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Wealth, risk and activity choice: cattle in Western Tanzania

Stefan Dercon *

Centre for the Study of African Economies and Nuffield College, Oxford University, UK
Katholieke Universiteit, Leuven, Belgium

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Abstract

Imperfect credit markets force households to use their savings for investment. Profitable activities often require lumpy investments, limiting entry by poorer households, resulting in increasing welfare differences. In Tanzania, cattle are a profitable but lumpy investment and a liquid asset for consumption smoothing. Richer households own substantial cattle herds, while poorer households specialize in low return, low risk activities. A dynamic programming model and simulations are presented to analyze entry into asset accumulation under income risk. The evidence suggests that households with lower endowments are less likely to own cattle and returns to their endowments are lower. © 1998 Elsevier Science B.V.

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1. Introduction

One of the main issues in development economics is the study of how economic change comes about. At the household level this entails inter alia the study of how some households can grow richer and accumulate wealth, and how others stay poor. This paper deals with a traditional, but still very relevant form of rural wealth accumulation: the acquisition of cattle in an agro-pastoral (mixed)

* Corresponding author. Centre for the Study of African Economies, University of Oxford, St. Cross Building, Manor Road, Oxford OX1 3UL. Tel.: +44-1865-271084; fax: +44-1865-271094; e-mail: stefan.dercon@economics.ox.ac.uk

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farming environment. It analyzes wealth accumulation via cattle among households in rural Shinyanga in the semi-arid areas of Western Tanzania based on a survey conducted in 1990. The data reveal some puzzles which call for explanation. First, differences in welfare levels seem closely related to differences in cattle holdings. Secondly, despite the high returns to be earned from cattle, only half the sample owned any cattle. Thirdly, non cattle-owners seem to specialize relatively more in off-farm activities, and comparative advantage arguments seem unlikely to explain this fully. Fourthly, non cattle-owners specialize relatively more in low return and low risk crops.

A model of activity choice and asset accumulation is developed to explain these outcomes. The central point is that the most profitable activities and assets are characterized by entry constraints, cattle-rearing being the main option identified. Combined with credit constraints and risk, households with relatively low endowments will find it hard to accumulate sufficient assets to build up a cattle herd. Since crop income is risky, low assets in the form of cattle, small livestock and other liquid means will also affect the risk-bearing capacity of non cattle-owning households, providing incentives to enter activities with low risk or low covariance with crop income to mitigate the riskiness of total income, even at the cost of lower levels of total income.

The theory of comparative advantage provides a classic explanation of observed differences in activity choice across households. Households will then specialize in these activities in which they have a comparative advantage and trade ensures pareto-optimal welfare levels for all. In its simplest form this explanation ignores the fact that missing markets may prevent some households from taking up particular activities. For example, Eswaran and Kotwal (1986) have analyzed the consequences of credit constraints on labour allocation in a rural setting. Their model postulated the existence of fixed set-up costs to enter agricultural cultivation. They showed that if credit constraints are linked to collateral needs and if land can be used as collateral, then households with relatively low land endowments may not be able to cultivate all their land and instead will rent out (some of) their labour to households with larger land holdings. More generally, if investments are needed to enter particular activities, then credit constraints may only allow the richer households to take part in the activity, allowing them to grow richer, while the other households stay poor. [1]

Substantial credit market imperfections have been commonly observed, even though important differences exist across countries (for an overview see Hoff and

[1] Banerjee and Newman (1993) and Banerjee and Newman (1994) also develop the idea that differences in occupational choice and entrepreneurship is not just linked to inherent productivity differences or preferences but to capital market imperfections. In their (1994) paper for example, poorer households will find it harder to borrow and insure because the threat of punishment if they default on loan repayments is larger, works less well for households closer to the lower bound on their utility than households with larger initial wealth.

Stiglitz, 1990). Informational problems and covariate risks in rural economies are often at the root of these imperfections (Binswanger, 1987). In a static model such as by Eswaran and Kotwal (1986), the need for collateral for investment lending will effectively constrain poorer households to enter into profitable activities. However, in a dynamic setting this may not hold. If these activities provide high returns, then the household has a strong incentive to save to self-finance the investment, provided that assets are available which could be used as stores of wealth and if the required hurdle for investment is not too high. [2]

The introduction of income risk would not in itself change this result. Income risk combined with credit constraints, however, provide incentives for consumption smoothing through the use of liquid savings (Deaton, 1991). [3] Furthermore, as shown by Eswaran and Kotwal (1989), the need for liquid savings accumulation to cope with income risk may affect (illiquid) investment into new, profitable activities. If credit constraints force the poor to save to self-finance investment, then the need to smooth consumption might regularly deplete the accumulated savings and force the household to start again. However, not all investment in profitable activities is illiquid. Rosenzweig and Wolpin (1993) consider bullocks as investments in India, which provide high returns as a productive investment but can also be used for consumption smoothing. Nevertheless they find that credit constraints and consumption smoothing demands result in underinvestment in bullocks for efficient production, implying lower incomes.

The relationship between risk, activity choice and credit constraints is not just related to the need for investment for particular high-return activities. Different activities may be taken up as part of a diversification strategy to reduce total income risk (Reardon et al., 1992; Walker and Ryan, 1990). If the high return activity is also more risky, then differences in risk aversion may explain differences in portfolio's across households. Poor households may then stay poor in the long run because they are risk averse. A more appealing explanation for differences in portfolio's is offered by Eswaran and Kotwal (1990) who show that credit constrained households will be more willing to sacrifice income for less risk than other households, even if their risk preferences are *ex-ante* the same. [4]

[2] However, this may not hold if preferences between present and future consumption are different across rich and poor households. The present wealth of the richer households may be a reflection of their past savings, while the presently poor households did not save at that time. The reason could be different discount rates of future consumption: the high impatience of the poor keeps them poor (for a discussion see Deaton, 1990).

[3] Empirical evidence for this type of behaviour in developing countries, albeit not always conclusive, is discussed in Alderman and Paxson (1992), Deaton (1992), Morduch (1990), Udry (1995).

[4] Rosenzweig and Binswanger (1993) have found that wealthier households allocate their productive assets to riskier activity portfolios than poorer households in some villages in India. Using the same data, Morduch (1990) found that credit constrained households entered less in high yielding but risky crops. Dercon (1996) using data on Tanzania (also used here) found that households with lower asset holdings allocate more of their land to the low risk crop.

In this paper we aim to explain the observed patterns of activities and asset holdings across a random rural sample survey of 80 households, conducted in 1990 in rural Shinyanga in Western Tanzania. [5] In Section 2, the welfare levels of the households will be related to the structure of their incomes from different activities and differences in endowments. In Section 3, a model will be developed to explain the observed activity and asset holdings. A discrete stochastic dynamic programming model is specified in which households can choose to allocate labour, land and liquid assets across low-risk off-farm work, risky agricultural cultivation and cattle rearing. While households are assumed to own exogenous endowments of land without a land market, cattle can be bought and sold in discrete units. Investment in cattle is lumpy and credit is not available, but small livestock are available to build up sufficient assets to invest in cattle. Both cattle and other livestock are liquid so they can also be used to smooth consumption. The model is used to derive predictions on entry into cattle-rearing, other asset holdings and labour allocation across different activities. In Section 4, simulations are presented on some of the distributional consequences of entry constraints into the high return activity for households with relatively small differences in initial land and labour endowments. In Section 5, the model is used to test some of its implications in the cross-section. Section 6 concludes.

2. Rural households in Shinyanga District, Tanzania

Shinyanga District forms part of Shinyanga Region in the West of Tanzania. Together with Mwanza Region, this region forms the main part of what is traditionally referred to as Sukumaland (Malcolm, 1953; Cory, 1953). The area is semi-arid and the main crops grown are cotton, different types of sorghum and millet, maize and sweet potatoes. Significant numbers of livestock are kept, which are partly integrated in the farming systems: oxen are used for ploughing and sometimes transport, while some households use manure as fertilizer (Von Rotenhan, 1966; Ruthenberg, 1964; Ruthenberg, 1968; Collinson, 1972; Marketing Development Bureau, 1987). A random rural household survey of 80 households was conducted in 1989/90 in the district, of which the data on one household were too incomplete to use. In this section, the survey data are used to explain differences in living standards across households. In line with other studies, consumption is used as an approximation for living standards. This consumption inequality will be related to differences in the structure of income. Furthermore, it will be analyzed whether inequality in endowments and assets may explain the observed differences in income and consumption.

[5] The survey was conducted by USAID (see USAID, 1990). For more details on the survey see Dercon (1992, 1996).

Table 1
Income from different sources per adult equivalent for consumption terciles (income shares in brackets) in 1989/90 Tanzanian Shilling; US$1 = TSh145

Sample means	Consumption terciles			
	All	Poor	Middle	Non-poor
Crop income				
Subsistence	6427 (22%)	3333 (35%)	5408 (25%)	10,579 (18%)
Cash	1186 (4%)	805 (8%)	1621 (8%)	1115 (2%)
Livestock income				
Sale of live animals	8293 (28%)	1010 (11%)	5505 (26%)	18,472 (32%)
Subsistence livestock products	6698 (23%)	484 (5%)	2799 (13%)	16,962 (29%)
Cash livestock products	656 (2%)	28 (0%)	187 (1%)	1776 (3%)
Agricultural wage employment	198 (1%)	319 (3%)	193 (1%)	83 (0%)
Non-agricultural income				
Males' income	4613 (16%)	2508 (26%)	4567 (21%)	6767 (12%)
Females' income	1373 (5%)	991 (10%)	1065 (5%)	2076 (4%)
Total income	29,447	9478	21,345	57,828
Total consumption	24,264	7752	17,340	47,988

Consumption data were corrected for demographic composition using adult equivalent scales. [6] Table 1 gives mean annual income from different sources per adult equivalent for consumption terciles. Mean annual consumption per equivalent adult was found to be about 24,264 Tanzanian Shilling (about US$167 in 1989). [7] There are substantial differences across households: mean consumption and mean income per adult for the best-off tercile are more than six times that for the poorest tercile. Table 1 shows that this mean difference mainly stems from the much larger incomes from livestock of the former group: live animal sales income

[6] The adult equivalent scales used were taken from the study on rural households in Tanzania by Collier et al. (1986). They combine nutritional requirement data with estimates for scales economies in household size. For the methodology used to construct consumption and income from the survey data, see USAID (1990) and Dercon (1992).

[7] It is suspected that the consumption data reported are, if anything, underestimates of actual consumption. The reason appears to be deficiencies in the expenditure questionnaire design. The data were collected using recall questions for a two week period using explicit lists of food and non-food items. For some larger items, a three month recall period was used. It appears that the list of items was incomplete and that for some items the two week recall period was too short. These problems are by no means unique to this study. For a discussion and its implications, see Scott and Amenuvegbe (1990) and Grosh et al. (1995). In the present study extrapolated annual consumption was found to be on average 18% lower than total annual income and this is not likely to be evidence for a high savings rate. It is not likely that these measurement problems cause spurious results. For example, mean consumption in each of the terciles is also about 18% lower than mean annual income, and mean income of the richest tercile is also more than 6 times the mean income of the poorest group.

are 18 times larger, while income from livestock products is 36 times larger. Livestock income from all sources accounts for about 74% of the differences in mean total income between the poor and the non-poor tercile. Mean crop incomes and male and female off-farm incomes are between two and three times larger for the richer tercile. Mean agricultural wage income for the non-poor is only close to a quarter of those for the poor, even though the levels remain relatively low.

Looking at the structure of income in Table 1, crop income in 1989/90 constitutes about 43% for the poorest group, but this share declines to about 20% for the non-poor. Livestock income for the poorest group this is only about 16% of total income, compared to 54% for the richer group. Non-agricultural income, including agricultural wage labour and male and female off-farm income constitutes about 22%, but the share is considerably larger for the poorest group — about 39% — compared to only 16% for the non-poor group. These differences are also reflected in the proportions of households earning income from the different sources. [8]

To conclude, poorer households rely proportionately more on crop income, agricultural wage employment and non-agricultural incomes than richer households. [9] Next, I investigate whether differences in endowments and assets can account for these differences in living standards and incomes. Table 2 gives mean labour supply characteristics, land, livestock and other asset ownership data for each of the three consumption terciles. Mean labour supply characteristics show relatively little difference across the richest and poorest tercile. The educational level of all male and female adults is somewhat higher for the non-poor, even though educational levels are generally low (with an average of about 3 years of schooling). A crude measure of the educational level of the children of the household head indicates that the children of the non-poor households have completed an almost 50% larger percentage of their schooling up to secondary

[8] Some of the livestock sales income may be a depletion of the asset base, and should be looked upon as dissaving rather than income. This suspicion is based on the fact that total sales of livestock are more than 25% of the value of the herd, or more than double a reasonable estimate of the natural growth of the herd in value terms in the region (Mackenzie, 1973). This will not change the general trust of the results thus far: excluding live animals sales income for total income still shows that livestock products income is larger for the non-poor than for the poor (17% compared to 10%) and off-farm income constitutes 46% for the poorest tercile, compared to 35% for the richer group.

[9] This result will need further investigating, since it does not easily square with other evidence from Tanzania and other African countries. For example, Collier et al. (1986) found for other areas in rural Tanzania that off-farm income was considerably lower for poorer households than for richer ones. Although covering 20 villages in different parts of the country, their survey did not include any of the semi-arid areas of Western Tanzania. The average share of income earned from off-farm sources in their study was however higher (27%) than in the present study. Matlon (1979) on Northern Nigeria and Reardon et al. (1992) on Burkina Faso found similar results. This is however not a universal relationship. In semi-arid areas of India, Walker and Ryan (1990) found that poorer households relied relatively more on off-farm incomes than richer households.

Table 2
Labour supply characteristics, endowments and assets for consumption terciles

	All	Poor	Middle	Non-poor
Labour supply				
Number of adults	3.3	3.1	3.7	3.0
Male adults	1.6	1.4	2.0	1.5
Dependency ratio (children under 15 years/adults)	1.0	0.9	1.1	0.9
Female-headed households (%)	16%	15%	11%	23%
Education of male adults (years)	3.5	3.3	3.6	3.5
Education of female adults (years)	2.5	2.4	2.2	3.0
Education of children (percentage)[a]	51%	40%	55%	59%
Land and land allocation				
Total cultivated land per adult equivalent in hectares	0.8	0.6	0.8	1.0
Return from crops per cultivated hectare (TSh)	11,967	8170	14,270	13,430
Proportion of land cultivated with cotton	14%	14%	9%	18%
Proportion of land cultivated with maize	26%	22%	28%	30%
Proportion of land cultivated with paddy	10%	8%	10%	11%
Proportion of land cultivated with sorghum	32%	36%	34%	25%
Proportion of land cultivated with sweet potatoes	9%	12%	8%	8%
Livestock values per adult equivalent				
Livestock values (Tsh)	31,817	9320	19,924	66,666
Cattle (TSh)	30,287	8362	18,041	64,929
Cattle owners (%)	49%	35%	56%	58%
Livestock owners (%)	66%	58%	67%	73%
Other assets (per adult equivalent)				
Value of house (building materials) (TSh)	261	87	262	435
Investment in tools in last year (TSh)	78	25	96	113

[a] Percentage of full education completed by children of the household head, with 12 years or above equal to 100%, or, for children below 18 years of age, the percentage of years schooling they have completed since the age of six; data are the average for households with children within each group.

school than the poorest tercile of households. [10] The latter result is, however, more an indicator of investment in future labour supply and welfare rather than a measure of the present quality of the labour supply. Overall, therefore, it is unlikely that the large mean living standard differences are directly caused by differences in the labour endowments or dependency ratios of the household.

[10] ‘Complete schooling’ (100%) is defined as 12 years of schooling for children of the head above 18, and for younger children, continuously taking classes since the age of six for children up to years of schooling since the age of six. It is calculated by taking for all the children of the head above 18 years the number of years schooling divided by 12, and for children below 18 years of age the number of years they have been to school divided by their age minus 6. The measure given is the average attainment of all children in the household. Note that the measure does not value university education, but this is not a problem in the data set since it did not apply.

Mean land holdings per adult equivalent are larger for the non-poor tercile than for the poorest tercile by about 75%, but note that this is substantially less than the difference in mean income from crop cultivation which is on average 180% higher for the non-poor than for the poorest tercile. Consequently, there are differences in the returns on land for richer and poorer households. Indeed, returns per hectare cultivated were found to be 65% higher for the non-poor tercile than for the poorer tercile. Unfortunately, few data are available from the survey to satisfactorily explain the reasons for these differences in returns on land. A possible explanation may be that richer farmers have access to better land. Given the large diversity in soils in each area of Sukumaland this may well be correct.

Two alternative explanations can be offered: first, differences in technology used or access to inputs and secondly, differences in crop choice. It is quite unlikely that the first explanation is very relevant in the present sample: all but two households used ox-ploughs, and very little purchased inputs, such as fertilisers, were used. Nevertheless, Table 2 also shows that cattle ownership is very unequal, with only a third of the poorer households owning any, compared to 58% of the richer tercile. Many households have to rent in oxen, often having to wait for the use of the oxen until the owners have ploughed their own fields. Although we do not have direct evidence for this, it may well be that ploughing on many of the poorer households' land will occur at sub-optimal times [see for evidence on India, Rosenzweig and Binswanger (1993) and Gryseels (1988) on Ethiopia].

An alternative explanation may be differences in crops grown by the poorer households: they may grow lower return crops than the richer households. Table 2 gives some indication that this is indeed true, by presenting data on the main crops grown. Cotton is the main cash crop in the area, while maize is presently the preferred staple in Tanzania, gradually replacing sorghum and millet in the area. Sorghum and millet are however somewhat less vulnerable to drought than maize. Paddy is considered a high value crop in the area, albeit quite risky (Marketing Development Bureau, 1987). Finally, sweet potato is a low return, but quite safe crop, and is a substitute for cassava in the area as the main drought-resistant crop. [11] Poorer households allocate more land to low risk and low return crops (sorghum, millets and sweet potatoes) than the non-poor households, contributing to the differences in returns to land between these groups.

Nevertheless, crop incomes, crop allocation or land inequality are insufficient to explain the kind of consumption and income differences observed. The live-

[11] Mean returns (in value) of maize and sorghum per hectare were about the same in the sample, while returns to sweet potatoes were about 75% of the returns to cotton and the returns to sorghum about 90%. Paddy returns were three times the returns to cotton. Similar relative returns were found in surveys by Von Rotenhan (1966) and Marketing Development Bureau (1987). Dercon (1996) discusses in detail the particularities of the farming system and the findings related to sweet potatoes.

stock data in Table 2 show far more pronounced differences across consumption terciles. The value of livestock at market prices is almost seven times larger for the non-poor than for the poorest tercile. Cattle ownership is especially skewed, being eight times larger for the non-poor. Smaller livestock such as goats and sheep are far less unequally distributed. Differences between total incomes between richer and poorer terciles can thus be traced to differences in cattle ownership across households. In value terms, cattle is also by far the most important asset owned by these households. The average value of the houses for example, measured by the building materials used, is very small compared to livestock values (Table 2). Only incomplete data on other assets were available, but, for example, investment in tools in the previous year was also quite small, in comparison to livestock. It was also found that very little cash or other assets were kept. To conclude, it appears that some households have been able to accumulate substantial cattle herds and the return on this investment provides permanently higher incomes and consumption. These observed differences in relative asset holdings can be better understood by looking at the different options for asset accumulation available in rural Tanzania.

Asset growth could take many forms, depending on availability and the household's choices. If credit and insurance markets are incomplete, then asset choice will be governed by the characteristics of the assets: their return and riskiness, but also their indivisibility and liquidity, governing the reversibility of the investments. Assets chosen could be human capital (such as education and health investments) or physical (such as investment in land, in land improvement, the adoption of new technology or investment in non-agricultural activities). In Tanzania, and especially in the west of the country, the asset choices of rural households are relatively limited. At present, land does not form a secure asset for accumulation. During colonial times, land tenure rights were gradually controlled. [12] Contrary to neighbouring Kenya, government policy after independence did not encourage registration of land titles, but instead brought all land in state ownership and granted rights of occupancy to farmers. Land transactions were made illegal. Despite considerable debate in recent years about a possible privatization of land, the government position has not yet been reversed (Hoben et al., 1992). Despite government policy, some land transactions take place, especially in highly commercialized areas of the country. They happen nevertheless under customary law and are usually restricted to members of the seller's community. Being illegal, these land sales cannot be upheld in court, obviously considerably reducing the security of the investment, and remain therefore rela-

[12] Before independence, there was a relative land abundance, in the region through the opening of new areas (Malcolm, 1953; Ruthenberg, 1964; Von Rotenhan, 1966). Customary law provided user rights and some transfer rights subject to control by the community (Cory, 1953; Wily, 1988).

tively rare. The survey data illustrate this point well: virtually all land was according to the respondents in the 1990 Shinyanga District survey acquired through inheritance or given by the government. Only 9% had acquired any of their land via purchase and 3% were hiring land from someone. Larger land holdings may result in higher incomes but land does not provide a secure means of the accumulation of wealth in present-day rural Tanzania. [13]

Human capital formation through health and education investments may be another alternative asset (Gersovitz, 1988). Past educational investments of the present adult labour force in the sample, however, seem very small and not to be at the root of wealth differences. One explanation may be that the provision of health and education facilities is in general rationed by the state. Furthermore, these household investments may provide high expected returns, but can be very risky. Many may invest in education, but for few households it may succeed to raise living standards significantly. It will also take many years for the returns in investments in the education of household members to materialize. The fact that the educational investments in the children of the household head, measured crudely in Table 2, are lower for the poor is more likely to be a consequence rather than a cause of the relatively poverty of the household.

Livestock, especially cattle, has been identified as the traditional asset for accumulation in Sukumaland (Malcolm, 1953; Von Rotenhan, 1966). About a third of the national cattle herd is kept in this region, mainly by agro-pastoralists (Marketing Development Bureau, 1987). It is a reasonably liquid asset and the investment is reversible because of the presence of well-developed livestock markets (Mackenzie, 1973; Frankel, 1982). The material characteristics of cattle are fully interwoven with a set of traditional social functions including social prestige and obligation to the extended family. Some part of cattle tends to be acquired through inheritance and bride-price payment, and the disposal of cattle obtained in this way is ruled by strict constraints (Malcolm, 1953). Otherwise, cattle tend to be acquired through purchase and exchange, and obtained in this way, the owner can dispose of cattle at will.

Livestock provides a positive return, in the form of off-spring, livestock products and its contribution to the land via manure and animal traction. The returns in the form of livestock products were found to be about 23% per year, consistent with other surveys in the region. [14] Off-spring provide another return to investment in cattle. Natural growth rates in the sample could not be calculated,

[13] This does not exclude that investment in land improvement may provide a way to accumulate wealth. Few successful irrigation schemes exist, but in some areas (such as in Kimba District) some smallholders have successfully found ways to introduce irrigation to allow the switch to the cultivation of high return crops such as tomatoes and other vegetables (Ravnborg, 1990). From the survey in Shinyanga District in 1990 no such information was available.

[14] Collinson (1972) reported a return of 25% per year for cattle; Von Rotenhan (1966) found 16% per year for livestock; FAO/IBRD (1975) found approximately 30%.

but positive returns in the form of off-spring can be expected. [15] Purchased livestock inputs in the present sample were small, and constituted less than 2% of the value of livestock. Consequently, the return to livestock in the sample area from livestock products and herd growth could therefore be reasonably estimated as being close to 25–30% per year. This estimate is nevertheless incomplete: it does not value the contribution to crop agriculture via traction and manure, although it also does not take into account the need to allocate scarce resources such as labour to livestock rearing. Land also needs to be allocated, even though at present most grazing occurs on communal grazing land. [16]

The mean return needs to be considered in relation to the risks and liquidity of the investment. Livestock investment is quite reversible, since the animals can easily be sold. Important primary and secondary livestock markets exist in Western Tanzania, and the possibility of 'transport on the hoof' allows fairly easy movement to markets in response to price signals. In fact, livestock markets were among the very few markets which the government allowed to operate freely throughout the 1970s and 1980s (Frankel, 1982). Livestock returns are nevertheless risky and will be affected by disease and climate. Drought could reduce substantially the returns, even though the consequences can often be limited since livestock herds can be moved over large distances in search of fodder and water [see Hankins (1974) for evidence on Sukumaland]. Generalised drought or other disasters are a very rare phenomenon in Tanzania and its neighbours, compared to for example the Horn or the Sahel. Large fluctuations in livestock prices do not seem to take place: data on cattle prices deflated by a consumer price index for Shinyanga Region for the period 1977–88 showed only a coefficient of variation of 7%, while in the worst year, 1981, cattle prices were only 10% lower than the average price over the 12-year period for which data were available. [17] Consequently, cattle keepers in this region are not exposed to the risks of a sudden collapse in the re-sale values of their investment found in some other parts of Africa, increasing the relative attractiveness of cattle.

Even though it is impossible to give exact figures on returns, the returns on livestock (relative to risk and liquidity) would appear to compare favourably with

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[15] Other surveys suggest that natural reproduction rates are between 7 and 13% for Western Tanzania, while mortality rates tend to be well below 10% (Mackenzie, 1973; Von Rotenhan, 1966; Lindström, 1986). Collier et al. (1986) estimate from their sample an off-take rate of about 6% on average for Tanzania. As was argued before, the data on sales of live animals are an overestimation of the actual natural growth rate of the value of the herd, since they were more than 25% of the value of the herd.

[16] In the region, grazing land has nevertheless become relatively scarce, raising concerns about local overgrazing and effects on crop land productivity through a reduction of fallow (Brandström, 1985; Ravnborg, 1990).

[17] Data from the Ministry of Agriculture, reported in Dercon (1996).

the returns to other liquid assets available such as cash, other financial assets or food stocks. Cash or other financial assets holdings were insignificant in this survey as in other earlier surveys in Tanzania (Collier et al., 1986; Amani et al., 1987). Financial repression and high inflation provide an explanation: the real returns on financial assets have been negative since the mid-1960s. Inflation in the 1980s has consistently been between 25 and 40% and real deposit rates remained strongly negative. [18] The available storage technology and the local climate typically result in negative inter-year returns to storage of food stocks. Stocks kept remain relatively small and are mainly used for seasonal consumption smoothing (Seenappa, 1987).

If investment in cattle provides a means to obtain permanently higher income and consumption, question arises about why only about half the households seem to own any cattle. [19] An explanation may be comparative advantage: given their own productivity in different activities, some households may find it more profitable to invest in other assets than cattle or to enter into other activities. Indeed, it was found that non cattle-owners proportionately derive a much larger share from off-farm income (53%) than do cattle-owners, who only earn about 8% from off-farm sources. It may therefore be that some households have relatively specialized in trade, wage employment or other off-farm activities since they have a comparative advantage in these activities. Average total incomes per adult equivalent—a crude measure of average returns to household labour—are, however, much lower for non cattle-owners than for cattle owners: the absolute returns from a portfolio which mainly combines crop agriculture and cattle rearing are higher than the absolute returns from off-farm activities and crops. Comparative advantage as an explanation for the relative allocation of labour in the sample would then only be acceptable if the non cattle-keepers are sufficiently different from the cattle owners so that the returns from cattle for the former group are substantially lower than for the cattle owners. Otherwise, if all households' returns to allocating labour to cattle would be the same in the area, then those households with a comparative advantage in off-farm activities would have a higher total income than those households with a comparative advantage in cattle-rearing.

Some differences in agricultural skills are likely to exist across households, affecting the returns to crop and livestock agriculture. Education may only be a

[18] This illustrates the present-day relevance of the Sukuma saying: ''Shillings do not breed'' (quoted in Malcolm, 1953).

[19] The proportion of households owning cattle does not seem to follow from the particularities of the sample only: earlier studies in Shinyanga District similarly found that about 40 to 60% owned cattle (Rounce, 1949; Von Rotenhan, 1966; Hankins, 1974; Kajumulo, 1980; Seenappa, 1987). These studies have also pointed to the apparent welfare differences between households who own and those who do not own cattle in their sample.

poor proxy for these skills. Nevertheless, cattle rearing is a long-established and traditional farming activity in the region and the technology used has not fundamentally changed in recent times. Skills differences between farmers are unlikely to be sufficiently large to suggest that half the households in the region would achieve the very low returns needed to conclude that the observed activity choices simply follow from differences in individual comparative advantage.

Rather than comparative advantage, the explanation which will be put forward in this paper is that non cattle-owners would find it profitable to enter into cattle rearing, but face binding entry constraints into the activity, linked to credit market imperfections. Lack of labour and land endowments are unlikely to be crucial: most grazing happens on communal grazing land, accessible to all members of the community, while wage employment seems relatively common, suggesting the existence of a rural labour market, although monitoring costs for herding labour may be high (Binswanger and McIntire, 1987). Imperfect credit markets pose more problems: since cattle are lumpy, entry into cattle rearing requires substantial investment to begin the process of building up a herd. In the sample, the average cattle unit value was about 15% of the mean income of the non cattle-owners.

Formal credit markets for rural households are poorly developed in Tanzania. In 1989, for example, only about 5% of commercial bank sector went to the private sector. [20] Informal credit markets are also quite limited in Tanzania, contrary to many other African countries. Surveys on rural credit in Tanzania in the 1980s found that only a very small number of informal loans were taken out and then mostly from relatives (Amani et al., 1987; Bevan et al., 1989). From their evidence it would seem that the typical problems associated with the development of rural credit markets, informational problems and covariate risks (see Binswanger and Rosenzweig, 1986), are applicable to rural Tanzania as well. Rotating credit and savings institutions (Rosca's) are not reported to exist in rural Tanzania and were not found in the area studied. Incomplete credit markets imply that the only way to invest into a high return asset like cattle is via own savings.

The accumulation of sufficient savings to invest could in principle be done through financial assets, but the high negative returns from holding cash or deposits make it quite unattractive. Small livestock, such as goats and sheep, are much less lumpy and well-functioning livestock markets make them quite liquid asset. On balance, they appear quite suitable for gradually building up the

[20] Individual farmers received very little of this lending: between 1985–1989, 90% of all 'private' sector lending to the rural areas went in fact to government controlled institutions, such as marketing parastatals and co-operatives (Government of Tanzania, 1990). Most of the lending to farmers is in-kind in the form of very specific inputs, such as pesticides and fertilizers. Lending for investment by farmers is largely absent (Due, 1978, 1983).

necessary wealth to invest in cattle. [21] Given their subsistence requirements and the lumpiness of the investment, poorer households will find it harder to accumulate the necessary savings for the investment than richer households.

Higher mean income and lifetime wealth increases are, however, not sufficient to generate permanent higher well-being for the households. Given the high income volatility in a rural setting, the household must also have the ability to obtain reasonable consumption stability. With absent insurance and poorly developed credit markets, self-insurance systems have to be used to cope with these fluctuations, combined with some village or kinship-based support. Broadly speaking, rural households adjust the structure of their income generation, develop their social networks into support structures or use assets as a buffer to be sold off whenever needed. [22] Livestock, including cattle, are commonly used as a store of wealth for distress sales in Sukumaland (Malcolm, 1953; Hankins, 1974). Well-developed livestock markets, relatively stable prices, the possibility to move cattle in case of drought and a reasonable return in comparison with other assets make cattle an effective store of wealth. Consequently, cattle are used both as an asset for smoothing consumption as for accumulation. [23] As pointed out by Von Rotenhan (1966), the saying of a neighbouring ethnic group, the Nyatura, applies to the Sukuma as well: ''Cattle are our banks, our stores, our fields, our wives, our families''.

A further implication is that those households which enter into accumulation are also better able to reach a smooth consumption path. Risk considerations will further limit poor households' investment into cattle. The need for consumption smoothing will mean that some small and larger livestock will be disposed off to buy food in case of income shortfalls. The slowly accumulated savings may be depleted before the household could achieve a higher mean income path from the investment.

Households in the area make further adjustments to deal with income risk: risk aversion will encourage households to enter into low risk activities or to construct a diversified portfolio with limited covariance in incomes; credit constraints may yield the same outcome (Eswaran and Kotwal, 1990) Liquid asset holdings, which are mainly livestock in the sample, would substitute for credit. In Dercon (1996) evidence was presented that households with relatively low livestock holdings were willing to allocate significantly more of their land to sweet potatoes, a low risk, low return crop than households with large livestock holdings (see also

[21] Such process is consistent with the evidence in Table 2: relatively small differences can be observed across consumption terciles in goats and sheep holdings, suggesting that they are not viewed as an asset for accumulation, but rather as a useful store of liquid wealth.

[22] For an overview see Alderman and Paxson (1992). Community support systems used to exist in Sukumaland (Malcolm, 1953), but little evidence could be found of their activity in recent years.

[23] This dual role of cattle as both insurance and an asset for accumulation has been identified by Binswanger and McIntire (1987) as common in relatively land-abundant areas.

Table2). [24] The higher share of land allocated to sorghum relative to maize and lower returns per hectare of cultivated land for the poorest tercile in Table 2 are also quite suggestive in this context.

Furthermore, these risk management considerations may also provide an alternative explanation for the relatively high income share from off-farm income. Off-farm activities generally have a lower risk than crop incomes, being less dependent on climate and having limited covariance with agriculture (Reardon et al., 1992; Walker and Ryan, 1990). Consequently, they are very useful as part of a diversification strategy to reduce income risk. Households with a limited asset buffer for consumption therefore have an incentive to allocate relatively more labour to these activities, even if the result means lower income. This may account for the higher income shares from off-farm activities for the poorer groups and the non cattle-owners (Table 1).

To view the choice for off-farm activities as merely a choice for low-risk activities to cope with crop income risk at the cost of lower incomes is somewhat limiting. A closer inspection of the data shows that the type of activities households are involved in varies considerably. They include shop-keeping, food-processing, tailoring, small-scale retail trade, firewood gathering, beer brewing, unskilled casual work, regular wage employment in the civil service, construction work, carpentry and work as a blacksmith. The literature on income diversification in rural households often appears to treat all off-farm activities the same (e.g., Reardon et al., 1992). This seems incorrect: returns are likely to be different and not all opportunities would be open to everyone. Entry into the civil service or setting up a shop is likely to be more difficult than, say, performing unskilled casual work. Constraining factors include skills, qualifications, contacts or credit constraints for start-up capital. Within the sample, three-quarter of the activities mentioned were activities with apparently low entry constraints, such a weeding or casual labour. A smaller group was involved in activities with likely entry constraints: five were involved in carpentry, three were tailors, two kept shops and one was a civil servant. The latter job is likely to require educational qualifications (the person completed secondary school), while the others will require specific skills and some set-up capital.

The data suggest that this small group of households may have different characteristics from the rest of the sample. Table 3 gives descriptive statistics for

[24] In Dercon (1996), an equation was estimated using OLS with a correction for multiplicative heteroscedasticity with the proportion of land allocated on sweet potatoes (PropSP) on the left hand side and a constant, liquid asset holdings per adult (Lassets) (instrumented to correct for endogeneity) and the land–labour endowment ratio (Land/Lab). *T*-values are given in parentheses. The results were: PropSP = 0.102 Constant (7.26), −0.043 Lassets (−2.45), −0.010 Land/Lab (−1.83). These results implied that 90% of the difference between the poorest and wealthiest quintiles in land allocated to sweet potatoes was caused by differences in liquid asset holdings and about 10% to differences in the land–labour ratio.

Table 3
Characteristics of cattle owners, off-farm earners and non-cattle owners

Sample means	Non-cattle (34)	Off-farm (10)	Cattle (35)
Crop income			
Subsistence	6295 (41%)	3326 (15%)	7440 (17%)
Cash	971 (6%)	747 (3%)	1520 (3%)
Livestock income			
Sale of live animals	422 (3%)	4137 (18%)	17,126 (38%)
Subsistence livestock products	424 (3%)	823 (4%)	14,472 (32%)
Cash livestock products	0 (0%)	171 (0%)	1435 (3%)
Agricultural wage employment	346 (2%)	26 (0%)	104 (0%)
Non-agricultural income			
Males' income	5723 (37%)	9153 (41%)	2238 (5%)
Females' income	1281 (8%)	4008 (18%)	710 (2%)
Total income	15,462	22,391	45,047
Total consumption	18,716	24,719	29,534
Labour supply[1]			
Number of adults	2.5	3.4	4.0
Male adults	1.2	1.3	2.1
Female-headed households (%)	24%	10%	11%
Education male adults (years)	3.1	5.7	3.2
Education female adults (years)	2.3	3.4	2.3
Land and land allocation			
Cultivated land per adult (ha)	0.7	0.6	0.9
Return from crops per hectare (TSh)	10,895	7570	14,140
Livestock values per adult equivalent			
Livestock values (TSh)	687	12,615	68,334
Cattle (TSh)	0	11,188	65,165

[1] See Table 2.

three groups: households not owning cattle and who are not involved in any off-farm activities with likely entry constraints (34), households involved in these specific off-farm activities (including 4 who also own cattle) and the rest of the sample, all cattle owners. Both in income and in consumption terms, the group with these specific off-farm activities reaches averages in-between the two other groups. They obtain about 60% of their income from off-farm activities, compared to 47% by the poorest group and 7% by the cattle owners. They have specialized far more into off-farm activities, and agriculture becomes relatively unimportant. This group has on average substantially better educational qualifications. Returns per hectare of cultivated land are only about half the returns obtained by the cattle owning households and more than a quarter lower than the non-cattle owners. This may suggest that this group are low productivity farmers and therefore have a comparative advantage to specialize in off-farm activities, rather than in crops or in cattle.

However, following a similar reasoning as before, since the total returns of this middle group are higher than for the non-cattle owners, this does not explain why the poorest group does not allocate more labour in off-farm activities. They may face lower returns in off-farm activities relative to the middle group following skill or educational differences (comparative advantage) or because of liquidity constraints to finance the set-up costs (credit market imperfections). Either of these factors would limit entry into the more profitable off-farm activities. Nevertheless, the poorest group continues to have a much higher share in off-farm activities than the cattle-owning households. For about 40% of the households in the sample, the combination of entry constraints following from credit market imperfections, skills differences which limit their opportunities and risk management considerations would seem the most plausible explanation for this larger share from off-farm income. [25]

In Section 3, a model of activity choice under risk and credit constraints is developed which will elaborate on the underlying causes why some households are able to enter into high return activities which require investment, while others cannot. In Section 4, the sample will be used to test some of the theoretical predictions.

3. A model of cattle accumulation and activity choice under risk

The model assumes the existence of a labour market and a rental market for oxen. The household is a price taker in these markets. All output prices are assumed to be given and constant, including for agricultural commodities, livestock and other commodities. Although risk will be important in the model, it will not stem from prices, but rather from yields. Insurance and land markets are absent. Credit markets are absent as well: no borrowing can take place against future returns and each asset has to be kept in non-negative amounts. The model

[25] A final point concerns the apparent inverse relationship between off-farm income shares and living standards, which contradicts for example the earlier findings of Collier et al. (1986) on Tanzania. Some of the characteristics of the sample area are likely to be responsible for this: the area is quite remote, with poor infrastructure and overall living standards in the area are not very high. Consequently, it is unlikely that there is much demand for many off-farm business products while poor infrastructure would make trade with other areas relatively expensive. A household which has a strong comparative advantage in non-agricultural activities, compared to crop and livestock farming, will have incentives to move to areas with better infrastructure or more demand. It is therefore likely that our sample includes fewer high income earners from off-farm activities than in a less remote area with better infrastructure.

has three activities to which labour can be allocated, each with a gross return at t of $p_i \cdot X_t^i$ $(i = 1,2,3)$. The first activity has a relatively low return and is considered safe. Entry into this activity is free, and labour L_1 is the only production factor. The activity will be referred to as agricultural wage labour at wage w per unit of labour, even though for our purposes it could include other casual employment, self-employment in the form of gathering of firewood or wild foods. Therefore, the net return is defined as:

$$p_1 \cdot X^1(L_1) = W \cdot L_1 \tag{1}$$

The second activity is agricultural cultivation, which has a higher return but is also risky. Labour (L_a) and cattle (oxen) (Y_a) are assumed to be the variable production factors, since no land transactions are possible. Each household is assumed to have some (non-negative) land S. Labour can be hired in at wage w but hired labour $(L_r = L_a - L_2)$ involves the need for supervision time which amounts to $s(L_r)$, with $s(0) = 0$ and both $s'(L_r)$ and $s''(L_r) > 0$: supervision becomes increasingly more costly (Eswaran and Kotwal, 1986). Oxen can be hired in $(Y_r = Y_a - Y)$, at a rental cost of k $(Y_r \geq 0)$. It will be assumed that there is a premium on using own oxen for ploughing. It is commonly observed that farmers without oxen have to wait for the use of oxen until the owners have finished, implying that ploughing often happens at sub-optimal times [see Rosenzweig and Wolpin (1993) for an example from India, Gryseels (1988) on Ethiopia]. To allow for this, the marginal return from rented oxen will only be m times the marginal return from owned oxen $(0 < m < 1)$. The production function is increasing in each factor and is concave. Constant returns to scale are assumed. Consequently, the profit function for agricultural cultivation is:

$$p_2 \cdot X^2(L_2 + L_r, S, Y + m \cdot Y_r) - k \cdot Y_r - w \cdot L_r \tag{2}$$

The third activity is cattle rearing: a risky, high return activity. Livestock is assumed to be herded on common land, but labour L_h is needed for herding. Cattle is the essential input (Y) and its marginal return is high. The production function is concave. Even though labour is needed, it is obviously a poor substitute for cattle in production. It will therefore be assumed that, at least after some level of labour input, very large quantities of labour are needed to compensate for small reductions in the cattle herd: the technology is assumed to imply that there exists a virtually vertical part of the iso-production curves in the labour–cattle space. Also, if no cattle are available, the marginal return to labour is assumed to be zero. Nevertheless, one cannot do without labour: animals require regular care and can easily be stolen or lost. Family labour (L_3) could be used or labour for herding hired in (L_{hr}). Even though relatively little labour is needed, hiring labour may involve substantial moral hazard (Binswanger and McIntire, 1987). Supervision time $h(L_{hr})$ needs therefore to be taken into account. As before, supervision becomes more costly with more hired labour, with $h(0) = 0$ and both $h'(L_{hr})$ and $h''(L_{hr}) > 0$.

Constant returns to scale for cattle herds may not be an appropriate assumption in general. Given a fixed supply of common grazing lands, the consequences of overgrazing would mean that returns are likely to decrease at some level. In other words, optimal herd sizes would exist [e.g., see Udry (1993) for Nigeria]. Nevertheless, since cattle can be moved over quite large distances and given the quite vast areas of uncultivated grazing land in Western Tanzania, it is not certain that decreasing gross returns are applicable. Furthermore, the fixed labour supply and the convex monitoring time would imply that for large herds, marginal profits would be decreasing, even if there are constant returns to scale. [26] Finally, given the existence of an oxen rental market, a small, but non-negligible, additional return can be obtained equalling $k \cdot Y$. [27] Net returns from cattle rearing, abstracting from the contribution to agricultural production, are defined as:

$$p_3 \cdot X^3(Y, L_{\mathrm{hr}} + L_3) + k \cdot Y - w \cdot L_{\mathrm{hr}} \tag{3}$$

Total available labour time L cannot be exceeded by the allocation of time across these four activities:

$$L \geq L_1 + L_2 + L_3 + s(L_{\mathrm{r}}) + h(L_{\mathrm{hr}}) \tag{4}$$

Labour allocated to each activity and hired labour has to be non-negative:

$$L_1 \geq 0 \tag{5}$$

$$L_2 \geq 0 \tag{6}$$

$$L_3 \geq 0 \tag{7}$$

$$L_{\mathrm{r}} \geq 0 \tag{8}$$

$$L_{\mathrm{hr}} \geq 0 \tag{9}$$

Thus far, the model has been presented in a static framework. It will now be put in a dynamic context. Total labour L is available and can be used in each

[26] As has been mentioned before, overgrazing does not appear to be a large problem as yet in the particular area and marginal returns still appear to be high at the given herd sizes.

[27] Implicitly, it is assumed in Eqs. (2) and (3) that all cattle are first used in agricultural production and then rented out to be used by other farmers at non-optimal times in crop production, for which a fixed rent is obtained. The fact that they are used at non-optimal times is taken into account by the factor m in Eq. (2). One could easily extend this model to make it more realistic. For example, one could make the rent k one can obtain from renting the animals a decreasing function of the extent to which animals are used in the own production, since they would be tied up longer and only later released for use by others. Alternatively, one could drop the emphasis on the timing of ploughing, and simply consider that an oxen rental market exists, but rented oxen are not prefect substitutes. Rather than using all oxen Y in agricultural production, households will choose this amount Y_2, while the remainder can be rented out (Y_{ro}). The argument in Eq. (2) becomes $Y_2 + m \cdot Y_{\mathrm{r}}$, while in Eq. (3) a return of $k \cdot Y_{\mathrm{ro}}$ will be earned from renting out cattle. This implies two new choice variables, Y_2 and Y_{ro} and a new constraint needs to be introduced: the sum of Y_{ro} and Y_2 cannot exceed Y. The changes in the first order conditions are straightforward.

period t. Land S remains constant over time, since no land markets are assumed. The stock of cattle at t, Y_t, can be carried over to and will start yielding return in $t+1$. Furthermore, cattle markets exist and cattle are therefore an asset that can be accumulated and also depleted. There are, however, some restrictions on cattle acquisition and disposal; in particular, they have to be kept in discrete units. This lumpiness constraint effectively limits the liquidity of cattle. Let n be an integer, and then Y_t always has to be equal to:

$$Y_t \equiv n_t \tag{10}$$

A non-negativity restriction applies to cattle holdings, as well as to cattle rental:

$$Y_t \geq 0 \tag{11}$$

$$Y_{\mathrm{tr}} \geq 0 \tag{12}$$

Cattle are not the only asset available for inter-year transfers. Another asset, Z_t, can be kept in non-negative amounts and yields a low, but constant return of r (assumed to be larger than -1).

$$Z_t \geq 0 \tag{13}$$

This asset will be referred to as sheep, but it could also be thought of as cash, food stocks or some other small livestock such as goats or poultry. They yield relatively low inter-year returns r and these returns are for simplicity assumed to be obtained without any labour allocation. This asset is also assumed to be perfectly liquid. In a low inflation environment, cash would have been the likely interpretation, but as was argued in Section 2, it appears that small livestock has taken on its role in rural Tanzania as a temporary store of wealth.

The household is assumed to be risk averse and will maximize expected intertemporal utility V, with instantaneous utility v a function of consumption c at t, and with δ as the discount rate:

$$\max V_t = E\Sigma_{\tau=t}^{T}(1+\delta)^{\tau-t}v(c_\tau) \quad t=0,1,2,\ldots,T \tag{14}$$

Using Eqs. (1)–(3) and defining p_{c} and p_{s} as cattle and sheep prices respectively with consumer prices as the numraire, the intertemporal budget constraint can be written as:

$$\begin{aligned} & p_{\mathrm{c}} \cdot Y_{t-1} + p_{\mathrm{s}} \cdot Z_{t-1} + w \cdot L_{t1} + p_2 \cdot X_t^2(L_{t2} + L_{\mathrm{tr}}, S, Y_{t1} + m \cdot Y_{\mathrm{tr}}) \\ & \quad - k \cdot Y_{\mathrm{tr}} - w \cdot L_{\mathrm{tr}} + p_3 \cdot X_t^3(Y_{t-1}, L_{t3} + L_{\mathrm{thr}}) - w \cdot L_{\mathrm{thr}} \\ & \quad + k \cdot Y_{t1} + r \cdot p_{\mathrm{s}} \cdot Z_{t-1} \geq c_t + p_{\mathrm{c}} \cdot Y_t + p_{\mathrm{s}} \cdot Z_t \end{aligned} \tag{15}$$

Cattle and sheep prices are assumed to be constant over time, a simplifying assumption which is unlikely to be satisfied in general. In particular, as was discussed before, risk and cycles in livestock prices would strongly affect their usefulness as stores of wealth. However, price fluctuations seem relatively limited in the particular area studied, so this complication though interesting would seem unnecessary.

The problem for the household is to find the optimal consumption, asset, cattle and labour allocations to wage employment, agricultural cultivation and cattle rearing in each year t. Labour and other inputs have to be allocated before uncertainty is resolved; actual consumption, investment into cattle and cash savings at t will be determined after the earnings are known for year t. The solution can be found by solving a dynamic programming problem: maximizing (Eq. (14)), subject to the intertemporal budget constraint (Eq. (15)), the total time constraint (Eq. (4)), the non-negativity constraints on cattle (Eq. (11)) and cattle rentals (Eq. (12)), the borrowing constraint (Eq. (13)), the lumpiness constraint on cattle (Eq. (10)) and the non-negativity constraints on all labour (Eqs. (5)–(9)).

A further constraint is that consumption in each period has to be non-negative. It will, however, be assumed that this constraint is never binding: the household will not allow this to happen. One way to justify this is to assume that $v'(c_t)$ will become infinite if c_t approaches zero (Dasgupta, 1993) or some minimal level to guarantee survival, as in Rosenzweig and Wolpin (1993). To make positive consumption feasible, it will be assumed that in any state of the world net income from the three activities will always remain positive. Consumption can then remain positive in each year t, even though this may imply driving sheep holdings Z_t and cattle holdings Y_t to zero. [28] Following Rosenzweig and Wolpin (1993), one could justify this assumption by referring to the existence of informal support networks in rural communities which provide some income assistance, albeit in some cases minimal (Platteau, 1991).

Solving this optimisation problem is not self-evident because of the presence of the lumpiness constraint. Generically, this is a stochastic dynamic (mixed) integer programming problem. The constraint that the feasible values for Y_t are restricted to particular integers implies discontinuities and non-convexities which render the usual non-linear programming techniques invalid (Stougie, 1985). In fact, no comparably attractive solution methods exist. A standard approach is the Branch and Bounds method (Land and Doig, 1960). It involves first solving the problem as if all variables were continuous. If the relevant solutions are satisfying the

[28] An alternative formulation would be to assume that $v'(c_t)$ approaches infinity if c_t approaches minimum consumption $c_{\min}$ and that gross returns are always larger than $c_{\min}$, to account for the fact that positive consumption close to zero may not guarantee survival. This assumption is used by Rosenzweig and Wolpin (1993).

integer constraint, then the problem has been solved. If not, neighbouring values, satisfying the integer constraint for the relevant variables, are introduced in the problem. The optimum of the problem is calculated keeping the integer constraint variables fixed. If any constraints are violated in this case the result is ignored. Otherwise the value of the objective function is registered. In principle all feasible values ought to be checked. Therefore this procedure is only feasible if only a limited number of values are feasible, or if one has grounds to restrict the feasible values.

In line with the Branch and Bounds method, the problem will first be solved as if Y_t and Y_{tr} were continuous variables. The problem becomes then a standard stochastic dynamic programming problem. Assuming that the time horizon is finite, and for a given initial asset position in the first year (Y_0 and Z_0), a solution can be found by backward solving using Bellman's principle of optimality (Stokey and Lucas, 1989). Given the assumptions made, the constraints (without the lumpiness constraint) define a convex set and since the objective function is continuous a solution to the problem exists. [29] Given the assumptions of concavity of the utility function, the first order conditions will be sufficient for a unique maximum to exist. The dynamic programming problem was solved using Lagrangean multipliers for each constraint: μ_t (borrowing constraint, i.e., the non-negativity constraint on sheep holdings), η_t (time constraint), ρ_t (non-negativity of cattle holdings), ϕ_t (non-negativity constraint on hiring cattle), and a set of multiplier on the non-negativity of labour allocation: λ_t (wage labour), σ_t (agricultural cultivation), τ_t (off-farm business), ϵ_t (cattle-rearing), ξ_t (hired agricultural labour), ω_t (hired herding labour). The first order conditions are given in Appendix A. The optimal solution to the objective function defines the value function at t, V_t^*, which is a function of all exogenous variables.

The first order conditions provide some insights in the consequences for activity choice and asset holdings of the constraints faced by households. They are presented in Appendix A and the implications will be discussed next (roman numbers refer to the appendix equations). First, liquid asset holdings in the form of sheep will be considered. Since positive consumption is feasible and marginal utility approaches minus infinity at very low consumption, Eq. (III) holds with equality:

$$v'(c_t) = \frac{(1+r)}{(1+\delta)} \cdot E'V(c_{t+1}) + \mu_t \tag{16}$$

This equation is the standard condition for optimal consumption with borrowing constraints and concavity: if the constraint is binding ($\mu_t > 0$), marginal utility at t will be larger than the discounted expected marginal utility at $t+1$ (Deaton,

[29] Convexity is obtained via the constant returns technology, imperfect substitutability between own cattle and hired cattle, and the monitoring costs when using hired labour.

1991). Since marginal utilities are decreasing, binding borrowing constraints imply that less will be consumed in t in equilibrium than needed to equate marginal utilities of consumption without borrowing constraints.

Combining Eqs. (16) and (V) yields:

$$\frac{1}{1+\delta}\cdot E\left[\left(1+\frac{p_3\cdot\dfrac{\partial X_{t+1}^3}{\partial Y_t}+p_2\cdot\dfrac{\partial X_{t+1}^2}{\partial Y_t}+k}{p_\mathrm{c}}\right)\cdot V'(c_{t+1})\right]$$
$$+\rho_t=\frac{1+r}{1+\delta}\cdot E\left[V'(c_{t+1})\right]+\mu_t \qquad (17)$$

If cattle are kept, then ρ_t will be equal to zero. If cash is kept as well, then μ_t will equal zero. The standard portfolio choice model is obtained: households will keep both assets in quantities which equalize the marginal utilities of holding each asset. The marginal return to the asset 'cattle' consists of the direct returns from cattle rearing, but also their contribution to agriculture and the return from renting out cattle.

Eq. (17) allows an evaluation of the causes for why a household may *not* invest in cattle ($\rho_t > 0$). First, the return to the liquid asset may be higher than the return to cattle: even the return from cattle rearing plus its contribution from renting out oxen and from ploughing may not outweigh the return. Secondly, even if the marginal returns from cattle are on average quite high compared to the returns from keeping sheep, the household may be sufficiently risk-averse to make the expected utility from cattle not outweigh the marginal utility from keeping sheep. Finally, intertemporal credit constraints are binding implying that the household would in fact rather dissave today than keep any cattle.

Assets perform a double function in this model. Besides income, they provide a means for consumption smoothing (Rosenzweig and Binswanger, 1993). Risk aversion will encourage the household to stabilize consumption. [30] There may be a third reason for keeping assets. Households may have a precautionary motive for savings: they build up assets as insurance against consumption shortfalls caused by income risk (Sandmo, 1970; Kimball, 1990; Deaton, 1991). This requires, however, the additional restriction of convexity of the instantaneous marginal utility function. There seems considerable theoretical and empirical appeal for this additional assumption (Deaton, 1991; Dasgupta, 1993; Muellbauer and Lattimore, 1994), but it is not needed for the remainder of the results.

The conditions for optimal labour allocation between the three activities follow

[30] Strictly speaking, the household's aversion to consumption fluctuations is governed by the intertemporal substitution elasticity, which is in additive intertemporal utility formulations a function of the inverse of the coefficient of relative risk aversion.

from Eqs. (VI), (VII) and (VIII). The standard result is obtained that labour will be allocated to each activity until the marginal utilities are equal to marginal cost of labour (the multiplier on the time constraint, η_t) (Eq. (18)).

$$v'(c_t)\cdot w = E\left[v'(c_t)\cdot p_2\cdot\frac{\partial X_t^2}{\partial L_{t2}}\right] = E\left[v'(c_t)\cdot p_3\cdot\frac{\partial X_t^3}{\partial L_{t3}}\right] = \eta_t \tag{18}$$

Eq. (18) is only valid if labour is allocated to each of the activities in the optimum, which need not be the case. If cattle holdings were zero, the marginal product of labour allocated to cattle rearing is zero and Eq. (VIII) would hold with strict inequality. Given the nature of cattle rearing it was also assumed that the marginal returns decline very strongly, at least after some level of labour for a given cattle holding (virtually flat part of the isoquant). If additional labour becomes available it will be allocated across the activities to retain the validity of Eq. (18), but the brunt of the labour adjustment will take place in agricultural cultivation or wage labour.

Looking more closely at Eq. (18), the expected marginal utility to each of the agricultural activities will be equated to the marginal cost of labour (the multiplier on the time constraint). Risk is an important reason for being involved in the low return activity. Concave utility implies that there is a premium on certainty about marginal utility outcomes under different activities. More labour will therefore be spent on lower risk activities. Besides risk aversion, a second reason can be identified why some households would engage more in low (or zero) risk activities than in risky agriculture, related to inter-year borrowing constraints. With concave utility, Eqs. (16) and (17) can be combined to write the condition for optimal marginal consumption at t as the maximum of three terms:

$$\begin{aligned} v'(c_t) = \max\Bigg[&\frac{1}{1+\delta}\cdot E\left[\left(1+\frac{p_3\cdot\dfrac{\partial X_{t+1}^3}{\partial Y_t}+p_2\cdot\dfrac{\partial X_{t+1}^2}{\partial Y_t}+k}{p_c}\right)\cdot V'(c_{t+1})\right], \\ &\frac{1+r}{1+\delta}\cdot E\left[V'(c_{t+1})\right], v'\big(p_c\cdot Y_{t-1}+p_s\cdot Z_{t-1}+r\cdot p_s\cdot Z_{t-1}+w\cdot L_{t1} \\ &+p_2\cdot X_t^2(L_{t2}+L_{tr},S,Y_{t-1}+m\cdot Y_{tr})-k\cdot Y_{tr}-w\cdot L_{tr} \\ &+p_3\cdot X_t^3(Y_{t-1},L_{t3})+k\cdot Y_{t-1}-w\cdot L_{thr}\big)\Bigg] \end{aligned} \tag{19}$$

If both ρ_t and μ_t are positive (binding liquidity constraints), then the last term will be the maximum: all earnings plus assets will be consumed. The first term will be the maximum if the borrowing constraint on cash is not binding, while the second term will be the maximum if the non-negativity constraint on cattle holdings is not binding. The first and second term will both be the maximum if neither constraint binds ($\rho_t = \mu_t = 0$). One way of interpreting Eq. (19) is that borrowing constraints effectively remove the floor on consumption outcomes: despite the disposal of all assets, consumption could remain very low if no consumer credit is available. [31]

An implication shown by Eswaran and Kotwal (1990) applies in this model as well: binding credit constraints will result in a less risky activity portfolio. The three possible outcomes will be used by the household when evaluating the allocation of a marginal unit of labour. If under some states of the world the return to the risky activities becomes very low, then a household may prefer to sell all its assets and (if it were possible) to obtain credit to keep its consumption at an optimal level. If credit is no option and credit constraints are binding then lower consumption levels may occur (and hence higher marginal utility) than with credit. As can be seen from Eq. (19), a risk averse household will then allocate relatively less labour to the risky activities than it would if it had access to credit.

In an intertemporal framework, assets may perform a similar role as credit. Higher initial asset holdings in t make it less likely that credit constraints will bind in Eq. (19), since they provide a buffer against low consumption outcomes. Higher initial assets at t would then imply that households will allocate more marginal labour to risky activities than households with low asset holdings, providing a second reason for relatively higher allocation to the first activity in the model.

To conclude, household income in this model is determined by initial endowments of land and labour, and (accumulated) asset holdings, especially in the form of cattle. Households with the same risk preferences and initial endowments, but with different initial assets may hold a different activity portfolio and make different marginal investments into assets. First, a household without cattle and low assets will work relatively more outside risky farming to provide better protection against risk. Lack of cattle would cause lower returns to agriculture because they depend on rented oxen which they can only apply at sub-optimal times and they have to pay for this service. Thirdly, overall returns to labour would be lower, also because of the adjustment in the cropping pattern in response to risk. Finally, since cattle are risky, they are likely to keep relatively more low risk, low return assets. What may seem comparative advantage is actually a response to wealth differences and risk. [32]

[31] The simulations provided in Deaton (1991) illustrate this.

[32] Note that by design, the model excludes households which have an absolute or comparative advantage to enter into off-farm activities, irrespective of risk considerations, for example because they have specific skills to enter into off-farm activities. It would be straightforward to include a fourth possible activity, which requires a specific skill to enter in and which in that case can give a large return. Alternatively, agricultural skills may be included as an input in the agricultural production function. As was argued before, for a small part of the sample, both additional factors may provide the explanation for their observed activity choice.

These observations square reasonably well with the evidence presented in Section 2. However, this would not easily explain why relatively few households take up cattle in the long run, if it provides such a high return. Households were keeping relatively small amounts of small livestock (rather independent of wealth), while cattle holdings were very skewed to the richer households. This would suggest that livestock returns from small livestock are likely to be relatively smaller than cattle returns. The model allows for diversified portfolio's of assets with different returns, but only if risk characteristics are different across assets. It does not seem very appealing as an explanation of actual asset holdings. If anything, it is unlikely to be much less risky than cattle. [33] Nevertheless, far more households seem to keep it compared to cattle. The lumpiness constraint on cattle would provide an important additional reason for keeping small livestock, and account for why relatively few households succeed in entering into cattle, even at low numbers.

Introducing the lumpiness constraint would change these optimal conditions. Mathematically, the marginal conditions would change as would the shadow prices linked to the other constraints. In fact, the uniqueness of these prices and therefore of the solution cannot be proven. It is nevertheless certain that at any new optimum allocation the intertemporal utility obtained would never be larger than V_t^*. Defining this (not necessarily unique) level of utility taking into account the lumpiness constraint as V_t^+, then one could define the utility cost of the this additional restriction, θ_t, as:

$$\theta_t = V_t^*(\cdot) - V_t^+(\cdot) \geq 0 \tag{20}$$

There is an obvious similarity between the interpretation of the Lagrangean multipliers in the problem and θ_t, since they both express the utility benefits from relaxing constraints, although Eq. (20) expresses a discrete change, rather than a marginal change in utility from relaxing the lumpiness constraint. If θ_t is larger than zero, then the lumpiness constraint may result in the first order conditions defined above not to hold. Since we are particularly interested in the effect this constraint has on the holdings of cattle and other assets, one could define an expression, linked to Eq. (17), illustrating the choice between cattle and sheep. Suppose the household keeps both cows and sheep. Since one extra cow will reduce spending on consumption or on sheep by p_c, one could define a value α_t which determines the (*ex-post*) deviation from the equalization of utility gains

[33] Making r risky would change the first order conditions, but in a straightforward way and it would not substantially change the interpretation.

from investing in an additional unit of cattle or in an equivalent value of sheep at the optimum V^+, taking into account the lumpiness constraint, as:

$$\frac{1}{1+\delta}\cdot E\left[\left(p_c + p_3\cdot\frac{\Delta X_{t+1}^3}{\Delta Y_t} + p_2\cdot\frac{\Delta X_{t+1}^2}{\Delta Y_t} + k\right)\cdot\frac{\Delta V^+(c_{t+1})}{\Delta c_{t+1}}\right]$$

$$= p_c\cdot\frac{1+r}{1+\delta}\cdot E\left[\frac{\Delta V^+(c_{t+1})}{\Delta c_{t+1}}\right] + \alpha_t \tag{21}$$

Note that this equation is expressed in discrete changes, since it illustrates the choice between adding a discrete value to either cattle or sheep. Although not necessarily so, binding lumpiness constraint would usually result in α_t to be different from zero. α_t could be positive or negative, implying that the amounts of cattle kept may in the optimum be respectively smaller or higher than without the lumpiness constraint. This follows again from decreasing marginal utilities. Borrowing and lumpiness constraints could be reinforcing: it could be that without the lumpiness constraint it would have been optimal to borrow (i.e., to keep negative amounts of sheep) to invest this into cattle. If lumpiness constraints are binding with α_t positive, too few cattle are kept and the household would find it optimal to save even more in the form of sheep. If the investment needed to enter into cattle is found to be high, the result could be that households are keeping only sheep, despite the high returns in cattle.

In their evaluation of expected future consumption households will value the costs of future constraints. The cost of future borrowing constraints encourages the household to save to build up a buffer (Deaton, 1991). Similarly, in this model the cost of future lumpiness constraints will provide incentives to the household to save more of the liquid asset to allow investment in cattle at a later date. But savings will always have to be weighed against present consumption and concave instantaneous utility will make this more costly for households with relatively lower incomes. Since the price of one (indivisible) unit of cattle is the same for all, households with relatively lower incomes find it harder to save sufficient means to enter into cattle.

4. Simulations

The model suggests that lower incomes are caused by low endowments of land and labour, combined with low initial asset holdings. If lucrative investment opportunities exist, income differences increase over time. In turn, this allows the relatively wealthier households to enter into more risky but higher return activities relative to poorer households. The lumpiness constraint exacerbates this further, since relatively poorer households will find it harder to enter into the most profitable assets and activities. Some simulations were performed to illustrate the dynamic process involved. They focus on the consequences of small initial wealth conditions for long run welfare differences. The emphasis is on the effects of the lumpiness constraint and entry in high return and high risk activities. To simplify the simulations, risks in the assets was ignored. [34]

Consider two risk-averse households, one 'rich' and one 'poor'. They are identical in preferences, including their attitude towards risk. They have the (discrete) choice between two crops or activities: a safe, low return option and a risky but higher return alternative. The 'rich' and the 'poor' are distinguished through differences in the mean incomes from their activities. They face, however, the same riskiness in each activity, measured by the coefficient of variation. Differences in mean income can be thought of to stem from larger land or labour endowments in quantity or quality. Both households have access to two assets, cattle and sheep, which for simplicity are assumed to be yielding a safe return. They can be bought and sold at a constant price at all time. Cattle yield a much higher return than sheep, but the former is indivisible, so that it has to be bought as units which are quite expensive each. To keep the simulations more tractable, I abstract from another important interaction in the model: the interdependence of cattle and crop production. Implicitly, cattle ownership is not a necessary condition for high return cropping. It simply adds a substantial additional income irrespective of whether high or low risk activities are entered into. While this obviously ignores important choice problems for households, the consequence is that observed choices of the low risk activity in the simulations will be driven by the overall consumption risk position linked to asset holdings, which will be clearly separated from higher returns linked to the ownership of assets. [35]

The households face borrowing constraints and start with zero initial assets. I simulate the evolution over a 10-year life-cycle. Given the high returns to cattle, both households have strong incentives to invest any surpluses in each year into cattle to increase total earnings on top of crop income. Decreasing marginal utility and the necessity for survival provide incentives to smooth consumption and not to allow consumption to fall to extremely low levels. They also provide incentives

[34] These simplifications were also necessary to economize on computer time, since Branch and Baud methods require the evaluation of a large number of different possible outcomes.

[35] Rosenzweig and Wolpin (1993) have argued that this interdependence is a crucial element in the pattern of asset accumulation behaviour in their Indian sample. They assume that oxen ownership is necessary for timely farm operations, since rental markets cannot be relied upon. In our model, rental markets are available, albeit at a cost with rented and own oxen not perfect substitutes. A simple way to include this interdependence in the simulations would be to force those without cattle only to take the low return, low risk option. This would, however, mean that using cattle in crop production would increase risk, which is unlikely to be true, so the results are not presented. Alternative routes are possible, but presented further computational complications. In any case, linking crop returns to cattle ownership would provides extra incentives to enter into cattle, but it also results in even further diverging wealth between those owning cattle and those who do not, compared to the results presented in this section.

for entry in a low risk, low return activity, even at the cost of lower mean income and lower accumulation. The simulations aim to give insights into how subsistence requirements, risk aversion and lumpiness constraints will affect the chances of a household with relatively low endowments to invest in a profitable asset, compared to a household with higher endowments. It will be shown that relatively small differences in initial income can result in substantial differences in welfare.

The underlying risky crop income process is assumed to be independently identically distributed with a mean of 50 for the 'rich' household and of 35 for the 'poor'; both face a coefficient of variation of 20% in income. The safe alternative is assumed to have a mean which is 1% lower than the respective means of the risky activities. Instantaneous utility at t is equal to the natural log of consumption at t, implying a coefficient of relative risk aversion equal to one. [36] Households maximize expected utility over their 10-year life-cycle; no bequest motive is included. A rate of time preference of 5% is assumed to exist. Following Deaton (1991), income is approximately normal using a discrete approximation (with 10 power-points). A symmetric truncation of 5% at each tail was used, which also avoided the possibility of negative income, for which utility would not be defined with logarithmic utility. [37] Cattle have a price of 10 and are indivisible; sheep do not suffer from this problem in the example. The net return on cattle is 10% per year, while the return on sheep is 0%, i.e., the latter is just a store of wealth. With a rate of time preference of 5% and the cattle return of 10%, households would prefer an increasing consumption path and therefore have a strong incentive to invest in cattle early in the life-cycle. Income risk and risk aversion encourage households to smooth the variability of this consumption path and to save and dissave for this purpose. Both households are assumed to have no initial cattle or sheep holdings; either can be used for accumulation and smoothing. An additional case will be considered in which the constraints on accumulation are further tightened. In particular, it will be assumed that households cannot sustain assets if consumption falls below subsistence requirements, assumed to be equal to 30. This could be justified by referring to the issue of the 'social context of savings' identified by Besley (1995): households may have difficulties in safeguarding savings from claims from particular household members. This would be especially so if the household is facing a low consumption outcome: under these circum-

[36] With logarithmic utility and in a static model (one-year life cycle), the risk premium for the 'poor' household if it were to be involved in the risky activity is about 1.82% of mean income and slightly lower for the 'rich' household. Consequently, the household would choose to take up safe activities with a mean up to this percentage lower than the mean of the risky activity. The safe activity was defined in the text so that it would be entered by both households in a static world.

[37] In practice this meant that 10 power-points from the standard normal distributions were used starting from -1.64 to 1.64, each with a probability of 10% of occurring. This implied that the lowest income draw in the example is 23.5 and 33.6, respectively, for the poor and rich households. Some informal support system could justify this floor in income, as in Rosenzweig and Wolpin (1993).

stances it may not be possible to sustain household savings even if intertemporal utility could be increased. This assumption is introduced as an off-setting effect of the incentives to invest in a high return asset at the cost of present consumption. [38]

The question of interest is whether the relatively poorer household facing these circumstances will find it harder to take up cattle-rearing and whether poorer households will enter more often in low risk activities. Both may cause welfare divergences from the richer household. The programming problem was tackled using backward solving: for possible values of initial assets and income draws, the optimal value V^+ and the related consumption and asset choice are calculated which maximizes expected utility, first for the last period, then the one but last, etc. (Stokey and Lucas, 1989). Numerical simulations were then used to determine the probability that the household will take up cattle and sheep in each period of their life-cycle. [39]

Table 4 presents some of the results. To separate the consequences of income portfolio choice from the lumpiness constraint, results are also given for the case in which households do not have access to a low risk alternative so that crop income is always risky and exogenous. First, the table gives the probability that a poor and a richer household with no initial assets will find it optimal to invest in cattle. Without the additional restriction on very low consumption and with exogenous income, risky income will result in a more than 65% probability that

[38] With a return of 20%, even a reasonably risk-averse household as considered in the example would be willing to save considerably now for future higher consumption, i.e., its optimal consumption path would be strongly increasing. As pointed out by Deaton (1991), borrowing constraints are unlikely to be an important issue, since saving is the main concern for these households. Introducing a minimum level of consumption before savings in cattle or sheep can be kept reduces this incentive to save. Lower consumption is still possible if not sufficient initial savings plus income are available to the household. Although the assumption is quite ad-hoc, it mainly meant to show that more pressure on the household at lower levels of consumption reduces significantly the possibility of accumulation. Higher coefficients of risk aversion could obtain a similar result, but the estimates available on developing countries rarely suggest risk aversion much larger than one (Binswanger, 1980; Alderman and Paxson, 1992). A more strict 'Safety First' model could have provided an alternative formulation, but the discontinuity in utility functions involved required a different theoretical model than the expected utility formulation. Finally, Rosenzweig and Wolpin (1993) impose a subsistence requirement in their model, but at same time assume the existence of informal support networks to guarantee this consumption levels at all time, immediately weakening an important reason for keeping assets and increasing the incentives to invest in cattle.

[39] In principle, the entire asset probability distribution at each point in time could be calculated in this numerical example for each household, using transition functions linking different periods (Stokey and Lucas, 1989). Comparing these distributions would provide an answer to the question. Since this is a finite horizon problem, these distributions will not be time-invariant, so no convergence rules can be derived (Stokey and Lucas, 1989). The presence of the lumpiness constraint also implies that no optimal first order conditions can be derived, forcing the design of an algorithm that, using the Branch and Baud method, considers all possible solutions. The computational complications involved made a numerical simulation the only feasible approach. They were obtained using 1000 randomly generated income paths for each household over the life-cycle.

Table 4
Simulations results

Probability of investing in cattle or sheep in year 1	Cattle		Sheep or cattle	
	Poor	Rich	Poor	Rich
Only risky activity				
No subsistence requirements	50.0%	65.5%	71.6%	72.6%
Subsistence requirements	23.9%	65.1%	66.6%	72.6%
Risky and safe activity				
No subsistence requirements	50.0%	65.5%	71.6%	67.4%
Subsistence requirements	23.9%	65.1%	66.6%	67.4%

Probability of not owning cattle in three or more years of the life-cycle	Poor	Rich
Only risky activity		
No subsistence requirements	20.1%	11.2%
Subsistence requirements	40.8%	11.2%
Risky and safe activity		
No subsistence requirements	31.0%	11.7%
Subsistence requirements	43.6%	11.7%

Probability of entering twice or more in safe activity during life-cycle	Poor	Rich
Risky and safe activity		
No subsistence requirements	66.2%	13.0%
Subsistence requirements	70.3%	13.0%

Source: Own simulations.

the households with high mean income will find it optimal to buy cattle, which is almost a third higher than for the poorer household. That this difference is largely caused by the lumpiness constraint is illustrated by the fact that there is virtually no difference between richer and poorer households when considering savings in any form: both have about 72% chance to be observed investing in any assets (sheep or cattle) in the first year. Once additional pressures exist for poor and rich households to avoid very low consumption outcomes, the differences become more pronounced: poor households have a far smaller chance of taking up cattle than richer (24% compared to 65%), while the difference remains much smaller when savings in any form are considered. [40] Introducing the option to take up a safe activity only marginally changes these results.

[40] That most of these differences are caused by the lumpiness constraint is illustrated by simulations in which this constraint was dropped. They showed that the poor and the rich household had an equal chance (84%) of owning cattle (with obviously no investment in the lower return asset); with the constraint on low consumption the probabilities were still 84% for the rich household and 72% for the poorer household.

In all cases, the simulations showed that the incentives to invest in cattle are sufficiently large for most poor and rich alike to invest into cattle at one point or another in their life-cycle. Nevertheless, the poor household finds it not only more difficult to enter into the lucrative asset, it finds it also harder to stay in the activity. Smoothing requirements mean that regularly cattle will have to be depleted to cope with income shortfalls. Especially if pressures exist to avoid very low consumption outcomes and with exogenous income, more than 40% of the households will find themselves without cattle in 3 or more years of their 10 years life-cycle, while only one-tenth of the richer households are in this position (Table 4). Introducing the possibility to enter in safe activities exacerbates this outcome further. Even though the safe activity implies the same percentage reduction in mean income for the rich or the poor, concave utility encourages the poor to take up this activity more regularly: only 1 in 10 'rich' households will choose to take up the safe activity during two or more years in their life-cycle, while this increases to more than two-thirds for the 'poor' households. This affects investment in cattle-rearing by the poor further: if minimum subsistence requirements are introduced, about 44% of the poor will find themselves without any cattle in three or more years.

Since richer households find it easier to invest in cattle and since poorer households enter more in the low return crop or activity, a divergence in total earnings follows. The initial income gap in year one was 15 $(50 - 35)$. With exogenous risky income, this gap in total income (inclusive of returns to assets) rises by 9% by year five. If the low risk crop is available, the increase in the gap is about 11% by year five. The lumpiness constraint and risk aversion imply that 'rich' households invest in high return assets which offer them also consumption security, while the 'poor' need to enter more in low return activities, resulting in gradual further divergence in incomes.

5. Empirical results

The main predictions of the model are that some households are able to enter into a high return asset which requires a substantial initial investment. Once they have entered into this activity they will obtain higher total earnings, partly due to the high returns from the asset on top of their initial income, but also since their reduced risk position through their assets allows them to enter in higher risk activities which also yield higher returns. Initial endowments, which determine the initial income position before they can accumulate assets, provide the main explanation for entry into assets: higher endowments provide higher incomes and allows the household to save relatively more so that the lumpiness constraint can be overcome. Nevertheless, as the simulations have shown, the relation between who can enter into the high return assets and initial endowments is not deterministic: risk in the underlying income process means that some households with a relatively high mean income process may not succeed in entering or keeping the high return assets and some households with a low mean income may be able to enter after all, and grow out of their poverty.

The latter characteristic of the model implies that an appropriate model should be probabilistic: household with higher mean income are more likely to enter into the high return asset than relatively poorer households. A probit-model will be used to express this entry constraint. Consider an underlying response variable c_i^* and define a dummy variable c_i which takes the value 1 if the household owns cattle and equals 0 if not. Let the relationship between this dummy variable and the underlying response variable be:

$$\begin{aligned} c_i^* &= \delta' Z_i + e_i \\ c_i &= 1 \qquad \text{if } c_i^* \geq 0 \\ c_i &= 0 \qquad \text{if } c_i^* < 0 \end{aligned} \tag{22}$$

In this equation, Z_i are the observable factors determining entry into cattle, such as endowments and household characteristics, while e_i is random. In the estimation a set of land and labour supply characteristics of each household were included to explain who owns cattle and who does not. In particular, variables included are: total farm size in hectares, the number of male adults, the number of female adults, the number of children between the age of 5 and 15. Squares of the adults variables and farm size were included to allow for further curvature in the effects. These household size characteristics will at the same time affect the possibility to save sufficiently above subsistence requirements. Other household characteristics included were the gender of the household head (one if male) and a series of educational variables of the head and adults in the households: the number of years of education of the head, interacted with the sex of the head and the average number of years of education of the male adults and the female adults in the household. [41]

Once a household has entered into cattle rearing, different income processes are obtained from higher returns to and a different allocation of endowments. Consequently, two different income equations need to be specified. Since the selection between the two groups is not random, the appropriate specification would be a

[41] In Section 2 it was argued that even though it was unlikely that a large number of households did enter into off-farm activities rather than into cattle-rearing following individual comparative advantage. However, for a small group this may have been the case. This might imply behavioural differences across households, three groups of households need to be considered initially and a test of whether the groups can be pooled ought to be conducted. However, the size of this additional group does not allow this. As an imperfect solution, the regressions were also run excluding this group of 10 households as a means of inspecting whether leaving this group out affects obviously the results.

sample selection model, otherwise the estimates are biased (Maddala, 1983). However, the same factors which allow households to enter into cattle-rearing—land and labour endowments—are likely to determine the total earnings of the household. Consequently, the coefficients in the sample selection model would only be identified by the assumed distribution of the error terms in both stages, which is not very satisfactory. Below, income equations with and without sample correction are briefly discussed, but given the sample selection and identification problems only limited weight can be attached to these results.

There are further problems related to the income equations. The income variable is almost certainly measured with substantial error. While this is generally a problem in most rural household surveys, the problems are compounded because one part of income, live sales of animals, most likely includes a part which is in fact a depletion of assets which should not be counted as income. Even though excluding this source of income still made cattle owners earn substantially more income than other households, this still poses econometric problems. Nevertheless, excluding this source of income from the analysis in the regressions did not substantially change the general pattern or the significance of the results. Secondly, income is a choice variable in the model and consequently, errors, to the extent that they reflect deviations from mean returns caused by risk, will not be identically distributed across households. This will cause inefficiencies in the estimation in the form of heteroscedasticity. As a tentative step towards solving this problem, White's (White, 1980) heteroscedasticity-consistent estimator of the variance was used to obtain the standard errors of the regressors. Income per adult was used as the left hand side variable as a proxy to express returns per income earner in each household, even though specifications using total household income or income per adult equivalent performed very similar in terms of the significance and interpretation of the results. The prediction is that both groups will behave differently and to check this a Chow-test on the equality of the coefficients is conducted.

Table 5 gives the results; the means of all variables are found in Tables 1–3. The entry equation performs reasonably well. Significant positive effects can be observed on farm size, the number of male adults in the household and the number of children between 5 and 15. The variables related to the gender and the age of the head, all the education variables and the number of female adults are not significant. Farm size squared and the number of male adults squared get negative effects, suggesting that the marginal increases in the probabilities to enter into cattle decline with higher farm sizes or a larger number of male adults. The results are consistent with the predictions: higher endowments, especially in terms of the male labour force and the acreage of land, give a higher probability to be able to enter into cattle. For example, relative to the mean household of the sample, an additional male adult will increase the probability to enter into cattle by 54.5%, an additional hectare of land by 41.4% and an additional child between 5 and 15 years 26.3%. The fact that a child contributes less than a male adult is consistent

Table 5
Probit model: Owning cattle (1) or not (0)

	Full data set (79 observations)		Excluding specific off-farm househods (69 households)	
	Coefficient	T-value	Coefficient	T-value
Constant	−4.17	(−3.34)***	−4.52	(−3.03)***
Farm size	0.85	(3.17)***	0.95	(2.96)***
Farm size^2	−0.05	(−2.90)***	−0.06	(−2.85)***
Male headed	−0.64	(−0.65)	−0.09	(−0.08)
Education male head	−0.10	(−0.64)	−0.14	(−0.74)
Education female head	−1.03	(−0.11)	−1.51	(−0.17)
No. of male adults	1.73	(2.20)**	1.49	(1.72)*
No. of male adults^2	−0.28	(−2.04)**	−0.27	(−1.77)*
Education of male adults	−0.09	(−0.60)	0.00	(0.00)
No. of female adults	0.14	(0.18)	−0.54	(−0.57)
No. of female adults^2	0.18	(0.96)	0.51	(1.61)
Education of female adults	0.01	(0.14)	0.03	(0.37)
No. children 5–15 years	0.26	(1.99)**	0.27	(2.01)**
Joint significance test				
Chi-squared (12)		53.91***		50.13***

* Significant at 0.1 (one-sided).
** Significant at 0.05 (one-sided).
*** Significant at 0.01 (one-sided).

with expectations about productivity. However, female adults seem not to increase significantly the probabilities to enter into cattle.[42]

Table 6 gives the results for the income equations, estimated separately for cattle-owners and non-owners. The same variables as in the probit equation were included; however, none of the female headed households who own cattle had any education so this variable had to be dropped for this equation. Overall significance is high for the equations for cattle-owners, but relatively low for the non-owners, with adjusted $R^{2'}$'s of 49 and 13% respectively. Farm size, the number of male adults, the number and education of female adults and the included squares are significant in both equations, although especially in the non-cattle owners equation several are only significant at 20%. The sex and the education of the head matter as well in the income per adult equations for cattle-owning households. A

[42] Estimates excluding those households involved in relatively high return off-farm households are also given in Table 5, but the results are barely different.

Table 6
Income per adult (in TSh) for cattle-owners and non-owners (OLS)

	Households owning cattle (39 observations)		Households not owning cattle (40 observations)	
	Coefficient	t-value	Coefficient	t-value
Constant	75,446	(1.88)*	49,715	(3.08)***
Farm size	21,886	(2.53)**	−1669	(−1.54)
Farm size^2	−1105	(−1.94)**	327	(1.41)
Male headed	−36,315	(−1.99)**	−3759	(−0.18)
Education male head	19,596	(3.62)***	916	(0.25)
Education female head	(no observations)		93	(−0.51)
No. of male adults	−27,895	(−1.89)*	−10,518	(−1.32)
No. of male adults^2	6640	(1.38)	2271	(1.75)*
Education of male adults	1695	(0.35)	−1875	(−0.67)
No. of female adults	−69,819	(−3.58)***	−31,168	(−2.57)***
No. of female adults^2	8158	(2.56)**	6387	(2.39)**
Education of female adults	6669	(1.39)	2211	(2.20)**
No. children 5–15 years	5265	(0.93)	1389	(0.61)
Adjusted R-squared		0.49	0.13	
Pooling-test two sub-samples: $F(67,12) = 4.78$ (rejected at 1%)				

Standard errors corrected for heteroscedasticity using White (1980).
* Significant at 0.1 (one-sided).
** Significant at 0.05 (one-sided).
*** Significant at 0.01 (one-sided).

Chow-test, testing whether the coefficients in each equation are different from the other equation, rejects pooling at 1% (F-test-statistic 4.78), supporting the approach taken. Estimates of the same model but with a sample selection term from the probit equation were found to be similar.

Given the sample selection and identification problems, further interpretation of these results can only be tentative. A one-year increase in the average level of education of the female adults increases incomes for both groups, but the effect is three times as large for the cattle-owning households. Similarly, the education of the head increases incomes per adult for the cattle-owning households, but not for the non-owning households. The quality of the labour force seems to be more rewarded at the margin for cattle-owning households. The estimates suggest further that for a household with mean characteristics, the marginal returns to male adult labour and to land are considerably larger for cattle-owning households than for non-owners. [43] This is consistent with the predictions that cattle owners can allocate labour and land to higher return activities, both because they could enter

[43] For male adults the marginal returns are TSh58,250 for cattle-owners and −3631 for non-owners, evaluated for the mean household. An additional hectare of land gives TSh40,772. for cattle-owners and only TSh3544 for non-owners. The same order of magnitude is obtained taking into account a sample correction term or by running the equations excluding specific off-farm households.

into cattle-rearing and because they can be less concerned with low risks in their activity mix.

6. Conclusions

This paper aimed to provide an explanation for the observed differences in economic welfare across a small random sample of rural households in Tanzania. It was found that richer households tend to specialize more in cattle rearing, while poorer households derive a larger share of their income from off-farm activities. The evidence suggests that differences in individual comparative advantage, based on individual productivity, do not offer a convincing explanation, especially since most households specializing in off-farm activities also have much lower incomes, while the households come from a traditional farming area, in which cattle have always had an important economic and social role. It is unlikely that productivity differences in cattle-rearing are sufficient to explain the entry into off-farm activities by the poorer households from a comparative advantage point of view.

Investment into cattle is likely to occur because it provides a relatively high return to the entrants, while it is also relatively liquid to use as a buffer for future contingencies and few alternatives exist. Despite being a relatively high return asset, only about half the sample was observed to own any cattle. The reason appears to be that investment into cattle is hindered by missing credit markets and indivisibility in the asset, which imply that households have to be able to put up relatively large amounts of money to invest into cattle rearing. The consequence is that households with relatively low endowments, resulting in relatively low total incomes may find it harder to invest into this high return activity, resulting into a widening of the income gap.

Since cattle is also a liquid buffer which provides insurance against income shortfalls, households not owning cattle may also have to resort to reduced income risk via entry in low return activities with little risk. Given its relatively low correlation with agricultural income, off-farm activities may be a useful option. An inspection of the type of off-farm activities performed by households suggests that most of them enter into activities which require relatively few skills or investment, which is consistent with this low-return/low-risk interpretation of the relatively high share of off-farm income for poorer households.

A theoretical model reflecting these salient features was developed. Simulations were used to illustrate how crop income risk and the lumpiness constraint may cause households with relatively lower mean incomes to become less likely to invest into the high return assets and more likely to enter safe activities than households with a higher underlying income process. If a household can enter, the return on the asset implies higher permanent incomes for this household than otherwise.

An empirical model was set up for a tentative test of this process. The factors determining entry and the effect of entry on the marginal returns to production factors were investigated in the sample. It was found that entry into cattle was mainly explained by the endowments in the form of male labour and land, consistent with the view that this reflects the income earning capacity of households. Identification problems hinder the estimation of the income equations, but the results are suggestive of the theory as well.

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Appendix A.

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Define the objective function linking t and $t+1$ as

$$\begin{aligned}\mathscr{L} = v(c_t) + \frac{1}{1+\delta} \cdot V_{t+1}(c_{t+1}) + \mu_t \cdot p_s \cdot Z_t + \eta_t \cdot \\ (L - L_{t1} - L_{t2} - L_{t3} - s(L_{tr}) - h(L_{thr})) + \rho_t \cdot p_c \cdot Y_t \\ + \phi_t \cdot Y_{tr} + \lambda_t \cdot L_{t1} + \sigma_t \cdot L_{t2} + \epsilon_t \cdot L_{t3} + \xi L_{tr} + \omega_t \cdot L_{thr}\end{aligned} \tag{I}$$

with:

$$\begin{aligned}C_T = p_c \cdot Y_{T-1} + p_s \cdot Z_{T-1} + r \cdot p_s \cdot Z_{T-1} + w \cdot L_{T1} \\ + p_2 \cdot X_T^2(L_{T2}, L_{Tr}, S, Y_{T-1} + m \cdot Y_{Tr}) - k \cdot Y_{Tr} - w \cdot L_{Tr} \\ + p_3 \cdot X_T^3(Y_{T-1}, L_3) + k \cdot Y_{T-1} - w \cdot L_{Thr}\end{aligned} \tag{II}$$

The (Kuhn–Tucker) first order conditions are:

$$\frac{\partial \mathscr{L}}{\partial c_t} = v'(c_t) - \frac{(1+r)}{(1+\delta)} \cdot EV'(c_{t+1}) - \mu_t \leq 0; c_t . \frac{\partial \mathscr{L}}{\partial c_t} = 0 \tag{III}$$

$$\frac{\partial \mathscr{L}}{\partial p_s \cdot Z_t} = -v'(c_t) + \frac{(1+r)}{(1+\delta)} \cdot EV'(c_{t+1}) + \mu_t \leq 0; Z_t \cdot \frac{\partial \mathscr{L}}{\partial Z_t} = 0 \tag{IV}$$

$$\frac{\partial \mathscr{L}}{\partial p_{\mathrm{c}} \cdot Y_t} = -v'(c_t) + \frac{1}{1+\delta} \cdot E\left[\left(1 + \frac{p_2 \cdot \dfrac{\partial X_{t+1}^2}{\partial Y_t} + p_3 \cdot \dfrac{\partial X_{t+1}^3}{\partial Y_t} + k}{p_{\mathrm{c}}}\right) \cdot V'(c_{t+1})\right] + \rho_t \leq 0; Y_t \cdot \frac{\partial \mathscr{L}}{\partial Y_t} = 0 \tag{V}$$

$$\frac{\partial \mathscr{L}}{\partial L_{t1}} = Ev'(c_t) \cdot w - \eta_t + \lambda_t \leq 0; L_{t1} \cdot \frac{\partial \mathscr{L}}{\partial L_{t1}} = 0 \tag{VI}$$

$$\frac{\partial \mathscr{L}}{\partial L_{t2}} = E\left[v'(c_t) \cdot \left(p_2 \cdot \frac{\partial X_t^2}{\partial L_{t2}}\right)\right] - \eta_t + \sigma_t \leq 0; L_{t3} \cdot \frac{\partial \mathscr{L}}{\partial L_{t2}} = 0 \tag{VII}$$

$$\frac{\partial \mathscr{L}}{\partial L_{t3}} = E\left[v'(c_t) \cdot \left(p_3 \cdot \frac{\partial X_t^3}{\partial L_{t3}}\right)\right] - \eta_t + \epsilon_t \leq 0; L_{t3} \cdot \frac{\partial \mathscr{L}}{\partial L_{t3}} = 0 \tag{VIII}$$

$$\frac{\partial \mathscr{L}}{\partial L_{\mathrm{tr}}} = E\left[v'(c_t) \cdot \left(p_2 \cdot \frac{\partial X_t^2}{\partial L_{\mathrm{tr}}} - w\right)\right] - \eta \cdot s'(L_{\mathrm{tr}}) + \xi_t \leq 0; L_{\mathrm{tr}} \cdot \frac{\partial \mathscr{L}}{\partial L_{\mathrm{tr}}} = 0 \tag{IX}$$

$$\frac{\partial \mathscr{L}}{\partial L_{\mathrm{thr}}} = E\left[v'(c_t) \cdot \left(p_3 \cdot \frac{\partial X_t^3}{\partial L_{\mathrm{thr}}} - w\right)\right] - \eta \cdot h'(L_{\mathrm{thr}}) + \omega_t \leq 0; L_{\mathrm{thr}} \cdot \frac{\partial \mathscr{L}}{\partial L_{\mathrm{thr}}} = 0 \tag{X}$$

$$\frac{\partial \mathscr{L}}{\partial Y_{\mathrm{tr}}} = E\left[v'(c_t) \cdot \left(p_3 \cdot \frac{\partial X_t^2}{\partial Y_{\mathrm{tr}}} - k\right)\right] + \phi_t \leq 0; Y_{\mathrm{tr}} \cdot \frac{\partial \mathscr{L}}{\partial Y_{\mathrm{tr}}} = 0 \tag{XI}$$

$$\frac{\partial \mathscr{L}}{\partial \mu_t} = p_{\mathrm{s}} \cdot Z_t; p_{\mathrm{s}} \cdot Z_t \cdot \mu_t = 0 \tag{XII}$$

Similar first order conditions to Eq. (XII) are defined for all the other non-negativity constraints on the choice variables.

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