES OF FREEDOM	2	
CRITICAL χ^2 VALUES		
.500 Upper tail area	1.386	
.100 Upper tail area	4.605	
.050 Upper tail area	5.991	

6.4 Policy instruments to alleviate the open access problem

There is a large demand for livestock products (especially goats and sheep) both within the pastoral system and the greater national economy. Grazing land represents a renewable resource that should not be destroyed. Livestock capital represents a private investment in the part of pastoralists, whereas rangeland ownership is a resource for which ownership is not well defined. The situation in recent times is characterised by many goats and sheep chasing a diminishing forage resource. If the future demand for the cattle and camel products increase, their production may increase also up to the point where economic rent is exhausted as in small ruminant production.

The environmental deterioration caused by non exclusiveness of the grazing land use in northern Kenya can be solved by establishing of *res communes* property rights. The extensive grazing land mass means that the specification of exclusive property rights may be infeasible. However, policy makers may try to influence and encourage the move from *res nullius* to *res communes*. *Res communes* may not achieve Pareto efficiency but may provide a second best solution for sustainable grazing in Northern Kenya through various restrictive rules to reduce livestock accumulation and massive waste during droughts.

To move from *res nullius* to *res communes,* policy makers have to modify the economic behaviour of pastoral communities. This modification can be achieved by changing the nature of the economic incentives pastoralists face in their production decisions. There are three classes of methods that can be applied to modify the economic behaviour of pastoralists.

1. Market solutions after assignment of liability rules
2. Charges, fines, per unit taxes, tradable permits, or subsidies
3. System of standards enforceable by threat of fines or jail sentences.

The first class of solutions depends on private negotiations, while the last two depends on government intervention. Rules and conditions specifying who shall have access to grazing land established and enforced such as limiting grazing seasons. Limiting grazing seasons may not really remove the rule of capture problem. Pastoralists may strategically use fast multiplying species to maximize on forage capture within a specified season. This restriction can however be administered through the control and distribution of bore holes and other water resources.

Entry into pastoralism could be checked through granting of licenses to current pastoralists and their heirs. Licenses can acquire capital value thus, enabling pastoral families wishing to leave pastoral lives can sell their licence. If livestock numbers per pastoralist are not controlled, issuing of licences can do little to preserve rangelands. Marketable livestock production quotas can be establish at a level which does not destroy the rangeland. These quotas can be distributed to the exiting pastoralists. Those wishing to pursue other lifestyles could have an advantage in selling their livestock quotas to entering or expanding pastoralists. The government or environmental agencies can buy off some quotas to reduce overgrazing and environmental decay.

An economic system requires enforcement of the right to use economic resources. To enforce the rights to use a resource, one has to incur a cost to be able to police the participants of the economy. To enforce rules of access established by government, an agency with authority can be established to closely monitor rangelands. Resources are often valued depending on how property rights are defined and, the ability to police the actions of economic units. The tendency to treat the Northern Kenya rangelands as a free good while it is in fact an economic good is related to property rights and enforcement. Thus, the private value of the rangeland is low compared to the social value. Ways to reduce policing costs can be devised to try and bring the private value of the rangeland in line with the social value, by altering property rights.

7.0 SUMMARY AND CONCLUSIONS

The results of this study boost in part the validity of criticisms aimed at nomadic pastoralists that;

(i) Pastoralists use discount factors equal to zero (i.e. extremely high discount rates).

(ii) The "tragedy of the commons" argument applies to nomadic pastoralists

We may surmise that the development of a cash economy and increased demand[1] for goats and sheep changed the property rights system for this class of livestock. This development has increased the incidence of externalities (overgrazing) in the rangelands. However, this phenomenon is not exhibited in camels and cattle. Cattle are most hard hit by drought, hence their numbers are controlled by the harsh climate of zone V and VI. Camels, although best suited for zone V and VI climate have very low fertility rates and face a low market demand, hence accumulation of capital (live animals) in this class is limited. Policy should be aimed at decreasing small ruminants while encouraging increase in camel populations.

In other words these results indicate that pastoralists do appear to sacrifice long term benefits for short term gains

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[1] Increased demand accompanied by high livestock prices is likely to raise profits. Hence, encourage raising more livestock for larger profits.

at the expense of the environment. Pastoralists choosing to maximize their share of forage will tend to overstock goats and sheep. High stocking rates of small ruminants will overgraze. The soil fertility and the environment will therefore be destroyed. Negotiations cost to curtail overgrazing is not zero. The government and environmental groups should bear this cost and initiate stocking rate negotiations among pastoralists for the following reasons:

(a) It may be difficult to arrive at a mutually satisfactory agreement if pastoralists are not assisted and where large interest parties (pastoral groups from different ethnic groups)are involved; and

(b) Weighting under *res nullius* is very large for the present generation at the expense of future generation (therefore to give future generations more equity, the government may act as a broker on their behalf).

Pastoralists may recognize the necessity of preserving the environment and sustaining their resource base. However, due to the recent interference on settlement patterns and economic pressures they may not be able to mutually agree on how to conserve range resources. Property rights problems arise when it becomes economic for those affected by the externalities to try to influence internalization of the costs and the benefits involved. Various methods can be devised to persuade pastoralists to reduce their livestock numbers and conserve the environment. Communal property rules, such as pay-to-use-the-property, can be used to encourage full cost accounting by the users.

As the assurance game[2] suggests (Runge, 1981), the occupance of inferior outcomes like overgrazing is more likely to occur because coordinated actions are difficult under situations of population growth, climatic variation and land base changes. Under such conditions, outside interference to enforce coordination becomes a second order solution. The key to this problem is to create property rights institutions that solve the assurance problem. Outside interference is second order because it is more expensive to administer especially for a poor country. The main idea is to get pastoral communities to pursue a path that will maximize the present value of communally owned land rights. This process is achieved by taking into account the supply and demand conditions that exist both at the present and in future.

Policing costs, once the agreement is reached, have to be borne. To reduce or avoid these police costs, it advisable to

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[2] Commonly referred as the "battle of sexes". This is a two-person (two-group) cooperative game, unlike the conflict prone prisoners dilemma game were a dominant strategy exists. That is, in the assurance game, there is no incentive to defect once an agreement is made. The dominant strategy in the prisoners' dilemma game acts as an incentive to defect even after a agreements are made. More effort is required in the prisoners dilemma game to obey the rules of the game than in the assurance game.

develop a form of institution whereby voluntary cooperation is encouraged, by involving pastoralists in the decision making process. This voluntary cooperation is only possible where such institutions incorporate social values of the pastoralists. The government should act as a catalyst to encourage development and evolution of these institutions, with minimum interference, but full local participation. It should also facilitate information flow to the pastoralists.

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APPENDIX

Stability Tests[1].

The stability tests are necessary in order to show that the models have a sound mathematical basis and to show that the models are related to each other. The difference equations 10 and 11 in Chapter 4 have S_t as the control variable. The rest of the variables are exogenous or given. These equations can be rewritten in the form;

$$\beta S_{t+1} + \Upsilon S_t + S_{t1} = h(t, \beta) + \nu_t \qquad (10A)$$

$$-\phi S_t + S_{t1} = \hat{h}(t, 0) + \upsilon_t \qquad (11A)$$

Where $\hat{h}(t, \beta)$ is $h(t, \beta)$ with the θ_i's replaced by ϕ_i's. These two equatons are difference equations (recurrent relations).

$$h(t, \beta) = -\theta_3[\beta\Upsilon_{t+1} - (1 + \beta)\Upsilon_{t+1}] - \theta_4[\beta w_{t-1}$$

$$- (1 + \beta)w_{t+1} + w_t] - \beta\theta_5(\Upsilon_{t+2} - \Upsilon_{t+1}) - \theta_0$$

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[1] This development would not have been possibe without the help of Dr. J. Macki, Department of Mathematics, University of Alberta.

$$\Upsilon = 1 + (1 - \beta)\theta_1 + \beta\theta_2$$

The type 10A equation

$$\beta S_{t+1} + \Upsilon S_t + S_{t1} = f(t) \text{ given } \beta,\ \upsilon,\ f(t),\ \wedge\ t=0,\ 1,..(say) \quad (10A)$$

This is a linear second order difference equation with forcing term f(t) or a three term recurrence equation with forcing term f(t).

THEOREM

If S_{t-1}, S_0 are given, then 11A has a unique solution. This solution exists for all $t \geq 0$. Equation 10H[2] as below is a homogeneous version of equation 10A above.

$$\beta S_{t+1} + \Upsilon S_t + S_{t-1} = 0 \qquad (10H)$$

THEOREM.

If $S_t^{(1)}$ (t=-1, 0, 1...), and $S_t^{(2)}$ (t=-1, 0, 1...) are two independent solutions of 10H, then every solution of 10H, S_t is of the form

$$S_t = c_1 S_t^{(1)} + c_2 S_t^{(2)}$$

Where c_1 and c_2 are real numbers. $S_t^{(1)}$, and $S_t^{(2)}$ are independent if and only if their determinant is not equal to

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[2] Where H is homogenous

zero.

$$0 \neq S_0^{(1)} S_1^{(2)} - S_1^{(1)} S_0^{(2)}$$

Ussually, we take $S_0^{(1)}=1$, $S_1^{(1)}=0$ $S_0^{(2)}=0$ and $S_1^{(2)}=1$, so that the determinat equals 1.

Theorem

Consinder 10A with forcing term f(t). Suppose $S_t^{(1)}$, $S_t^{(2)}$ are independent solutions of 10H. Suppose also you can find a single solution called a particular solution of 10A, say $S_t^{(part)}$. Then every solution of 10A is included in the solutions S_{11}

$$c_1 S_t^{(1)} + c_2 S_t^{(2)} + S^{(part)} \qquad c_1,\ c_2 \text{ are } \Re \text{ numbers}$$

Thus to find all solutions of 10A, we first solve 10H for two independent solutions. Then we find one solution to 10, and finally the formula S_{11} gives all the solutions.

To solve 10H, try $S_t = a^t$, where a is the unknown. Plug this into 10H:

$$\beta a^{t+1} + Y a^{t} + a^{t-1} = 0$$

Divide this equation by $a^{(t-1)}$ to get

$$\beta a^2 + Y a + 1 = 0$$

By the quadratic formular, the roots of this equation are

$$a = \frac{Y}{2\beta} \pm \frac{[Y^2 - 4\beta]^{\frac{1}{2}}}{2\beta}$$

CASE 1a.

If $Y^2-4\beta>0$, then we get two distinct real roots

$$a_1 = \frac{Y}{2\beta} + \frac{[Y^2 - 4\beta]^{1/2}}{2\beta}$$

$$a_2 = \frac{Y}{2\beta} - \frac{[Y^2 - 4\beta]^{1/2}}{2\beta}$$

A simple argument shows that a_1 and a_2 are positive, unless $\beta=0$ in which case 11A is not a two form recurrence. In case 1a, we get two independent solutions of 10H; $S_t^{(1)}=a_1^t$, $S_t^{(2)}=a_2^t$

CASE 1b.

If $Y^2-4\beta<0$, in this case the roots are complex

$$a_{1,2} = \frac{Y}{2\beta} + \frac{i[Y^2 - 4\beta]^{1/2}}{2\beta} \qquad i = \sqrt{-1}$$

These roots can be shown to generate solutions of 11H of the form:

$$S_t^{(1)} = a^t \cos(w, t)$$

$$S_t^{(2)} = a^t \sin(w, t)$$

Where $$a = [\frac{4\beta}{4\beta^2}]^{\frac{1}{2}} = \frac{1}{\sqrt{\beta}} \qquad w = \arctan(\frac{4\beta - Y^2}{Y})$$

CASE 1c.

If $Y^2-4\beta=0$, then we only have a root

$$a = \frac{Y}{2}\beta$$

The independent solutions are ;

$$S_t^{(1)} = (\frac{Y}{2\beta})^t, \qquad S_t^{(2)} = t(\frac{Y}{2\beta})^t.$$

So we have found the general solution

$$S_t = c_1 S_t^{(1)} + c_2 S_t^{(2)} \qquad c_1,\ c_2 \text{ are abitrary}$$

If we can find one solution to 10A, $S_t^{(part)}$, then we have found all solutions of 10A. They are of the form

$$c_1 S_t^{(1)} + c_2 S_t^{(2)} + S^{(part)}$$

There are two ways to find $S_t^{(part)}$. One is to use a formula called "variation of parameters". The other way is to use a discrete cousin of Laplace transform, called the Z-transform. The Z-transform takes a lot of preliminary work, so the variations of parameters method is used here.

The variation of parameters says , if $S_t^{(1)}$ and $S_t^{(2)}$ are two independent solutions of 10H, then the following formular gives a particular solution of 10A:

$$S_t^{(part)} = [\sum_{n=0}^{t-1} S_{n+1}^{(1)} \frac{f(n)}{\beta}] S_t^{(2)} - [\sum_{n=0}^{t-1} S_{n+1}^{(2)} \frac{f(n)}{\beta}] S_t^{(1)}$$

SUMMARY.

To solve 10A, given Y, β and f(t), first find the roots and write down the $S_t^{(1)}$ and $S_t^{(2)}$. Then every solution of 11 is of the form;

$$c_1 S_t^{(1)} + c_2 S_t^{(2)} + S^{(part)}$$

Where $S_t^{(part}$ is given by variation of particulars (VP). If you know S_0 and S_1, then c_1 and c_2 will be found by solving

$$S_0 = c_1 S_0^{(1)} + c_2 S_0^{(2)} + S^{(part)}$$

$$S_1 = c_1 S_1^{(1)} + c_2 S_1^{(2)} + S^{(part)}$$

Now to solve 11A

$$-\phi S_t + S_{t]} = \hat{h}(t, 0) + \upsilon_t \equiv \hat{f}(t) \qquad (11A)$$

The first order difference equation 11H is

$$-\phi S_t + S_{t1} = 0 \qquad (11H)$$

We solve 11H by writting $S_t = a^t$;

$$-\phi a^t + a^{t-1} = 0$$

Then divide by a^{t-1};

$$-\phi a + 1 = 0 \,, \qquad a = (\frac{1}{\phi_1})$$

THEOREM.

All solutions of 11H are of the form

$$c(\frac{1}{\phi_1})^t$$

Where c is any real number. If we find one particular solution of 11H, call it $S_t^{(part)}$, then every solution of 11H is of the form

$$S_t = c(\frac{1}{\phi_1})^t + S_t^{(part)}$$

THEOREM.

$$S_t^{(part)} = \left(\sum_{n=1}^{t} \phi_1^{n-1} \hat{f}(n)\right)\left(\frac{1}{\phi_1}\right)^t$$

Thus the only general solution for 11 is

$$\hat{S}_t = c\left(\frac{1}{\phi_1}\right)^t - \left(\sum_{n=1}^{t} \phi_1^{n-1} \hat{f}(n)\right)\left(\frac{1}{\phi_1}\right)^t$$

This solution for model 11 is comparable to the solution for model 10 discussed earlier, thus establishing the basis for similarities of the unrestricted model 25 and the restricted model 26 in chapter 5.