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Exploiting the potential for expanding cropped area using animal traction in the smallholder sector in Mozambique

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Raimundo Matule

National Director

Directorate of Planning and International Cooperation

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EXECUTIVE SUMMARY

We use a combination of descriptive and econometric analysis of rural household animal traction use to assess the relative role of disease pressure as compared with other potential determinants of animal traction use. The focus on the potential of area expansion using animal traction rather than motorization is because draft animals appreciate while tractors depreciate over time. Second, the direct transition from hand-hoe to tractorization is usually not cost-effective (Pingali et al., 1987). The costs of destumping are much higher for tractor tillage because a much higher quality of destumping is required in order to minimize the damage to tractor-drawn implements. Third, maintenance costs are also lower for animal traction than tractorization, and farmers get the additional benefit of the production of manure if they choose to use animal traction (Pingali et al., 1987). Fourth, tractor mechanization is quite challenging in an environment of poor infrastructure such as Mozambique.

We combine data on rural household animal traction use in 2005 with spatial data on agro-ecological factors as well as data on trypanosomosis prevalence that was collected in various districts of several central and one northern (Zambézia) province to assess the relative roles of various potential constraints to adoption to explain observed adoption behavior in these areas. Tsetse flies are vectors of trypanosomes, a threat to animal health because animals suffering from trypanosomosis are weakened and therefore rarely used for draught power in agriculture. Low adoption of animal traction north of the Zambezi River is often attributed to tsetse flies (Bias and Donovan, 2003; Walker et al, 2004; World Bank, 2006; Mather, 2009). Such adoption would increase agricultural land and labor productivity and reduce poverty. The importance of animal traction adoption cannot be stressed enough: agricultural productivity in Mozambique is among the lowest worldwide; human population continues to grow and migrate to urban centers; the average cropped area per smallholder farmer has declined in the last decade; history teaches us that it is easier to move from manual agricultural to animal traction, rather than jumping into motorized agriculture; and even though it may take longer to create the tradition of rearing oxen than to teach smallholders to use a two-wheel tractor, the former appears to be more sustainable over time.

Our analysis of data from household surveys and trypanosomosis prevalence surveys finds that trypanosomosis pressure was a very large negative constraint to animal traction ownership from 2002 to 2005. Moreover, there could be also problems of pasture availability, smallholder motivation, and profitability issues. Assuming sufficient investment in support and access to technologies to control trypanosomosis and large livestock extension services, the large potential benefits to crop and household incomes from expansion of animal traction into northern regions could justify a program of cattle restocking that was observed before independence in 1975.

There has been no nation-wide testing of tsetse fly populations or trypanosomosis prevalence since 1995-2000, though more recent prevalence testing in some central districts in 2002-2005 found higher prevalence in those districts in 2002-2005 than in 1995-2000 period.

Specht (2008) suggests that this increase may be due to the phasing out of subsidies for large livestock vaccination between 2000 and 2005. However, no one knows what trypanosomosis prevalence might exist in the north at this point in time, and it is difficult to even theorize about it given that tsetse fly populations may have changed since 2000 due to continuing changes in land use (begun at the end of the civil war) and continued deforestation. The absence of widescale testing in Sofala and the north since 2000 implies that prior to consideration of programs to promote large livestock keeping and animal traction in those areas, there first must be new and extensive field surveys of trypanosomosis prevalence there to establish the extent to which trypanosomosis is still a serious constraint (or not) to large livestock keeping. This kind of widescale trypanosomosis prevalence testing is required because it is quite likely that unless farmers have not only extension education and perhaps subsidized access to livestock and also access to vaccination and dip tanks, the enormous investment made by the government and households in large livestock could vanish in a year if trypanosomosis is still present in the north. Because there are currently no large livestock in the north, this implies that a survey would require that livestock be brought to extension stations and monitored over time to test for trypanosomosis incidence.

While tsetse flies are clearly not the only constraint that has resulted in the near-complete absence of large livestock (and thus animal traction) in northern regions, Mozambique still lags behind other countries in the region in terms of animal health. Indeed, Mozambique was one of the latest to create the veterinary services in southern Africa in 1909 when its cattle were banned from entering in neighboring countries. It does not have enough dip tanks, and the coverage of yet compulsory vaccination misses at least one quarter of smallholder farmers' cattle. Veterinary services are poorly staffed. All these factors have a bearing on cattle ownership and adoption of animal traction.

Our results also show that the probability of cattle ownership is greater among smallholder farmers who are located in villages that border either Zimbabwe or Malawi because there is a longer tradition of animal traction use. We also find significant differences in animal traction adoption rates even between neighboring districts often sharing similar agro-ecological conditions. This merits additional studies that are more focused in exploring cultural barriers to technology adoption, which would require new data collection as this kind of analysis is not possible with the available data. We also note that the emphasis of animal traction projects in Mozambique has been on land preparation. Yet, this is a seasonal operation, suggesting that perhaps more emphasis should be placed on promotion of non-seasonal activities such as transportation. Such a study would compare districts in terms of their use of draft power for transportation purposes and other activities, such as pulling water from wells for irrigation in replacement of the treadle pumps. Cattle can also be used threshing, when the animals walk in circles over beans or cereals, separating the husks from the grains. Animal traction promotion projects should ideally include a package of all those activities. The fact that the people south of the Zambezi River are mainly Christians whereas people north of the Zambezi are mostly Muslims also deserves further investigation about the role of religion in shaping cattle ownership in the country.

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We also thank the 4,908 smallholder farm households and community leaders that participated in not just the TIA 2002 household and village surveys but also agreed to be re-interviewed in late 2005 (to respond to questions regarding the 2004/05 agricultural year). Without the time and care which they took in participating in this survey, the analysis in this and various other MASA/DPCI papers would not have been possible.

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ACRONYMS

APE	Average Partial Effect
CRE	Correlated Random Effects
GoM	Government of Mozambique
IIAM	Instituto de Investigação Agrária de Moçambique (National Agricultural Research Institute)
INE	Instituto Nacional de Estatística (National Statistics Institute)
MASA	Ministry of Agriculture and Food Security
MSU	Michigan State University
OLS-FE	Ordinary Least Squares, with household fixed effects
SIMA	Sistema de Informação de Mercados Agrícolas (Agricultural Market Price Information System)
TIA	Trabalho de Inquérito Agrícola (National Agricultural Household Survey)

1 INTRODUCTION

In Mozambique, agricultural productivity is extremely low. Yields of the main food crops are just 16-20% of their potential, and data on cultivated area per smallholder farmer show a negative trend in the last decade. At present only 2% of smallholder farmers use tractors and 8% use animal traction, and the average cropped area is just 1.5 hectares although the country is considered to be land-abundant. Mozambique ranks second to Sudan in Sub-Sahara Africa, and sixth worldwide in terms of the countries with the largest amount of suitable but uncultivated land (Deininger and Byerlee, 2012). There is ample potential for area expansion, and this could be accomplished through the use of either motorization or animal traction. This paper exploits the potential for expanding cropped area in the smallholder sector in Mozambique with an emphasis on animal traction. We define animal traction as the use of cattle to assist farmers in crop production operations such as plowing, planting, and weeding.

The transition from hand hoe to plow, whether animal-drawn or tractor-drawn was well-studied by Pingali et al. (1987). They reviewed several case studies in Sub-Saharan Africa and concluded that the substitution of mechanical tillage (motorization) for hand tillage generally has a minimal effect on yields, unless animal traction is used as an intermediate step.

Agricultural productivity growth for both land and labor are without doubt key to reducing poverty, raising the need for the adoption of productivity-enhancing technologies, such as animal traction. Animal traction can increase household crop production and incomes in several ways. First, using TIA02 data, Walker et al. (2004) find that the adoption of animal traction can generate income benefits via area expansion and/or production and sale of livestock products. Second, adoption of animal traction can spur agricultural intensification via its direct role in increasing land productivity, and its indirect role in facilitating production of key intensification crops and increasing labor productivity (Pingali et al., 1987; Savadogo et al., 1998).

Using panel household survey data from 2001/02 and 2004/05, Mather (2009) finds that use of animal traction increases total landholding of small and medium-holders by 13.8% in the central region and 18.5% in the south, and increases household crop income by 29% in the center (while controlling separately for total landholding). Using more recent panel smallholder household data from 2008 and 2011 (covering selected districts in central Mozambique), Mather et al (2015) find that the adoption of animal traction also has significant and positive productivity effects (while separately controlling for landholding), by increasing yields of common bean by 86% and cassava by 270%. In addition, Mather et al (ibid) find that smallholder application of manure has a large, significant, positive effect on yields of a number of crops in central Mozambique, and that manure use is almost exclusively limited to households that either own large livestock or live in a village with large livestock.

Despite its apparent economic benefits, there is limited smallholder use of animal traction in the southern and central regions of Mozambique, and virtually no use in northern regions. There is considerable regional differences in animal traction use in Mozambique, as about 40% of farmers in either Gaza or Inhambane (south of the Zambezi River) used animal traction in 2012, compared with 2% in Sofala, 12% in Tete and 20% in Manica (in the central zone, also south of the Zambezi), and less than 0.2% in Niassa, Cabo Delgado, Nampula and Zambézia (north of the Zambezi River). The near absence of large livestock (and thus animal traction) north of the Zambezi River is primarily attributed to tsetse fly infestation (RTTCP, 2000; Bias and Donovan, 2003; Walker et al, 2004; World Bank, 2006; Mather, 2009).

Tsetse flies are vectors of blood parasites of the genus *Trypanosoma* which cause trypanosomiasis (often called “sleeping sickness” in humans) and trypanosomosis (also known as Nagana) in animals. This disease causes anemia, production losses, abortion, and mortality in cattle herds, making trypanosomosis among the most important constraints on many agricultural activities in much of sub-Saharan Africa (Rogers et al., 1994; Pingali et al., 1987; Scoones, 2014). Mozambique, Malawi, Zambia and Zimbabwe belong to what is known as the ‘tsetse fly belt’ in southern Africa, covering an estimated area of 322,000 Km^2 (Robinson et al., 1997). Apart from mountain areas, Mozambique north of the Save River and small parts of the southern provinces of Inhambane, Gaza, and Maputo, the rest of Mozambique is considered to be infested by tsetse flies. However, the last nationwide survey work to measure trypanosomosis prevalence was done in 1995-2000 (RTTCP, 2000), thus precise knowledge of current prevalence by region is unknown.

While tsetse control received high priority in the 1980s and early 1990s, this period coincided with the demand by the World Bank and International Monetary Fund for structural adjustment programs throughout Africa, making it more and more difficult to justify the maintenance and expansion of tsetse control services in the face of pressure to privatize all services (Schofield and Maudlin, 2001). During the colonial period each province and sometimes district north of the Save River had a so called “Mission for the combat of the tsetse fly and trypanosomiasis (MCT)” and fly pickets were installed at strategic points. Since the independence in 1975, the use of pyrethroide insecticides has been the only method to treat cattle in areas with relatively high prevalence of trypanosomosis.

The new direction in development policy, following the implementation of structural adjustment programs in Africa, came at the cost of postponing efforts to address the tsetse fly problem (Scoones, 2014). Neither the current poverty reduction strategy plan, its predecessors, nor several other development programs contemplate measures to eradicate tsetse fly. In Africa, the literature on animal traction started to dry up in the late 1990s, and in Mozambique, both the government and researchers in general tacitly assumed that trypanosomosis pressure was a serious constraint that likely explained low to no adoption. That said, areas of neighboring Zambia have been successfully cleared of tsetse fly (Gowke), yet there have been no GoM or donor initiatives to assess the level of this constraint in Mozambique since 2000, and GoM subsidies for vaccination and other veterinary services were phased out in the mid-2000s

(Specht, 2008). However, trypanosomosis is likely only one of several factors that may explain the low levels of animal traction in southern and regional regions, and the virtual absence of it in northern Mozambique.

In this paper, we use a combination of descriptive and econometric analysis of rural household data to assess the relative role of disease pressure as compared with other potential determinants of animal traction ownership. There are several reasons why we focus on the potential of area expansion using animal traction rather than motorization; first, draft animals appreciate in value over time while tractors depreciate, and maintenance costs are lower for animal traction. Second, the direct transition from hand-hoe to tractorization is usually not cost-effective (Pingali et al., 1987). One reason for this is because the costs of destumping are much higher for tractor tillage because a much higher quality of destumping is required in order to minimize the damage to tractor-drawn implements. Third, animal traction provides farmers with the additional benefit of the production of manure that serves as organic fertilizer for crop, if they choose to use it (Pingali et al., 1987). Fourth, tractor mechanization is quite challenging in an environment of poor infrastructure such as Mozambique because maintenance costs are higher and fuel prices increase as we move to more remote areas.

We combine data on rural household animal traction use in 2005 with spatial data on agro-ecological factors as well as data on trypanosomosis prevalence that was collected in various districts of several central and one northern (Zambézia) province to assess the relative roles of various potential constraints to adoption to explain observed adoption behavior in these areas. The findings have important implications for government of Mozambique strategies for promoting greater smallholder access to large livestock and animal traction, area expansion, and agricultural growth. The remainder of the paper is structured as follows. Section two presents the data sources while section three presents the conceptual framework. Section four discusses empirical models. Section five discusses estimation issues while section six discusses presents descriptive results. Econometric results are presented and discussed in section seven. Section eight concludes with policy recommendations.

2 DATA SOURCES

2.1 Household and community-level survey data

This study uses a two-wave panel of rural household-level survey data known as the *Trabalho do Inquérito Agricola* (TIA) covering the 2001/02 and 2004/05 agricultural years. The sampling frame was derived from the Census of Agriculture and Livestock 2000, used a stratified, clustered sample design that is representative of small- and medium-scale farm households at the provincial and national levels. The sample was stratified by province (10 provinces) and agro-ecological zones, and included eighty of the country's 128 districts in 2005. A total of 4,908 small and medium-sized farms were interviewed in 559 communities (clusters), with recall questions covering the household's farm and non-farm activities during the 2001/02 agricultural year. A subsequent panel wave was conducted in 2005 (covering the 2004/05 agricultural year), that revisited the same TIA02 villages and attempted to re-interview as many TIA02 respondents as possible, though attrited households were replaced to retain a representative sample of the population for that survey year (TIA05).

The TIA 2002 and 2005 surveys were implemented by the Ministry of Agriculture in collaboration with the National Institute of Statistics (INE) and Michigan State University (MSU), between August and October (the end of the agricultural production year of 2001/02 and 2002/05) and both asked very similar recall questions concerning: the household's demographics, farm and non-farm activities, crop and livestock production, farm equipment owned/used and household assets (including livestock holdings and landholding and land tenure status), access to and use of agricultural inputs (among others) during the 2001/02 and 2004/05 agricultural years.

Given that over time, some households move away from a village and others dissolve as part of a typical household life-cycle, panel household surveys typically have to contend with at least some sample attrition over time. In the three-year TIA panel, n=804 households (17.3% between the two surveys, or 5.8% per year) out of the n=4908 TIA02 households were unable to be re-interviewed (Mather and Donovan 2007). Overall, the rate of attrition in this sample is relatively low, as compared to other African country surveys described in Alderman et al. (2001) and elsewhere (Chapoto 2006 for rural Zambia). In addition to the panel survey, we also used the TIA survey from other years to look at trends of various indicators.

TIA02 and TIA05 surveys both included a community questionnaire in addition to the TIA household survey instrument. From these community questionnaires, we use information related to community-level access to input and output markets, the month of the main season planting in a given year for maize, and the distance from the village to the nearest public transportation.

2.2 Data on trypanosomiasis incidence

The data on the prevalence of bovine trypanosomosis in central Mozambique come from a publication by Specht (2008). She obtained the parasitological prevalence of trypanosomes through the examination of a total of 16,895 blood smears, collected between 2002 and 2005 at 180 sites in 23 districts of Central Mozambique. Samples were taken from cattle at dip tanks and treatment crushes indicated by the veterinary services to determine the prevalence of blood and intestinal parasites. Priority was given to sample cattle of most of the smallholders present at the sampling sites.

Samples were collected from cattle of both smallholders and commercial farmers. The sample size was proportional to the total cattle population at a particular site, with a maximum of 72 cattle per site given the limits in the capacity of the laboratory staff to perform the in vivo examination for trypanosomes at the site. About 5-25% of the total cattle population in each site was sampled among smallholders, and 25-90% of the cattle population among commercial farms. About 75.6% of the total sample were collected from smallholder cattle.

The data were at the level of *posto administrativo*, which is the administrative level below the district. The data also included information about the *localidade*, but this proved more difficult to match with the TIA data. TIA data also contain information about the *posto administrativo*, and we used that to match the trypanosomosis data to the TIAs. Since the trypanosomosis data were collected between 2002 and 2005, and this period coincides with the TIA panel data, we decided to match this district-level trypanosomosis prevalence data with panel household-level TIA data from 2002 and 2005 on animal traction ownership.

A total of 1,023 households from TIA 2005 were matched with the trypanosomosis data (Table 1). About 66% of these were panel households interviewed in both 2002 and 2005. The trypanosomosis prevalence data covered a number of districts in both central and northern Mozambique. Survey areas north of the Zambezi River included the districts of Chinde, Maganja da Costa, Mocuba, Mopeia, Morrumbala, and Nicoadala (in Zambézia province); and Mutarara from Tete province. The trypanosomosis data south of the Zambezi River covered the districts of Changara and Magoe in Tete; Gondola, Guro, Machaze, Mossurize, and Sussundenga in Manica province; and Buzi and Nhamatanda districts, both in Sofala province. In total, 16 out of the 23 districts covered by the trypanosomosis survey were also covered by TIA2002-2005. Cahora Bassa and Machanga are examples of the districts where a corresponding *posto administrativo* could not be found in the TIA.

Table 1 Sample size of the TIA 2005 subset matched with trypanosomosis data

Province	State-owned	Smallholders	Commercial farmers	Total
Zambézia	0	9	187	196
Tete	58	273	0	331
Manica	0	319	98	417
Sofala	0	17	62	79
Total	58	618	347	1,023

Source: Authors' based on Specht (2008) and TIA 2005

2.3 Data on market prices, agro-ecological potential, and market access

In addition to data from the TIA partial panel household survey data, we also use monthly retail price data of most of the key food crops in rural Mozambique, collected from urban and rural markets across Mozambique by SIMA (Agricultural Markets Information System).

We also incorporate information from several geospatial datasets that were matched to TIA02 village spatial coordinates (collected in the TIA02 community survey[1]). For example, we use locally interpolated time-series data on rainfall from the University of East Anglia's CRU-TS 3.1 Climate Database (CRU 2011; Mitchell and Jones 2005). Information on the length of growing period (LGP) – one of several indicators of agro-ecological potential – comes from the GAEZ 3.0 database (Fischer et al. 2000), which is measured in terms of the number of days experiencing temperatures above 5°C when moisture conditions are adequate for plant growth. Elevation data were obtained from NASA's SRTM data (Rodriguez et al. 2005), which is also used to generate an estimate of slope. Chamberlin (2013) used various data sources within his own 'travel time' model to estimate "travel time to the nearest town of 30,000 residents or more".

2.4 Other data sources

Because cattle rearing in Mozambique tends to be confined to a few geographic areas, we decided to use data from the agricultural census of 1999/2000 and 2009/2010 due to its statistical representativeness at the district level[2]. We use Census data (known by its Portuguese acronym CAP, *Censo Agro-Pecuário*) to look at cattle herd size both at the district and provincial levels. The CAP of 2009/2010 covered all districts and *postos administrativos*, both rural and urban, including Maputo city. It had a total sample of 3,500 large and medium-sized farms and about 35 thousand smallholders. The CAP is a sample census, and sample weights were used for all statistics computed from this dataset that we present in this paper. The total population, after using sample weights, is roughly 3.8 million small, medium, and large-sized farms in 2009/2010. The survey comprised two different questionnaires, one being for smallholder farmers and the other for medium and large-sized farms.

We also used spatial data from Hansen et al. (2013) to estimate forest loss in Mozambique for the period of 2000-2012, a proxy for the potential loss of tsetse fly habitat. These data encode 10x10 degree tiles, which equals to about 30 square meters at the equator, but is a little different from that depending on that exact longitude. The data provide a forest cover on a scale from 0 to 100% in 2000, and another layer where pixels are valued "1" where forest loss occurred, whether due to deforestation or natural and other causes. Given lack of data on tsetse fly population in Mozambique, we are unable to directly analyze its trend.

We subjectively assess the hypothesis of a reduction in tsetse fly habit by looking at deforestation data in the last 10 years up to 2012, and assess whether there are regional

[1] More details about how the spatial data were merged into the household survey data can be found in Chamberlin (2013).

[2] The TIA and IAI rural household level survey data is representative at the provincial and national levels.

differences on the rate of deforestation. An increase in total deforestation suggests a reduction in the preferred habitat of the tsetse fly, and hence a reduction in the total tsetse fly population. We used QGIS with the GRASS plugin to generate the map of total deforestation (Figure 1). We simply counted the percentage of the 2000 forest in each district that was lost over the 2000-2012 period. Note that we are counting equally pixels that were 20% and 80% forest, so in some sense this could be seen as overweighting loss of less dense forests.

Selected administrative data on livestock restocking and *Arrolamento Pecuário* (the estimation of animal stocks at the district level) were used for the years that we do not have the more reliable TIA or CAP data, 1973-1998. Data for the *Arrolamento Pecuário* come from the National Veterinary Services within the Ministry of Agriculture, and the projected livestock population from these data may not be congruent to the TIA and CAP estimates.

Finally, we use IFPRI's HarvestChoice database on livestock to compare cattle densities between Mozambique and other Sub-Saharan Africa countries (HarvestChoice, 2015). The calculations of cattle densities are based on data from gridded livestock of the World 2007 by G.R.W. Wint and T.P. Robinson. Rome, Italy: Food and Agricultural Organization of the United Nations (FAO), 2007, p. 131.

3 CONCEPTUAL FRAMEWORK

We begin by using the agricultural household model approach of Singh, Squire, and Strauss (1986) and assume that a representative farm household in rural Mozambique maximizes utility within an environment characterized by imperfect markets (or market failure) for outputs (primarily food staples), inputs (improved seeds and fertilizers) and credit. We assume that because of these market imperfections, household consumption decisions are not separable from decisions concerning household production (i.e. household input use and expected crop output levels). Under these assumptions, the typical farm household maximizes expected utility by allocating its resource endowment (land, labor, capital) across farm and non-farm activities as a function of input and output prices, conditioned by household and village-level factors. The solution to this optimization problem yields a set of output supply and factor demand equations, each of which is a function of expected output prices, variable input prices, and quasi-fixed factors (household, community, and district-level characteristics).

One implication of our assumption of non-separability is that these output supply and input demand functions also depend upon characteristics of household consumption decisions, such as household wealth/income or demographic characteristics (de Janvry and Sadoulet 2006). Another implication of the non-separability assumption is that unlike in a standard (separable) producer model of crop output supply, the prices of 'all other goods' in the economy are relevant (because the farm household's consumption decisions affect its production decisions), thus the prices we include in an output supply or factor demand model (under the assumption of non-separability) are not simply the nominal prices of crop outputs and inputs. We address this by using a regional CPI to inflate prices (values) from the year 2001/02 to 2004/05 levels.

Given these assumptions, our factor demand models (for household animal traction ownership) as derived from the constrained utility maximization model can be expressed as follows, as described by Sadoulet and de Janvry (1995):

(1) $$Q = f(P_0, P_w, T, C, A, Z^p, Z^c)$$

where Q represents either an output or input level, P_0 is a vector of expected prices of crops (outputs), P_w is a vector of input prices, T represents the fixed transaction costs of accessing an output or input market, such as travel time to the nearest town or distance to the nearest fertilizer retailer, and C is a measure of credit access. A represents household fixed productive assets such as total landholding, and Z^prepresents other household characteristics related to production, while Z^crepresents household socio-demographic characteristics related to consumption decisions.

4 EMPIRICAL MODELS

4.1 Estimable Model

From the conceptual model above, we estimate a factor demand model of household animal traction ownership as follows:

(2) $$Q_{it} = \beta X_{it} + \varepsilon_{it}$$

(3) $$\varepsilon_{it} = c_i + \mu_{it}$$

Q_{it} refers to household ownership of animal traction, a binary indicator that =1 for households that own one or more cattle (indicated as used for animal traction) and one or more animal-drawn plows. The subscripts refer to household *i* (n=1 of 681) in year *t* (the 2001/02 and 2004/05 agricultural years). X_{it} is a vector of controls that are typically included in a model of factor demand, such as agro-ecological potential and seasonal rainfall, output and input prices, measures of the fixed costs of access to input and output markets, household productive and financial assets, and household consumption characteristics.

We note that for the factor demand regression of interest (animal traction ownership), we use *expected* rainfall given that actual seasonal rainfall is not known when farmers make their cropping and input decisions. Because the post-harvest prices for food and cash crops paid by private traders to smallholders in Mozambique are not known to farmers at the time that they make their decision to own animal traction or not, farmers must make this decision based on the crop output prices that they *expect* to receive at harvest. Thus, for all models, we use *expected* post-harvest output prices.

The error term ε_{it} in (3) is a function of two components. The first component c_i represents unobserved time-constant household-level factors such as soil quality, farm management skill, and/or risk preferences that may be correlated with observable household-level determinants of household commercial fertilizer demand. The second component μ_{it} represents unobserved time-varying shocks that may affect output supply or input demand, such as adverse climatic, pest or crop disease events, household-specific health shocks, among others.

4.2 Measures of time-constant agro-ecological potential and time-varying season-specific agro-ecological conditions

To control for spatial variation in agro-ecological potential (on average), we include a village-level measure of expected seasonal rainfall[3] during the main growing season (for maize). We also compute the coefficient of variation of expected seasonal rainfall as a measure of rainfall variability (risk).[4] We also include village-level information on elevation (meters above sea level), average slope (degrees), the length of growing period (days), and a binary indicator that =1 for villages with soils that are categorized as having moderate to severe problems with nutrient retention. Finally, to control for the average effect of unobserved factors over time, we include a binary indicator for the year represented by the second survey wave (2004/05).

Rainfall patterns and temperature will have an effect on pasture quality and availability. Since we do not have data on pasture quality that can be used in a regression model, in section 6.1 we use descriptive analysis to discuss the relationship between pasture quality in the country and large livestock ownership.

4.3 Factor prices

Animal traction ownership is in part a function of access to large livestock and the purchase price. As we do not have information on purchase prices for large livestock (of a sufficient age/health for animal traction use), we instead use two measures of ‘access to large livestock’ as

[3] We measure main season rainfall as the planting month and the three months following that month, as based on the community-level survey indication of when that maize was planted this year in that village. We then compute expected main season rainfall as a ten-year moving-average of that village-specific main season rainfall from the ten main seasons preceding that year.

[4] The rainfall variables are derived from rainfall estimates based on data from satellites (such as on cloud cover and cloud top temperatures) and rain stations, which are combined to interpolate estimates of decadal (10-day period) rainfall, which can be matched to sample households using global positioning system (GPS) coordinates collected from their village ‘center’.

a proxy for both the price and access. The first is the village aggregate number of large livestock, the second the natural log of district-level aggregate number of large livestock. We take the natural log of each variable due to the large positive skewness of each.

Because we do not have reliable village-level data on agricultural wages, and because the majority of labor used in smallholder crop production is family labor, we use the number of prime-age adults (ages 15 to 64) as a proxy for availability of family labor (along with its square).

Another important input related to animal traction ownership is access to vaccination services and/or a dip tank, both of which are means by which owners protect and/or treat livestock diseases spread by the tsetse fly (such as trypanosomiasis) and other vectors. Livestock owners indicate whether they have vaccinated their large livestock, but this measure would undoubtedly be endogenous to animal traction ownership. Therefore, we instead construct a binary indicator that =1 if the village has access to vaccination services. The community surveys indicate whether or not the village has a dip tank (another binary indicator).

4.4 Crop Output Prices

We assume that a farmer's expected crop price is based on information available to the farmer at or before planting, such as prices observed by the farmer in previous years. However, because our two waves of panel survey data are three years apart, farm-gate post-harvest crop price data for the panel villages in the years preceding each survey wave are not available. Fortunately, SIMA collects weekly prices of many of the food crops of interest to us from a number of urban and rural retail markets in the center and north of the country. For this application, we use prices for maize (grain), small groundnuts, and common beans.[5] For each of these crops (except cassava), and for each TIA05 district, we use SIMA weekly retail price data to compute an average retail price for the planting period of the 2004/05 main season (i.e. October to December) and the three quarters prior to that. The SIMA market(s) used as the reference price for a given TIA05 district is preferably a SIMA market(s) within that district, otherwise the one to two SIMA markets closest to that district, keeping in mind typical trade flows from production zones to demand centers within and outside of Mozambique. For more details on how we decided which SIMA markets to assign to a given district (by crops), and how we computed average quarterly prices, please see Appendix B-2 of Mather, Cunguara and Tschirley (2015).

Prices between the two panels were adjusted so as to inflate 2002 values to 2005 Meticais, based on rural price deflators constructed from available secondary data as described by Mather,

[5] Because the sample size of districts for which we have trypanosomosis incidence data is not large, we were only able to use a few expected crop prices due to high collinearity across prices given the limited spatial distribution.

Cunguara, and Boughton (2008). Mather, Cunguara, and Boughton (2008) contains details on adjustments made to respondents' declared area of each of the parcels they control.

4.5 Village-level measures of market access

The TIA02 community level survey obtained measures of community access to the nearest fertilizer retailer, measured as the distance from the village to the nearest retailers. The same information was recorded for the nearest seed retailer. Both the TIA02 and TIA05 surveys included information on the distance from the village to the nearest public transportation. Because of the obvious need of water for livestock, we also use community-level information to measure a household's physical access to water. These include a binary indicator that =1 if the household is in a village that has or is near a watering hole, another that =1 for households in a village that has or is near a river or lake.

Chamberlin and Jayne (2012) demonstrate that the optimal measure of 'market access' may vary by region and by crop. Therefore, we also include an alternative measure of market access, which is the travel time (hours) from the village to the nearest town of 30,000 residents or more. This variable was computed using a travel time model developed by Chamberlin (2013), using the following spatial data from Mozambique: the spatial coordinates of each panel village, a spatial map from 2002 of all roads (of any type), towns/cities as well as spatial topographical information on the land terrain between the village and the nearest road.

We also include binary indicators for village location, such as coastal/non-coastal village and whether the village borders another country. Smallholder farmers in Mozambique can benefit from border trade in maize and other crops with neighboring countries, resulting in higher incomes which in turn favor the adoption of animal traction (Walker et al., 2004). Since tsetse fly control efforts require coordinated efforts with large geographical coverage to eliminate all residual foci of infestation (Schofield and Maudlin, 2001), this makes the inclusion of binary indicators for village location important. Indeed, tsetse fly move seasonally from Chifunde and Maravia districts of the Tete province in Mozambique to enter the Katete district of Zambia (van den Bossche, 2001). Despite the use of insecticide treatment, Mudzi district in Zimbabwe was unable to prevent substantial re-invasion of tsetse flies from Changara district in Mozambique (Hargrove et al., 2003).

4.6 Household production, marketing and financial assets

To control for inter-household variation in assets related to crop production, we include various measures of household ownership (or control) of production assets. For example, we include the household's total landholding as a measure of land access. We also include a measure of the household's medium-and-small-scale tropical livestock units[6] (TLU) as a measure of wealth, which also serves as a proxy for either credit access or the ability to self-finance inputs that require cash (such as inorganic fertilizer, improved seeds, hired labor, etc).

We include head's years of education as a measure of human capital, while head's age is included as a proxy for lifecycle wealth effects, though it may also measure human capital in terms of years of farming and marketing experience.

4.7 Household consumption characteristics

Because of our assumption that household production and consumption decisions are not made separately in rural Mozambique (Section 3), we include three variables that serve as a measure of the consumption needs of different kinds of household members that are assumed to be 'dependents': children age 0-4, children age 5-14, and adults 65 or older.

5 ESTIMATION ISSUES

5.1 Modeling the binary dependent variable

Binary dependent variables are typically modeled using one of three estimators: the Linear Probability Model (LPM), probit or logit. We use the LPM approach for several reasons. First, there are two endogenous variables in our model of animal traction ownership – total landholding and 1=village has access to vaccination for large livestock. Unfortunately, the control function approach to handling one or more instrumental variables does not produce appropriate standard errors if the binary endogenous variable (i.e. the second one above) is in fact endogenous. While a Stata user has written a special estimator to compute viable standard errors for a probit that has a binary endogenous variable, this estimator does not allow sampling weights – which in this case is a serious problem because many animal traction owners are medium-scaled households, and their sampling weights are much smaller than those of smallholder households.

We therefore use the LPM approach (OLS) as it enables us to include both a continuous and a binary regressor and apply sampling weights. Although LPM is known to have heteroskedastic standard errors, we correct for this using the robust option in Stata.

[6] TLU=0.4*pigs+0.2*(goats+sheep)+0.02*chickens+0.06*ducks/geese/turkeys+0.04*rabbits (FAO, 2007).

5.2 Controlling for unobserved time-constant heterogeneity c_i

If unobservable time-constant characteristics such as soil quality, farm management ability, or risk preferences are correlated with observable determinants of a household's decision regarding animal traction ownership, such as total land area owned, village access to vaccination services, or household wealth level, this can lead to biased coefficient estimates (i.e. termed omitted variable bias by Wooldridge (2002)). The household data set used in this paper is longitudinal, which offers the analytical advantage of enabling us to control for time-constant unobservable household characteristics (c_i). With OLS, the fixed effect (FE) estimator is usually the most practical way to control for these unobserved time-constant household characteristics, since using FE requires no assumption regarding the correlation between observable determinants (vector X_{it}) and unobservable heterogeneity (c_i).

However, because some of our key regressors of interest either do not vary over time or vary only slightly, use of OLS-FE would effectively drop these variables from the model. We therefore use the next best alternative, which is pooled OLS with a version of Correlated Random Effects (Mundlak 1978; Chamberlain 1984), which explicitly accounts for unobserved heterogeneity and its correlation with observables, while yielding a fixed-effects-like interpretation. In contrast to traditional random effects, the CRE estimator allows for correlation between unobserved heterogeneity (c_i) and the vector of explanatory variables across all time periods (X_{it}) by assuming that the correlation takes the form of: $c_i = \tau + \alpha\overline{X_i} + a_i$ where $\overline{X_i}$ is the time-average of X_{it}, with t = 1, ..., T; τ is a constant, and a_i is the error term with a normal distribution, $a_i|X_i \sim Normal(0, \sigma^2 a)$. We estimate a reduced form of the model in which τ is absorbed into the intercept term and $\overline{X_i}$ are added to the set of explanatory variables.

5.3 Controlling for Unobserved Shocks μ_{it}

While the OLS-CRE approach outlined above controls for time-constant unobserved household heterogeneity (c_i), our estimate of the partial effects of regressors on the household decision to own animal traction may still be subject to another source of endogeneity bias. This could occur if unobserved time-varying shocks μ_{it} are correlated with explanatory variables X_{it} of interest in (2). Such unobserved time-varying shocks could include adverse climatic, pest or crop disease events, household-specific health shocks, etc.

However, we do have some observed factors that may help to control for such unobserved time-varying shocks. For example, we include in each model a year dummy that =1 for the second year of the panel wave, and this will pick up the average effect of all unobserved factors (across the whole sample). More importantly, our production and yield models already include both the actual seasonal rainfall plus a community-level measure of the coefficient of variation of expected seasonal rainfall, a measure of expected seasonal rainfall variability. Nevertheless, given the likelihood of correlation between unobservable factors and household landholding and village vaccination access, especially within a regression explaining animal traction ownership, and/or potential simultaneity bias, we use 2SLS to test and correct for potential endogeneity of household landholding and village vaccination access.

Our instrumental variable for landholding is a community-level variable that =1 if the community leader respondent indicated that "additional land is readily available in the village". This variable does have a significant positive effect in the first-stage regression of total landholding. Second, *a priori* we would not expect that land availability would necessarily have a positive or negative effect on animal traction ownership given the context of rural Mozambique, in which population density is quite low in all but about 10% of districts (Mather, Benfica and Pitoro, 2013) – that is, farm sizes in rural Mozambique are not becoming quite small as in higher population density countries like Kenya and Ethiopia. In addition, while animal traction is a means by which a farmer may expand their area cultivated, it also can have positive productivity effects on crop production (via improved soil aeration, better weed control, etc).

Our instrumental variable for 1=village has access to vaccination services is 1=village has a dip tank. While presence of a dip tank has a strong positive effect on village access to vaccination services, there is no reason to expect that presence of a dip tank would necessarily lead to animal traction ownership. The reason is because many livestock owners in rural Mozambique focus on livestock production and not crop production, and thus they do not own animal traction.

5.4 Panel Attrition

For our econometric work, we only use TIA02 households (from specific districts in the North and Center where we also have data on trypanosomiasis incidence) that were interviewed in 2002 and re-interviewed 2005. Panel household surveys typically have to contend with at least some sample attrition over time, given that some households move away from a village over time and others dissolve as part of a typical household life-cycle. If households that are not re-interviewed are a non-random sub-sample of the population, then using the re-interviewed households to estimate the means or partial effects of variables during one of the later panel time periods may result in biased estimates.

To test for attrition bias, we follow the regression-based approach described in Wooldridge (2002) and define an attrition indicator variable that is equal to one if the household dropped out of the sample in the next wave of the panel survey, and equal to zero otherwise. This binary variable is then included as an additional explanatory variable in each regression model for each crop, which is run using all household observations from 2007/08 (in panel villages only). If the coefficient on this binary variable is statistically different from zero, this indicates the presence of attrition bias with respect to that model.

We applied this regression-based attrition test to each output supply and input demand model to explicitly test for evidence of attrition bias and report the findings in Appendix Tables A-1 and A-2. Where we find evidence of attrition bias, we use Mather and Donovan's (2007) attrition correction for the TIA panel income dataset sampling weights via the Inverse Probability Weighting (IPW) method (Wooldridge 2002). However, we report results using unadjusted sampling weights as the use of attrition-corrected weights does not change the key results.

6 DESCRIPTIVE ANALYSIS

6.1 Pasture quality and availability

Three types of natural pasture occur in Mozambique: sweet, mixed, and sour grasses (Timberlake and Dionísio, 1984). Their main difference is that "sweet" grasses, which when dominant result in "sweetveld", hold their crude protein values after flowering, so can remain palatable into the dry season. "Sour" grasses or sourveld rapidly lose their crude protein values after flowering, so are only palatable to cattle for a relatively short period. Sourveld cannot sustain livestock production through the dry season or year-round, while sweetveld can.

Pasture quality, like some other plant attributes, is driven by plant physiology. Here we look at the mechanism by which the plant carries out photosynthesis: either via C3 or C4 pathways. The distribution of C3 and C4 vegetation is influenced by light intensity and temperature, but mainly rainfall (Swap et al., 2004; Castañeda et al., 2009). Using data from southern Africa, Swap et al. (2004) found a pronounced (over 50% of the variance explained) inverse relationship between mean annual rainfall and the abundance of C3 vegetation. They also argue that such relationship between rainfall and C3 vegetation appears to be valid across country regions of large differences in soil and rainfall characteristics.

Given the strong gradients in climate and vegetation across Mozambique, the abundance of C3 and C4 grasses will vary by region, too. This in turn will have important implications on pasture quality and availability. While C3 and C4 plants can grow together in the same areas, for a given region and vegetation type one photosynthetic pathway are often more abundant than the other. C3 grasses tend to occur in arid climates (lower rainfall) such as in southern Mozambique or in a few pockets in the central province of Tete. Much of the natural pasture is considered to be of good quality, called sweetveld. Feed quality is often higher in C3 grasses because the plant is less fibrous and contains less lignin, making them more digestible. Moreover, C3 grasses grow during both the cool and the warm seasons, thus extending feed availability especially when the animals need the most during the beginning of the cropping season. Nevertheless, not all C3 grasses are sweet and not all C4 grasses sour.

Higher rainfall levels make C4 grasses more common in the northern provinces (Castañeda et al., 2009; Mercader et al., 2010). C4 grasses tend to generate more bulk than C3 grasses because they regrow faster following grazing. Indeed, Timberlake and Reddy (1986) estimate the potential pasture dry-matter production over Mozambique and find higher values north of the Zambezi River, a region that receives more precipitation and is dominated by C4 grasses. C4 grasses grow during the warm season, which coincides with the critical period for plowing.

Moreover, as the vegetation become drier right before the period of land preparation, C4 grasses tend to be the plants that are burned off the most by uncontrolled fires set by smallholder farmers, a practice that is still quite common in Mozambique. A dense stand of C4 grasses is believed to catch fire more easily than C3 grasses. Therefore, when the animals are needed the most for land clearing and plowing, animal feed may not be as available in the north either because C4 plants tend to grow during the warm season or because they are burned off due to uncontrolled fires. When they are indeed available, they may not be as accessible (digestible) because C4 plants are more fibrous and have more lignin, and hence are less digestible. Timberlake and Dionísio (1984) classify the natural pasture in the north as sourveld.

Since in Mozambique cattle are almost exclusively fed on natural pastures, the southern provinces and the central province of Tete currently hold the highest potential for cattle rearing, judging by pasture quality and availability. Availability of animal feed of good quality in sufficient quantities yearlong is a precondition for good animal health, unless they can get access to supplementary feed, and animal health is a key determinant of adoption of animal traction. Thus, availability of sweetveld as compared with sourveld grasses could theoretically be a very significant constraint for livestock production in some areas of Mozambique. Thus, prior to the implementation of any interventions aimed at promoting large livestock and animal traction in the north, the GoM needs to first assess the extent to which sweetveld grasses are either currently available in northern provinces and/or it is feasible to introduce them to northern regions for use as natural pasture. For example, developing cattle production in less suitable areas is extremely difficult unless and until a system with additional inputs (as with cattle-under-coconuts as practiced by Madal around Quelimane) relying more on cultivated pastures becomes commercially viable.

6.2 Disease pressure

6.2.1 Trypanosomosis prevalence

As noted in the introduction, trypanosomosis is a debilitating disease for large livestock that is spread by tsetse flies. Apart from fatality, trypanosomosis can severely weaken infected cattle, thus such cattle cannot be used for draught power in agriculture. The near-complete absence adoption of animal traction north of the Zambezi River is often attributed to trypanosomosis (Bias and Donovan, 2003; Walker et al, 2004; World Bank, 2006; Mather, 2009). Unfortunately, the last nation-wide field survey work in Mozambique that used blood samples to estimate the prevalence of trypanosomosis was completed in 1995-2000 (RCCTP). At that time, trypanosomosis was found in every region of Mozambique. However, we do not know what tsetse populations are like in the north at the present, nor what potential trypanosomosis incidence might be if larger numbers of cattle were raised in the north.

Since the RCCTP survey from 1995-2000, the only blood-testing-based estimates of trypanosomiasis prevalence of which we are aware is that of Specht (2008), who took samples from large livestock in various districts of Tete, Manica, Sofala and Zambézia between 2003-2005 (mostly south of the Zambezi River). She found that trypanosomosis prevalence rates in those districts ranged from 10-40% (Specht, 2008) in those years, and she notes that these prevalence rates were higher than those found in the same districts by RCCTP (2000) in 1997-2000. While neither RCCTP (2000) nor Specht (2008) have sufficient data to investigate the causal determinants of trypanosomosis incidence, Specht argues that the increase in trypanosomiasis prevalence rates (between 2000 and 2005) in the districts that she sampled was likely due to the removal in the early 2000s of government subsidies for large livestock vaccination.

6.2.2 Animal health in general

While low adoption rates of animal traction are usually associated with widespread occurrence of tsetse flies, there are many other debilitating livestock diseases other than trypanosomosis. In smallholder cattle, gastrointestinal parasitosis and tick-borne diseases (theileriosis, babesiosis, anaplasmosis and heartwater) are the most common debilitating diseases. Dermatophilosis, blackleg and anthrax, bovine brucellosis and tuberculosis, lumpy skin disease and foot-and-mouth disease can also occur. The circulation of the Rift Valley Fever Virus in animals tested in Zambézia, Sofala and Manica also gives reason to worry.

Prevention of many of these diseases could be met through compulsory vaccinations. That is the case with foot-and-mouth disease, blackleg, and anthrax. Vaccination occurs yearly at dip tanks or treatment corridors, although it would be more effective to vaccinate twice a year for some of the diseases. In the case of foot-and-mouth disease, vaccination could be administered twice a year when there is increased movement of animals in search of water, usually in April-May and August-September. An effective treatment against trypanosomosis requires the animal to be treated at least three times and preferably four times in heavily infested areas, and this should include vaccination at least against rinderpest and contagious bovine pleuropneumonia (Barrett et al., 1982).

However, vaccines are often in short supply and when available, they often reach the target population too late to prevent diseases (Specht, 2008). Effective control of livestock diseases also requires knowledge of disease management which is rarely found among smallholders. The veterinary services in Mozambique are stretched to their limit, poorly staffed and equipped. In 2013 only 47.3% of a total of 706 dip tanks were operational. The number of operational dip tanks nowadays is smaller than 53 years ago when there were 270 private and 153 state-owned dip tanks in the country (Mendes, 1974). In 1970 only 2.6% of the total dip tanks were located in Niassa and Cabo Delgado. Dip tanks were either privatized or handed over to associations in early 2000s and veterinary drugs were only available in very small amounts and only at the full commercial price, as the GoM phased out vaccination subsidies during this time period (Specht, 2008). This led to a near collapse of the health services at the dip-tank level and to an alarming increase of tick-borne diseases, trypanosomosis and gastrointestinal parasitosis, according to data from the Regional Veterinary Laboratory in Chimoio, 2002 - 2007.

Livestock policy changed again in the last few years and government veterinary services began to once more provide financial support for retook the responsibility for dip tanks and other animal health services such as vaccinations. As a result, the proportion of smallholder farmers whose cattle were vaccinated has increased from 61.7% in 2005 to 71.3% in 2012, according to TIA data. Nevertheless, the proportion of smallholder farmers who vaccinate their cattle still falls a bit short considering that the existing compulsory vaccination program is unable to reach about one-third of cattle owners in the country.

The effective delivery of veterinary services, which are still (primarily) offered by the public-sector, is inhibited by insufficient government spending in this area. Further constraints include the lack of trained veterinary staff and poor implementation capacity. Veterinarians in Mozambique work primarily work for the national and provincial veterinary services, in research institutions and agricultural education institutions, and only a few of the national/provincial veterinary services are actually working in rural communities (Specht and Quembo, 2009). Fieldwork is mainly carried out by the district veterinary personnel, mainly low-skilled technicians of animal husbandry, and they work together with a reduced number of dip attendants and community animal health workers (Specht and Quembo, 2009).

The occurrence of some of the major cattle diseases in Mozambique is greatly underestimated through the lack of surveillance and laboratory testing capacities, but the existing data show that the distribution of cattle diseases in Mozambique varies by location. For example, foot-and-mouth disease is endemic in Magude, Moamba, Manhiça, Chibuto, Massangir, Caia, and the boundary of the Kruger Game Park (African Development Fund, 1995). In these places there is a lot of cattle movement. Heartwater is more common in the south and is seldom found in the northern provinces. Trypanosomosis and lumpy skin disease and are more common where there is more rainfall, that is, central and northern provinces.

Given that the conventional explanation of lack of adoption of animal traction in the north is attributed to tsetse flies, we next look more closely at trypanosomosis and methods used to eradicate and/or limit the potential damage from this disease. While there are many methods of tsetse fly control, we do not cover biological methods as they are rarely used in Mozambique. Instead, we focus on chemical and environmental measures of tsetse fly control. In fact, there are no control measures in Mozambique other than the use of insecticides in the treatment of cattle, but we believe that reviewing experiences from other countries is still relevant for the Mozambican agricultural sector. For example, purposely clearing vegetation as a means to combat tsetse flies can lead to reductions in tsetse populations, as may also occur due to deforestation.

6.2.3 Environmental measures of trypanosomosis control

The literature identifies three main environmental measures that were common in the 20th century in Africa and Latin America in tsetse fly control. The first measure pertains to game control, motivated by the desire to reduce the number of vectors in which tsetse flies can feed on. In Botswana, the control of tsetse flies has been related to the eradication of wildlife between 1930 and 1970. Game control was also commonly used in Zimbabwe and Mozambique in the first half of the 20th century (Bolaane, 2008; Dias and Rosinha, 1971). This method is unacceptable nowadays on environmental grounds, and is not as effective as previously thought given that game destruction could lead to an intensification of trypanosomosis prevalence in cattle because of a lack of alternative hosts. In fact, game control began to be replaced by other methods of fly control in the second half of the 20th century.

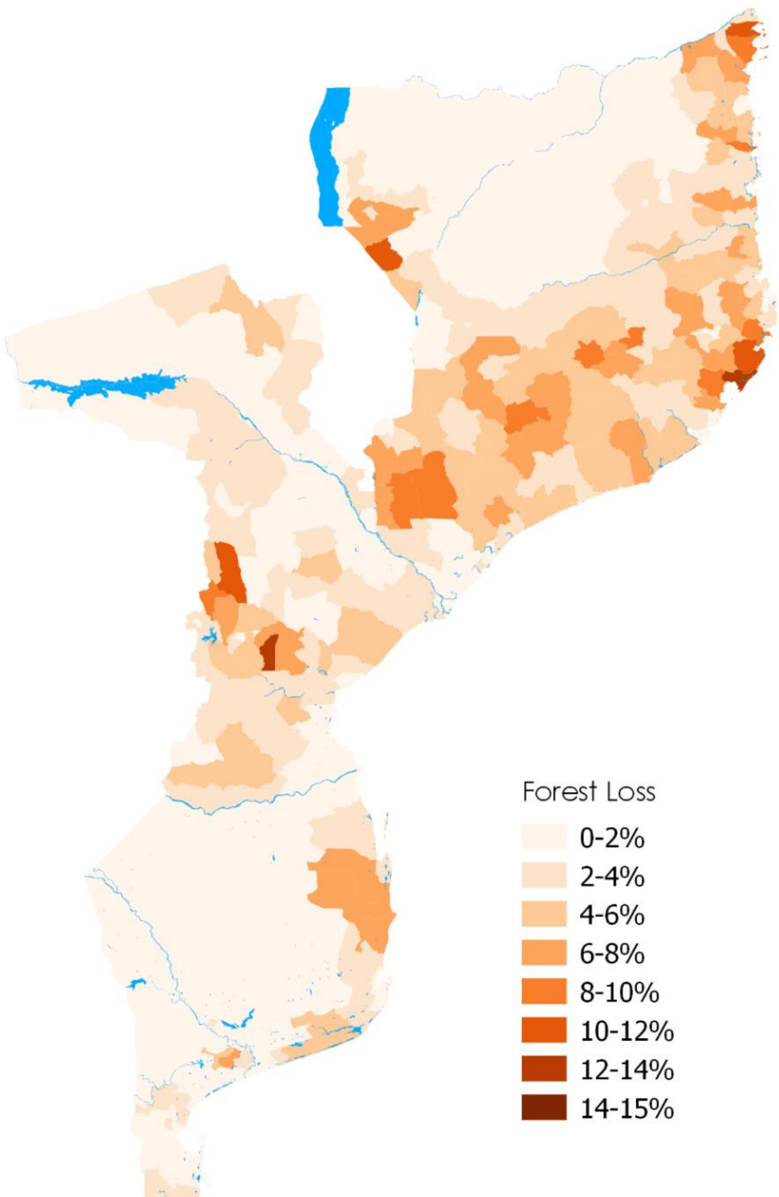
While there is no record of game control in Mozambique being used to control tsetse flies, one comparable event is the lack of animal stocks due to civil war that ended in 1992, which resulted in the decimation of all livestock (including wild animals), thus reducing the pool of potential animal hosts for the existing tsetse population.

The second measure involves clearing the types of vegetation where the fly prefers to rest, using either bushfires or manual/mechanized equipment. Vegetation clearing as a means to control tsetse was common to Ghana, Sudan, Nigeria, Kenya, South Africa, Zimbabwe, Uganda, just to name a few. Such clearings were made across the riverine vegetation for the purpose of isolation, dispersal or barriers, and they could be continuous for several kilometers (Hocking et al., 1963). One of the drawbacks of this measure is that vegetation clearings at such scale are expensive to both implement and maintain.

In the Okavango Delta in southern Africa, bushfires were used to clear the vegetation and therefore reduce the tsetse fly habitat (Bolaane, 2008). Bushfires make the area drier and less suitable for the tsetse fly (Pollock, 1982), but they can also encourage vigorous grass growth. Bushfires are also widely used in Mozambique for land clearing. While the use of fire can be effective in destroying the natural habitat for adult flies -- by burning the essential shade trees for tsetse flies and creating barriers across which they are temporarily incapable of migrating -- it does not destroy the tsetse pupae buried under the ground, stones, and logs. In general, more than half of the total population of tsetse in an area is below ground as pupae at a given point in time (Pollock, 1982). Therefore, while vegetation clearing (with the use of bushfires) can reduce tsetse populations, it is not sufficient by itself to eradicate them.

Again, there is no evidence in Mozambique of vegetation clearing being used as a method of tsetse fly control, but a comparable scenario exists. While land is not being cleared with the explicit purpose of fly control, massive deforestation due to increased timber extraction, slash and burn agriculture, and charcoal production may have significantly changed the tsetse population, particularly in Zambézia and Nampula provinces, and parts of Cabo Delgado – all three provinces are located north of the Zambezi River (Figure 1).

Figure 1 Total deforestation (hectares) between 2000 and 2012 in Mozambique[7]



The third measure involves improvements to rural housing. In Latin America, trypanosomosis control included replacing thatched roofs with tiles or corrugated sheets, and plastering the cracked mud walls where the bugs rest during the day (Schofield and Maudlin, 2001). Housing conditions have improved to some extent in rural Mozambique, with the likely positive side-effect of improved tsetse control. For example, between 1996/97 and 2002/03 the percentage of

[7] The map was thankfully created by Andrew Hobbs.

households whose houses had thatched roofs decreased from 84% to 75% (DNEAP, 2004). In the subsequent period up to 2008/09 the percentage of households with durable roofing increased from 25.8% to 30.2%. However, in rural areas in the central and northern provinces only 10% of households or less had durable roofs (DNEAP, 2010).

6.2.4 Chemical measures of trypanosomosis control

There are various types of chemical control of tsetse fly, including: (i) spraying the lower part of trees that are the favored resting sites; (ii) large aerial spraying, but this is usually criticized for the effects on non-target organisms and huge labor requirements (Scoones, 2014); (iii) and the development of odor-baited traps and targets impregnated with insecticides. Unlike many other insects (such as mosquitoes), tsetse flies tend to have lower population variability, and are slow reproducers adapted for efficient exploitation of stable habitats. These are desired features for chemical control because low gene variation within a species means that the probability that insecticide resistance will develop is low. For example, Maudlin et al (1981) show that the odds of a tsetse population surviving attacks with insecticides repeated at short intervals is very small.

Another form of chemical control of trypanosomosis involves the injection of a trypanocide into cattle, a drug that can provide both prevention and treatment of the disease. In southern and central regions where large livestock are raised, trypanosomosis is usually controlled by the use of prophylactic and curative trypanocide, often in combination to avoid the creation of resistance. However, in the northern province of Zambézia, there have been recent reports of trypanocide resistance due to chemical application that was carried out without enough repetitions within a given period of time. Drug resistance can also be caused by from mass treatment conducted regularly with only two drugs (diminazene and isometamidium, the most commonly used) and the introduction of a third drug that does not combine well with the others (Jamal et al., 2005). In other words, improper handling and application of trypanocide and lack of technical knowledge in Mozambique has apparently resulted in the development of resistance to trypanocides in some areas of Zambezia, which is quite rare in tsetse fly control. This example highlights the fact that while trypanocides can be highly effective in controlling trypanosomosis (as in the southern and central zones where cattle holding has been observed consistently between TIA 2002 and IAI 2012, and where vaccination rates are very high), these drugs only remain effective in the longer-term if used properly so as to minimize the potential that trypanosome parasites develop resistance to them.

6.3 Cattle ownership and access to veterinary services

We focus on the use of cattle for animal traction because neither TIA nor CAP has data on buffalo ownership, let alone camels and horses which are rarely found in Mozambique.

Nationwide, about 6.2% of small and medium-sized farmers owned cattle in 2012, and less than a percent owned donkeys (Table 2). Moreover, the proportion of smallholders who own donkeys has declined by half between 2002 and 2012. In contrast, the proportion of those who own cattle has been slowly increasing. Starting from a very small base, the rate of increase in the number of smallholders who own cattle is highest in the north, quintupling the number of smallholders rearing cattle in just 10 years. Another reason to focus on cattle is herd size, which is substantially larger for cattle than for donkeys.

Table 2 Percentage of households who own cattle and donkeys by year and region

Region/ year	North (%)		Center (%)		South (%)		Total (%)	
	Cattle	Donkeys	Cattle	Donkeys	Cattle	Donkeys	Cattle	Donkeys
2002	0.3	0.1	8.9	0.6	11.8	1.1	4.1	0.4
2005	0.2	0.0	12.3	0.3	16.1	1.2	5.6	0.3
2006	0.6	0.1	11.4	0.8	16.1	1.8	5.6	0.5
2007	0.6	0.0	11.4	0.9	17.1	1.8	5.9	0.5
2008	1.0	0.0	12.8	0.7	17.1	1.1	6.6	0.4
2012	1.2	0.0	11.7	0.2	14.4	0.9	6.2	0.2

Source: National Agricultural Surveys TIA 2002, 2003, 2005, 2006, 2007, 2008, 2012

It is clear from TIA02 that between 5% and 18% of households in every region (but Sofala) in the south and center owned large livestock, while in Sofala and the northern regions there is virtually no large livestock owned by small or medium holder households (Table 3). This pattern remains relatively similar among smallholder farmers in TIA05 panel villages (Table 4). It is therefore not surprising that we find almost no animal traction in the north given that a much lower proportion of smallholder farmers in the north own cattle.

In spite of reasonably high trypanosomosis prevalence, households in many regions in south and central Mozambique own large livestock. One obvious explanation for this is that there are technologies that households can use to help prevent their livestock from acquiring trypanosomosis, such as trypanocides and dip tank treatments (that help prevent insect bites for the dipped animals for a period of time), assuming households have access to those technologies. In fact, TIA data from both 2002 and 2005 clearly show that most households who own large livestock vaccinated[8] their livestock in that TIA year (Tables 3 & 4) and also live in villages that are more likely to have a dip tank than the average household from the sample. In addition, it appears that nearly all of the few households in the north who own large livestock live in a village with a dip tank. Finally, it is clear that the areas with very few dip tanks (Sofala and the

[8] While the TIA survey instrument does not ask what the vaccination is for, it is likely to include trypanocides as this is used to prevent and/or treat trypanosomosis.

northern provinces) are areas with virtually no large livestock ownership among small or medium holders.

Table 3 Cattle ownership and access to treatment services by province in 2002 (%)

Province	% of HH that own cattle	% HH in village w/ vaccination	% HH in village w/ dip tank	% of cattle owners that		
				Live in village with dip tank	Vaccinated cattle	Received visit from vet
Niassa	0.0	0.0	0.0	na	na	na
C. Delgado	0.0	5.7	2.1	45.3	100.0	100.0
Nampula	0.6	6.2	2.8	2.1	65.8	65.8
Zambézia	0.1	1.5	3.8	86.3	86.3	86.3
Tete	14.3	48.2	21.5	18.2	46.7	27.4
Manica	8.0	47.4	24.6	52.5	64.9	23.3
Sofala	0.5	9.7	2.4	9.3	88.7	69.2
Inhambane	8.2	56.9	19.8	26.7	81.1	41.0
Gaza	18.1	68.5	37.6	38.9	83.4	73.7
Maputo	5.4	55.5	17.2	29.3	68.8	42.6
Total	4.1	21.2	10.1	31.0	68.3	46.1

Table 4 Cattle ownership and access to veterinary services by province (2005 panel villages only)

Province	# of HH cases that own cattle (unweighted)	% of HH that own cattle	% of cattle owners that	
			Vaccinated or treated cattle	Bathed cattle
Niassa	1	0.4	0.0	0.0
C. Delgado	1	0.0	100.0	100.0
Nampula	6	0.6	98.4	98.1
Zambézia	1	0.0	100.0	100.0
Tete	181	15.4	22.4	8.2
Manica	83	6.3	75.6	55.7
Sofala	12	0.6	83.3	79.0
Inhambane	77	7.9	89.0	84.9
Gaza	218	18.6	89.2	64.7
Maputo	59	5.0	91.2	54.2
Total	639	4.1	65.3	48.6

That said, the relationship between livestock ownership and treatment technology use (or access to it) in Tete does not seem to fit the pattern of the other livestock holding regions. That is, although Tete is the province with the highest percentage of rural households that own large livestock, only 45% of cattle owners in Tete vaccinate their cattle (compared with close to 90%

in the southern provinces). There appears to be an easy explanation for this, in that Specht (2008) notes that the prevalence of trypanosomosis in Tete during 1995-2000 was only 1.4% (RCCTP, 2000) while it was 4.5% in Zambézia, 7.7% in Manica, and 4.1% in Sofala. That is, trypanosomosis prevalence is lower in Tete (where many households own large livestock) than it is in two provinces (Zambézia and Sofala) that have virtually no large livestock. The reason why Tete's trypanosomosis prevalence is so low – in spite of relatively few Tete cattle owners using vaccines against this disease -- is likely because various parts of Tete are above 1500 meters, and the tsetse fly is much less prevalent at that altitude given the cooler temperatures. It should also be noted that Tete is not without access to livestock disease treatment technologies, as half the farmers are vaccinating their cattle, and 20% of villages in Tete have a dip tank, though vaccinations and dipping in Tete may be for diseases other than trypanosomosis.

There are two clear implications from these descriptive results of household ownership of large livestock and household or village access to livestock disease treatment technologies. First, the evidence presented in this section makes it highly likely that many TIA households throughout the country who were surveyed in 2002 and 2005 and owned cattle in those years faced potential (and deadly) disease pressure from trypanosomosis carried by the tsetse fly. Second, given that technologies known to provide successful prevention and/or treatment for trypanosomosis are virtually absent in areas of the country where there is also virtually no livestock ownership, and given that vaccination rates (and thus access to veterinary services) are very high among livestock owners in areas of the country with livestock, this clearly suggests that the absence of access to treatment for trypanosomosis may be a significant constraint to large livestock holding. Subsequently, the lack of access to treatment for trypanosomosis may be a significant factor explaining why areas such as Sofala and northern Mozambique have virtually no animal traction.

This leads to two implications for our multivariate regression analysis of the determinants of household ownership of animal traction. First, the analysis must include measures of household access to technologies such as vaccination, which this descriptive evidence suggests are used by large livestock holders to avoid trypanosomosis and other cattle diseases. Second, because the relationship between animal traction ownership and access to trypanosomosis control technologies may be simultaneous, household vaccination of animals is very likely endogenous to animal traction ownership, thus our econometric approach must test and control for such endogeneity.

6.4 Cattle density, stocks, and restocking

A regional overview of cattle densities in Sub-Saharan Africa shows how much Mozambique is lagging behind other countries (Figure 2). Of the 43 countries listed, Mozambique ranks sixth from the bottom. In addition, all countries sharing borders with Mozambique have higher cattle densities than Mozambique. Among the SADC countries only the Democratic Republic of

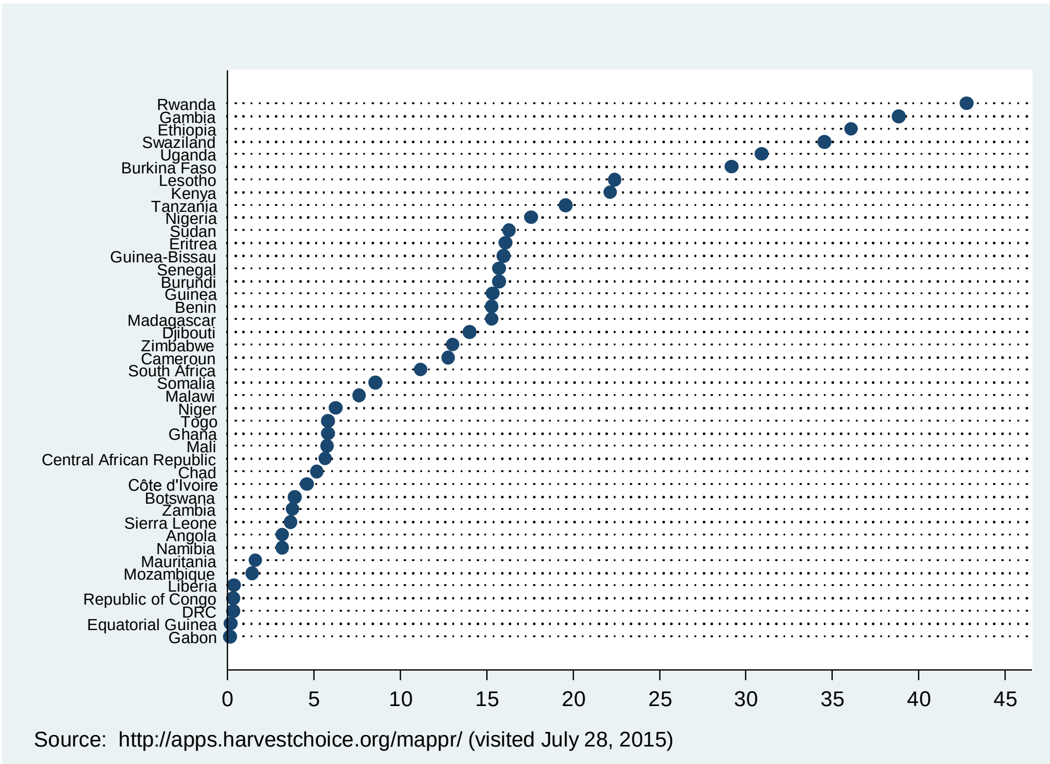
Congo has a lower density than Mozambique. It is important to note that Mozambique and DRC rank sixth and seventh worldwide, respectively, in terms of the countries with the largest amount of suitable but uncultivated land (Deininger and Byerlee, 2012)[9].

Cattle density in Mozambique is higher in the southern provinces than the rest of the country (Table 5). By contrast, farmers in Cabo Delgado did not have the option of adopting animal traction between 2006 and 2008 because there were no cattle in that province (Table 5). Cattle numbers in the very low density North may not be reliably estimated with a survey instrument like the TIA, which may explain why estimates of cattle numbers in the north are highly variable across years. Nevertheless, Mtwara province in southeast Tanzania provides an interesting comparison to Cabo Delgado, as the two provinces share a border and also share relatively the same altitude. We find that Cabo Delgado had only no cattle in 2008 and 4,482 in 2012, while Mtwara province had 3,291 households in 2007/08 that owned 18.115. In addition, cattle was the third dominant livestock type, and ox plows and ox carts were used by about 1% of all agricultural households in Mtwara province. The agricultural census from Mozambique that was conducted in 2009/10 shows that in Cabo Delgado province, only 0.07% of agricultural households raise cattle. While only 1.3% of rural households raise cattle in the Mtwara province, this percentage is about 19 times higher than in the Cabo Delgado province. And cattle stocks are at least five times higher in the Mtwara province relative to Cabo Delgado.

Relative to disease incidence and potential carrying capacity, Mozambique would also rank at the bottom if we had data on the gap between potential density and actual density. For example, all the countries below Mozambique are in the humid tropics and Mauritania and Namibia are largely deserts (Figure 2). Mozambique's cattle carrying capacity should be higher than any country in the bottom 10 with the exception of Angola. Arguably, Mozambique could be the country with the largest gap between potential and actual carrying capacity.

[9] That said, the enabling environment for agricultural investment could not be more different between Mozambique and DRC, as Mozambique has enjoyed peace since 1994, while DRC has suffered continued and very high political instability and civil conflict since 1996.

Figure 2 Cattle density (head/sq. km in 2005) by country



Cattle stocks in Mozambique plummeted during both the colonial war for independence (1964-1974) and the civil war (1976-1992). For example, total cattle herd size was 1.45 million in 1974, 1.34 million in 1980, and just 0.25 million in 1992 (See appendix Table A1). Between 1980 and 1992 there was an estimated 80% decline in cattle herd size in the country. Efforts were made to increase livestock numbers in the north even prior to the independence in 1975. Between 1967 and 1972 a total of 6,265 cattle were restocked in Nampula and Zambézia; and 4,152 cattle were restocked in Niassa and Cabo Delgado (Mendes, 1974). These four provinces in the north accounted for 66% of total cattle that were restocked in that period.

Besides the war(s), floods have also led to significant reductions in large livestock holding, prompting cattle restocking efforts in response. For example, in a small community in Manhiça district in southern Mozambique, cattle ownership declined from 45 households to just seven households due to the 2000 floods (Arnall et al., 2013). A third reason for restocking efforts relates to social factors. Following the social unrest in 2008, the government of Mozambique implemented the action plan to boost food production, known by its Portuguese acronym PAPA – *Plano de Acção para a Produção de Alimentos*. Among other actions, PAPA distributed cattle throughout the country, either for breeding or draught power.

Table 5 Cattle herd size among small and medium-sized households by province and year

Province/Year	2002	2005	2006	2007	2008	2012
	----cattle herd size (total number of animals)----					
North	102,758	33,030	66,330	61,092	101,992	131,596
Niassa	0	7,451	10,588	16,155	3,696	2,544
Cabo Delgado	2,451	1,727	0	0	0	4,482
Nampula	92,699	22,563	43,442	26,386	85,901	87,024
Zambézia	7,608	1,290	12,300	18,551	12,395	37,546
Center	388,594	588,185	503,010	561,757	662,934	721,697
Tete	270,955	426,047	312,474	377,759	432,075	394,731
Manica	112,140	151,907	178,212	163,419	184,347	263,289
Sofala	5,499	10,231	12,324	20,579	46,512	63,677
South	380,910	621,239	485,456	685,141	572,160	679,732
Inhambane	65,463	152,668	151,420	182,188	156,936	181,034
Gaza	270,801	395,574	255,121	417,940	317,106	381,102
Maputo	44,646	72,996	78,916	85,013	98,117	117,596
Total	872,263	1,242,454	1,054,797	1,307,990	1,337,086	1,533,025

Source: National Agricultural Surveys TIA 2002, 2005, 2006, 2007, 2008, and 2012

In 1992, about 70% of cattle were found in the southern provinces of Inhambane, Gaza, and Maputo. In 2012 there were 1.5 million cattle under smallholder farming, of which 44% were found in the south and just about 8% in the northern provinces of Niassa, Cabo Delgado, Nampula and Zambézia (see Table 5). Some provinces were able to bounce back their cattle herds to pre-war levels. In 2012 Gaza, Nampula, Inhambane, Tete, and Manica had more cattle than in 1973 (See appendix Table A1). In fact, Manica had 382% more cattle in 2012 than 40 years ago; Tete and Inhambane had 279% and 164% more cattle, respectively. Northern provinces, with the exception of Nampula, did not fare well: Niassa had just 16% of the total cattle in 1973, Zambézia had 21%, and Cabo Delgado 63%. During the 1970s fewer cattle were kept north of the Zambezi River due to the tsetse flies, and cattle husbandry was mainly done by commercial farmers due to the cost of keeping cattle in infested areas.

Looking at cattle herd size over time, adoption of animal traction is unfavorable in the northern provinces because in general there are not sufficient animals. The 1976-1992 war contributed to persistently low adoption rates because the number of animals plummeted, and in some provinces recovery has been difficult. Following the peace agreement signed in 1992, various livestock restocking projects re-emerged. For example, the Family Farming Livestock Rehabilitation Project was implemented between 1992 and 2002, and distributed a total of 5,500 cattle in Maputo, Gaza, Inhambane, Sofala, and Tete (African Development Fund, 2004) – all south of the Zambezi River, and thus favoring adoption of animal traction there. It is worth mentioning the difficulty we had in finding restocking data for the period of civil war. It is most likely that restocking was not done during that period or was only carried out on a minor scale.

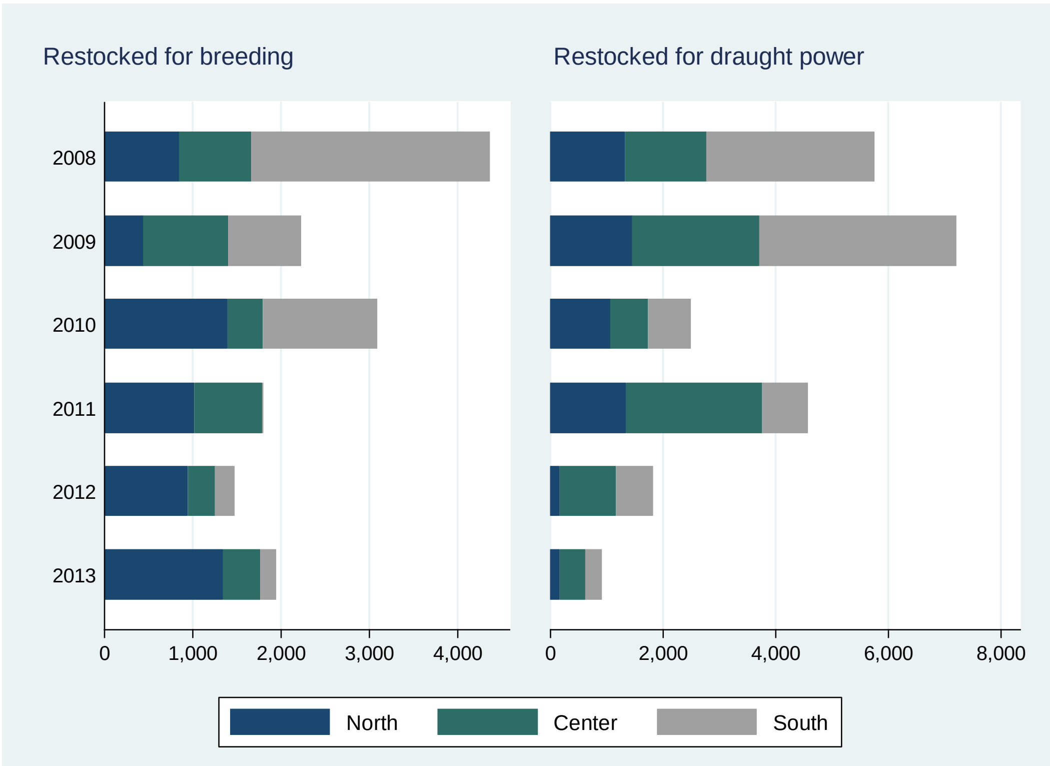
Several NGOs such as Vetaid, ATAP, Helvetas, and PASCO started restocking cattle following the peace agreement. Vetaid began restocking cattle in the southern provinces and Tete. Most of the NGOs were restocking animals in the south and almost none in the north, probably due to lower costs of transportation in the south. Due to poor road infrastructure in 1990s and early 2000s, it was very expensive to transport animals from areas with enough cattle to areas of low cattle density. The veterinary authorities had limited means of transporting cattle even if the farmers were to approach them for assistance (Keyserlingk, 1999).

In the Sussundenga district in the province of Manica, cattle rearing by smallholders was introduced with the distribution of cattle by GTZ (MARRP, Mozambique Agricultural Rural Rehabilitation Program) in 1989, with the purpose to get draft power to the smallholders. But having no knowledge about cattle keeping and basic animal health care, the success of the distribution depended on the work of the veterinary services, mainly the dip attendants employed until the change of government policy around 2000. Therefore, if there are less cattle kept and used for traction by smallholders north of the Save river, it is also due to the lack of the habit of keeping cattle and the limited knowledge about cattle husbandry.

Through PAPA, the northern provinces received significantly fewer animals for draught power, especially in 2012 and 2013, after having received more cattle in the previous years (Figure 3). Data from the national agricultural surveys show no significant improvement in animal traction adoption in the north (as it will be shown later) in the last few years, and this may have precipitated the government to shift from draught power to restocking the animals just for breeding.

The success or failure of these restocking programs either for breeding or for draft power have never been cautiously evaluated in Mozambique. These programs are potentially important if one can figure out where and when they are most likely to work. Lesorogol (2009) argues that restocking in northern Kenya, following a drought, goes beyond short-term income support to address the underlying causes of poverty and has the potential to enable households to emerge from poverty sustainably. The long-term benefit of restocking programs depends on smallholders' access to veterinary services, including inputs and technical support.

Figure 3 Total number of cattle restocked by country region, 2008-2013



6.5 Cattle composition (age and sex) and livestock competing activities

Cattle ownership is one of the pre-requisites for animal traction adoption, but that does not mean that all cattle owners will use their cattle for animal traction. While cattle can be raised/kept to provide inputs into crop production (animal traction; manure), they may also be raised to generate household income via sales of live cattle, meat, or cattle by-products such as milk or hids. In addition, cattle can be used for ceremonies, and some farmers may retain cattle as a form of savings or insurance against adverse village- or household-level shocks to crop productivity, human health, etc. A farmer must decide whether to engage in meat sales or use the animals for draught power for the productivity gains in agriculture. By looking at the cattle distribution by age and sex, it is possible to infer about the purpose of cattle rearing. Parameters such as the off-take rate and the proportion male/female cattle can tell us (or at least give some indication) whether cattle are reared mostly for breeding, sales or draught power.

The factors affecting off-take rate are the herd structure (availability of animals for sale), market demand, rates of return, the need for cash by the family, and disease outbreaks. Low off-take rates can reflect several scenarios: low growth rates of the animals, high calf mortality, an emphasis on milk rather than beef production, the importance of animal traction, the need for herd growth, and the retention of cattle for social and security reasons (Ngategize, 1982).

Another reason to look at cattle composition is because high prevalence of trypanosomosis in a given location results in low calving rate and high calf mortality. Moreover, we look at cattle composition because the ratio of female to male cattle could suggest the main reasons why cattle are being reared. Higher female to male ratios would suggest that cattle are being reared more frequently for meat production (and milk) than draught power provision. The ratio of female to male cattle is a decision variable under the smallholder farmer's control. Even if trypanosomosis was a major problem in a given location, it would have affected both male and female animals. In places where animal traction is uncommon, those who own cattle tend to consume or sell bulls and steers, and keep cows for breeding purposes.

The TIA data show that the ratio of female to male cattle, whether for all ages or just adult cattle, is higher in the provinces where the proportion of smallholder farmers using animal traction is low. Niassa, Nampula, Zambézia (and also Sofala) have the highest ratios, suggesting that smallholder farmers in those provinces tend to rear their animals most often for meat production (Table 6). They either sell their male cattle live or slaughter them and sell as meat. In contrast, Gaza and Tete have the lowest ratios of adult female to male cattle because they tend to keep the oxen for animal traction rather than selling them as meat. TIA survey has data on meat sales, but the number of observations is unfortunately quite small for further analysis.

Table 6 Livestock indicators in 2008

Province	Ratio total female/ total male cattle	Ratio adult female/ adult male	Young animals as a % of the total number of animals
Niassa	2.0	3.5	41.5
Cabo Delgado	NA	NA	NA
Nampula	1.9	1.5	18.4
Zambézia	1.7	3.2	33.2
Tete	1.6	1.1	34.8
Manica	1.5	1.6	30.4
Sofala	2.1	2.3	27.9
Inhambane	1.7	1.4	28.7
Gaza	1.3	1.1	23.4
Maputo	1.3	1.3	32.7
Total	1.6	1.3	29.0

Source: TIA 2008

Higher female to male ratios could also be related to the need for cash as the participation in off-farm activities tends to be lower in the northern provinces given fewer employment opportunities due to lower educational levels. However, employment opportunities might be changing with differential impacts across the country regions, given the recent boom in natural resources.

As far as the calving rate is concerned, with the exception of Nampula which scored low and Niassa which scored relatively high, all other provinces have similar calving rates. This suggests that cattle diseases that are common in Mozambique are yet to have a differential impact on calving rates and livestock composition across locations. It also suggests that while there are certain diseases that are more common to one location than to the other, overall the effect of one disease in a given location is off-set by the impact of another disease in another location.

6.6 Plough ownership and rental

Access to the large livestock, whether owned or rented, is a prerequisite for the adoption of animal traction. Yet, access to ploughs appropriate to be pulled by large livestock are also required. TIA data show that in 2008 about 10% of smallholder farmers used an animal traction plough (Table 7). Ploughs were more common in the south (especially in Gaza and Inhambane provinces), and in the central provinces of Manica and Tete. The majority of those using a plough obtain them through renting (58.2%). In Niassa and Zambézia where the use of animal traction is low, rental services are uncommon, but the number of observations from those two provinces is rather small for a conclusive argument.

Table 7 Plough ownership and rental in 2008 (%)

Province	HH used a plough (%)	HH own a plough (%)	HH borrowed a plough (%)	HH rented a plough (%)	HH owns cattle and a plough conditional on using a plough (%)	HH owns cattle and a plough unconditional of using a plough (%)
Niassa	0.02	100.0	0.0	0.0	100.0	0.2
C. Delgado	0.06	0.0	0.0	100.0	0.0	0.0
Nampula	0.00	-	-	-	-	-
Zambézia	0.17	100.0	0.0	0.0	0.0	0.0
Tete	15.46	42.5	18.7	38.8	69.2	17.5
Manica	15.14	45.8	10.4	43.9	59.6	12.4
Sofala	6.54	24.1	0.0	75.9	52.0	2.6
Inhambane	44.26	16.4	17.2	66.5	22.4	9.6
Gaza	44.21	26.9	13.7	59.5	52.8	30.1
Maputo	24.81	22.9	8.6	68.5	45.4	13.8
National	10.20	27.6	14.2	58.2	48.4	8.6

Source: TIA 2008

The proportion of smallholder farmers who used a plough (Table 7) is greater than that of those who own cattle (6.2%, see Table 2), demonstrating that a significant number of farmers have access to animal traction through renting-in animals and equipment. Indeed, among those who used a plough, only 48.4% own cattle, suggesting that 51.6% do not own cattle but still own animal traction equipment such as a plough. The proportion of smallholder farmers renting-in cattle to use with the ploughs they own is greater in Sofala (about 77.6%) and smaller in Tete (about 30.8%).

6.7 The use of tractors for tillage by smallholder farmers in rural Mozambique

The more urbanized yet less productive Maputo and Gaza provinces have a higher proportion of households who use tractor mechanization (Table 8). The last column in Table 8 shows the column percentages among users of tractors in the country. Maputo and Gaza represent 63% of the less than 2% of smallholder farmers who use tractors in Mozambique.

Table 8 Percentage of smallholder farmers who use tractors by year and province

Province/ Year	2002	2005	2006	2007	2008	2012	Col. % in 2012 among users
Niassa	2.16	0.38	0.93	0.01	0.95	0.00	0.00
Cabo Delgado	1.09	0.46	1.07	0.75	0.60	0.35	2.25
Nampula	0.00	0.32	0.01	0.14	0.12	0.11	1.39
Zambézia	0.00	0.01	0.27	1.14	0.18	0.36	6.76
Tete	0.35	1.56	0.60	1.10	0.52	0.50	3.21
Manica	2.90	0.46	2.83	1.35	2.79	2.25	10.96
Sofala	3.97	1.73	2.99	3.81	2.64	2.18	11.57
Inhambane	0.19	0.05	0.00	0.08	0.23	0.26	0.91
Gaza	7.56	9.55	5.76	6.27	4.32	4.84	17.11
Maputo	21.99	16.55	15.23	14.89	15.92	9.59	45.83
Total	1.77	1.53	1.41	1.51	1.41	1.45	100.00

Source: National Agricultural Surveys TIA 2002, 2003, 2005, 2006, 2007, 2008, 2012

Besides the difference in infrastructure across provinces, the dearth of progress in tractorization is also explained by the difference in the price of fuel. Diesel prices are lower in Maputo and Beira, and increase as we move farther from those two harbor cities. Nampula gets its diesel shipped from Beira. In Zambézia, a province of great agricultural potential, there are still districts that do not have a gas station, such as Lugela and Namarroi. In those districts, diesel can be sold in the informal markets at prices up to 50% higher than the official price (author's observation during fieldwork in 2011).

Baudron et al. (2015) show that the farm power (both tractors and draught animals) available per area of agricultural land in Mozambique has been stagnating over the past three decades, and argue that farm power represents a major limiting factor to productivity growth. Constraints in farm power may result in delayed land preparation and planting, which often result in severe yield losses. There is a need to increase farm power among smallholder farmers in Mozambique, but care should be given in choosing the 'appropriate' mechanization. Baudron et al. (ibid) compare farmers in Sub Saharan Africa with farmers using mechanized tillage in India, China, and Bangladesh. They conclude that the Bangladeshi model is more appropriate and applicable to countries like Mozambique. The model relies on small machines such as two-wheel tractors, and the access to them, especially among the poorest households, is usually through renting. But power tillers may not be viable in dryland agriculture with relatively low population densities like Mozambique. Bangladesh, the poster country for two-wheel tractors, is now switching to four-wheel tractors. Low horsepower four wheel tractors like those made in India could be the most viable option for Mozambique. 30-50 HP Indian tractors may break down more than higher HP models but they should be more cost effective over time than US or European manufactured products.

6.8 The use of animal traction for tillage by smallholder farmers

Table 9 shows that adoption rates are almost non-existent in the north. The estimates presented in Table 9 also beg the question of why animal traction might have declined markedly in Tete in 2012 since data collected in 2011 in that province suggests increasing adoption rates (see Cunguara et al., 2012). And it also shows a sharp decline between 2003 and 2005, and a sharp increase in Sofala from 2007 to 2008.

Table 9 Percentage of households that used animal traction by province and year

Province/Year	2002	2003	2005	2006	2007	2008	2012
North	0.0	0.1	0.1	0.1	0.1	0.1	0.0
Niassa	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Cabo Delgado	0.0	0.0	0.0	0.0	0.0	0.0	0.2
Nampula	0.0	0.2	0.1	0.1	0.2	0.0	0.0
Zambézia	0.0	0.0	0.1	0.1	0.2	0.2	0.0
Center	18.8	17.5	11.4	20.9	17.1	15.0	10.5
Tete	35.2	31.2	17.4	38.7	32.3	20.8	11.5
Manica	11.4	13.5	10.9	13.5	9.3	15.6	18.6
Sofala	1.5	1.5	2.1	1.9	1.8	6.1	1.7
South	41.1	42.9	37.9	46.1	43.2	41.9	25.8
Inhambane	46.9	46.4	45.8	50.6	43.5	45.7	37.9
Gaza	44.4	49.5	36.5	52.2	52.8	44.7	36.3

Maputo	11.6	13.7	14.8	13.8	13.8	26.7	9.0
Total	11.2	11.2	9.3	12.4	11.5	11.9	7.3

Source: National Agricultural Surveys TIA 2002, 2005, 2006, 2007, 2008, and 2012

One explanation could be related to the sampling frame. It is possible to have a high coefficient of variation (CV) in the animal traction data at the provincial level, which renders the data relatively less accurate at the provincial level. A high coefficient of variation would result, for example, from averaging the data from Macanga and Mutarara districts (with relatively low adoption rates) with data from Angonia, Maravia and Zumbo (with relatively high adoption rates in general, yet with a few years showing low adoption). Indeed, the CV of animal traction adoption in Tete in 2012 is about 198% whereas the CV for whether the household grew maize in that same year and location is just 34.6%. Nevertheless, the low percentage of households using animal traction in 2007 in Manica province is interesting. Parasitological prevalence of trypanosomosis was in 2007 at its highest with 45,8% of a total of 2056 blood smears examined by the veterinary laboratory positive for trypanosomes (Annual report for 2007, Regional Veterinary Laboratory).

In addition to provincial averages in adoption rates presented in Table 9, we also looked at the trend in the use of animal traction at the district level and ranked the districts from low to high by mean level of adoption across the seven survey years. This, of course, stretches the sampling properties of the survey to the limit, and results in higher coefficients of variations since the TIA survey was designed to be representative of the agro-ecological zone and provincial levels. However, since there are seven years of survey data, this increases the number of observations at the district level for the pooled sample. The objective was to determine if there are districts with secularly increasing or decreasing adoption or if adoption incidence bounces around from year to year so much that a trend cannot be established. The results are summarized in Table 10. The subset of districts that contains data on the prevalence of trypanosomosis is highlighted in either bold if the district in located South of the Zambezi River or *italics* if located North of the Zambezi River.

Table 10 Trend in the use of animal traction by district, 2002-2012

Item	Number of districts	Districts

No animal traction 2002-2012	63	Cidade de Lichinga, Cuamba, Lago, Distrito de Lichinga, Majune, Mandimba, Marrupa, Maua, Mavago, Mecanhelas, Mecula, Metarica, Muembe, Ngauma, Nipepe, Sanga, Pemba, Ancuabe, Balama, Chiure, Ibo, Mecufi, Meluco, Mocimboa da Praia, Montepuez, Mueda, Muidumbe, Namuno, Nangade, Palma, Pemba Metuge, Quissanga, Cidade de Nampula, Angoche, Erati-Namapa, Ilha de Mocambique, Lalaua, Meconta, Memba, Mogincual, Moma, Mossuril, Muecate, Cidade de Nacala, Nacala velha, Nacaroa, Quelimane, Alto Molocue, *Chinde*, Gile, Ile, Inhassunge, Lugela, Milange, *Mocuba*, *Mopeia*, Namacurra, Namarroi, *Nicoadala*, Pebane, Macossa, Cheringoma, and Muanza
Less than 1% adoption 2002-2012	22	Monapo, Marromeu, Mecuburi, Mogovolas, Chibabava, Gorongosa, Beira, Morrupula, Macomia, *Maganja da Costa*, Gurue, Dondo, Tambara, Chemba, **Nhamatanda**, Nampula, Malema, Maringue, *Morrumbala*, Caia, Ribaue, and Matola
Between 2% and 10%	12	*Mutarara*, Chiuta, Inhassoro, Namaacha, Matutuine, **Machaze,** Vilanculos, Cidade de Chimoio, **Gondola**, Macanga, Boane, and Moatize
Between 11% and 20%	9	**Guro**, Machanga, Cidade de Tete, Barue, **Buzi**, Massangena, Cidade de Xai-xai, **Sussundenga**, and Moamba
Between 21% and 30%	12	Mabote, Marracuene, Angonia, Inhambane, Manhica, **Mossurize**, Tsangano, Chifunde, Cahora Bassa, Zumbo, Bilene, and Magude
Between 31% and 40%	3	Inharrime, Maxixe, and Manjacaze
Between 41% and 50%	9	Govuro, **Magoe**, Funhalouro, Xai-Xai, Chigubo, **Changara**, Chibuto, Manica, and Chokwe
Between 50.1% and 84.1%	11	Massinga, Zavala, Maravia, Chicualacuala, Jangamo, Panda, Homoine, Morrumbene, Guija, Mabalane, and Massingir

Source: National Agricultural Surveys of 2002, 2003, 2005, 2006, 2007, 2008, and 2012

About 45% of the 141 districts covered in the seven years of TIA surveys have no animal traction use. These are mainly the districts in Niassa, Cabo Delgado, Nampula, and Zambézia provinces. In Manica, only Macossa district did not have animal traction. This is surprising since the neighboring districts of Barue and Guro have relatively high adoption rates, estimated between 11% and 20%. There were no districts in the north (Niassa, Cabo Delgado, Nampula, and Zambézia) with an adoption rate greater than 1%. The subset of districts with data on the prevalence of trypanosomosis included four districts with no adoption (all in Zambézia) and some districts of high adoption rates.

There are several districts where adoption incidence bounces around from year to year, and these include Namaacha, with 19% adoption rate in 2008, 0.2% in 2003 and 2012, 3.9% in 2002, and 4.4% in 2005; Barue with about 22% adoption in 2006 and 2012, 10% in 2002, and 19% in 2008; and Angónia with about 43% in 2002 and 2008, 21% in 2003, and only 3.3% in 2012. The districts with high adoption rates in all seven years are mainly located in the south, with the exception of Maravia, Magoe and Changara in Tete (the latter two are included in the subset of the prevalence of trypanosomosis data set), and Manica district.

6.9 Comparison of cropped area by tillage method

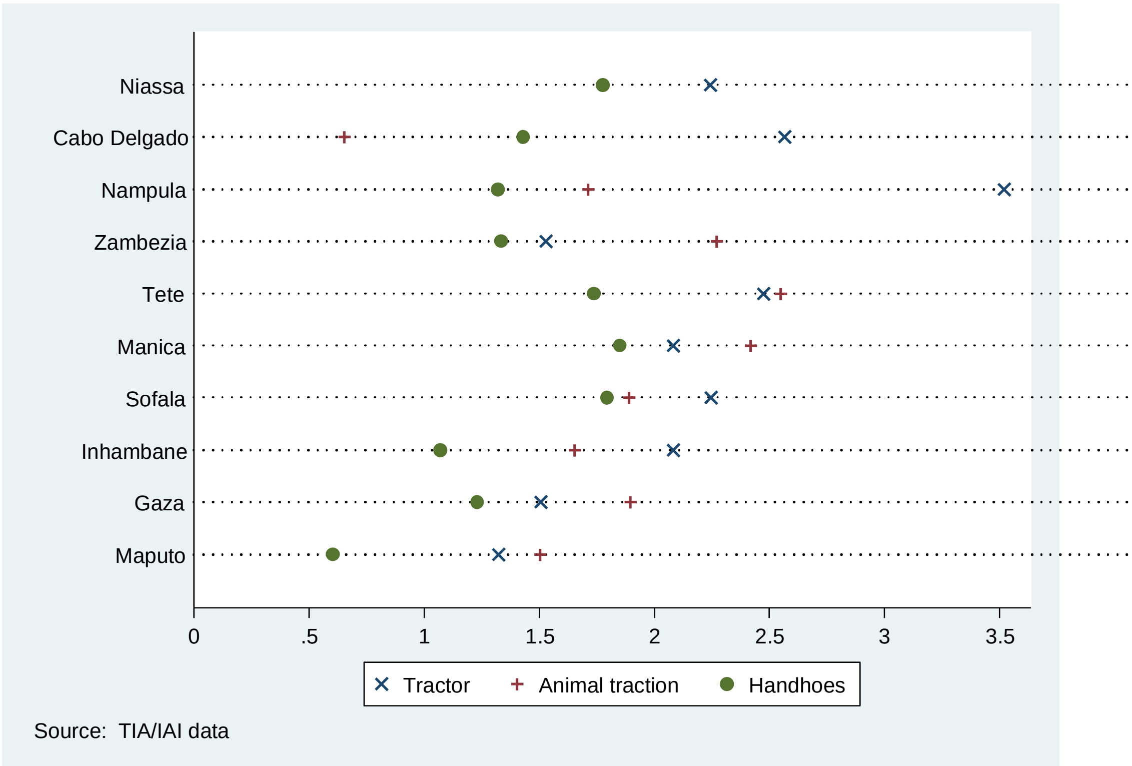
Strikingly, Mozambique is regarded as one of the seven countries worldwide that account for more than half of global land availability (together with Sudan, Brazil, Australia, Russia, Argentina, and the Democratic Republic of Congo) (Deininger and Byerlee, 2012). Land availability is defined in terms of area suitable for cultivation that is not currently under cultivation. Jayne et al. (2003) show that the average cropped area in Mozambique is small relative to other Sub-Saharan African countries, and that the trend over time is negative. The negative trend in cropped area can also be observed in the Appendix Table A2. The mean farm size in Sub-Saharan Africa is about 2.4 ha (Eastwood et al., 2010 cited in Deininger and Byerlee, 2012), compared to 1.3 ha in Mozambique in 2012. Reasons for ample suitable but uncultivated land are either because clearing it is unaffordable or uneconomical (for example, low demand for surplus crop production), technology for exploiting it or institutions to protect investment are unavailable, or the land is too far from infrastructure for households to want to migrate to that area or for there to be an economic incentive to produce surplus crops that are storable, such as grains (Deininger and Byerlee, 2012).

Figure 4 shows that i) the average cropped area among smallholder farmers is smaller in the south (Maputo, Gaza, and Inhambane) relative to other provinces; and ii) the average area cultivated is larger for animal traction than tractor in the provinces where tractors are more common. There is a positive and statistically significant correlation between tillage methods and cropped area, but the differences in cropped area are small in absolute terms (see Appendix Table A2).

The average cropped area among non-adopters of mechanical tillage in Tete and Manica is similar to the area among adopters of animal traction in either Maputo or Inhambane provinces. This is because in the south the prospects for expansion of cropped area are limited by low and erratic seasonal rainfall. The south has a comparative advantage in cattle production vis-à-vis the center and north where crop production benefits from higher and more assured rainfall during the growing season.

Between 2002 and 2012, the average cropped area was significantly larger among households that used animal traction in all provinces, except for Sofala in 2005 (significant levels not tabled to save space). But in 2005 there were only a few adopters in Sofala. The lack of adopters in the northern provinces is also the reason for having blank cells in the Appendix Table A2.

Figure 4 Mean cropped area by tillage method and province, 2002-2012



6.10 The prevalence of trypanosomosis and adoption of animal traction

Earlier in Table 1 we presented the sample of the TIA 2005 subset that was matched with data on the prevalence of trypanosomosis. The subset can be divided into smallholders, commercial (medium-size) farmers, and state-owned cattle. The latter data is from the *Estação Zootécnica de Angónia* in Tete province, and comprise 58 observations. The importance of making the distinction between state-owned, smallholders and commercial farms is because i) the latter treat their cattle regularly with trypanocides, and thus the prevalence of trypanosomes in commercial farms does not reflect the actual tsetse challenge (Table 11); and ii) smallholders are the ones using animal traction, not commercial farmers who raise cattle mostly for meat production.

The prevalence of trypanosomosis estimated for specific districts between 2003 and 2005 (Specht, 2008) varied by province. Manica province had the lowest prevalence of trypanosomosis among smallholder farmers while Tete (especially Changara and Mutarara districts) and Zambézia had higher prevalence rates; however, the data from Zambézia only have nine observations for smallholders. This is because there were only 40 samples from smallholder cattle in the original trypanosomosis data set since most of the cattle are kept under commercial farming. Changara district in Tete province had the highest prevalence rate among smallholder farmers, at 45.9%. This compares to 25.1% in the neighboring district of Guro, in Manica province.

Table 11 Prevalence of trypanosomosis by province and sector (%), 2005

Sector	Stat	Zambézia	Tete	Manica	Sofala	Total
State-owned	Mean		21.2			21.2
State-owned	Median		21.2			21.2
State-owned	Max		21.2			21.2
Smallholders	Mean	30.0	30.7	20.4	27.8	26.0
Smallholders	Median	30.0	27.8	19.6	28.1	25.8
Smallholders	Max	30.0	45.9	30.4	28.1	45.9
Commercial farms	Mean	23.0		6.8	21.9	20.3
Commercial farms	Median	25.4		1.0	14.7	22.2
Commercial farms	Max	32.0		26.3	29.2	32.0

Source: Tryps data (Specht, 2008) matched with TIA 2005 data.

The prevalence rates also varied by type of farmer, with commercial farmers on average having lower rates than smallholder farmers. Within the same district, commercial farmers had significantly lower prevalence rates of trypanosomosis than smallholder farmers. The mean prevalence rate among commercial farmers is also lowest in Manica, which suggests better access to veterinary services in that province and perhaps some geographical variation in tsetse control in the country (Table 11). Households in Tete usually have less access to cattle vaccine than in Manica. In fact, if we exclude the northern provinces where there are only a few observations (and hence less reliable statistics at the provincial level), Manica and Inhambane have the highest rates of cattle vaccination while Tete has the lowest. The access to dip tanks is also lowest in Tete, despite large cattle stocks and a high proportion of households that use animal traction. As noted above in section six, the combination of relatively low vaccination rates, fewer dip tanks, yet high percentages of households owning cattle in Tete may be due to the fact that Tete has areas of higher elevation where tsetse populations may be limited due to the colder temperatures.

6.11 Cultural barriers and lack of tradition of animal traction use

Macossa and Barue are two neighboring districts in the Manica province, and both belong to the same agro-ecological zone (Wet SAT, mid-elevation central). Macossa had no animal traction use between 2002 and 2012; Barue had 11-20% adoption rate during the same period. Guro is also a neighbor of Macossa, shares similar agro-ecological characteristics, and 11-20% of smallholder farmers used animal traction between 2002 and 2012, as previously shown in Table 8. The agricultural census shows that in 2009/2010 Macossa had only 488 head of cattle while cattle stocks were 34 and 28 times larger in Barue and Guro districts, respectively. The local chiefs (called *régulos* or *fumos* in Portuguese) from Barue and Macossa belong to the same ethnic group – the Barwe – and hence the two are more likely to face similar cultural constraints to livestock rearing.

One possible explanation for the differences observed in terms of cattle stocks between Barue and Macossa pertains to the presence of a *coutada* (protected conservation area) in the latter district. Conservation areas usually have a higher prevalence of trypanosomosis, both because there is more vegetation and also because wildlife provide hosts for the tsetse fly. A second explanation is that the people of Barue at some point in time shared the same culture as those from Gaza province. In the late 1830s Soshangane, a general of the Gaza Empire, attacked Manica and Sofala resulting in the takeover of Barue. Gaza has the highest proportion of smallholder farmers who use animal traction in the country.

The Gaza Empire extended between the Incomati and Zambezi rivers. Rivers such as the Zambezi, being the fourth longest in Africa, were important cultural markers separating people from different ethnic groups. The peoples north of the Zambezi River might have had little cultural interference in the 19th century with those south of the Zambezi River. The Zambezi River, thus, creates a distinct pattern of livelihoods and climate which in turn can partially explain the differences that we observe in terms of cattle ownership and adoption of animal traction. Similar to the southern provinces of Mozambique, and Gaza in particular, the people from Barue have a longer tradition of cattle rearing and animal traction use.

Meanwhile, Mopeia and Maravia also belong to the same agro-ecological zone (The Zambezi valley and south Tete), but between 2002 and 2012 there was no animal traction use in the former, compared to 50-84% in the latter. The agricultural census data show no cattle ownership among smallholder farmers in Mopeia in 2009/2010. Here, one possible explanation for the differences in cattle stocks between these two districts is also the tradition in livestock rearing. The Ntumba, a subgroup of the Chewa ethnic group in what is now Angonia, had relatives in Maravia and owned cattle at least since the first half of the 19th century when António Gamitto, a Portuguese captain, settled there in 1830. The Portuguese had entered the Zambezi valley in 1531, but lost their territory in 1693 except a narrow strip along the Zambezi in what later became known as the Quiteve kingdom (Newitt, 1968).

Tribal warfare gave rise to permanent new grouping among the Zambezi peoples. For example, the names Chicunda, Macanga, and Massingire trace their origins to the followings of the Portuguese landlords. The Chicunda are today widely scattered throughout the Portuguese sphere of the Zambezi from Zumbo to the Shire. The Massingire was only founded on the Zambezi in the 1820s and its rise to power and notoriety was due to the exploitation of the slave trade on the Shire. The Macanga inhabit land to the north of Tete, and includes the Maravia district which has a longer tradition of cattle rearing. In the lower Zambezi we find the Nhungue who are also known as Sena, and this includes the Mopeia district which has no tradition of cattle rearing, and Caia. Between 1994 and 1999 several cattle restocking activities occurred in the lower Zambezi.

In Caia, the restocking activities were not well received apparently because the Sena people in Caia usually do not keep the assets that are inherited from their loved ones. Such resistance to restocking, however, was not observed among the Sena people in Mutarara[10]. But Mutarara borders another country (Malawi), with a larger cattle density as previously demonstrated in Figure 1. Note that during the civil war about 1.7 million Mozambicans fled the country and might have been exposed to cattle rearing and to the animal traction technology; Malawi alone had more than one million Mozambican refugees, more than 10% of the total population in Malawi (Lischer, 2003).

Another interesting comparison is between Mutarara, Changara and Magoe. The three districts are also located in the Zambezi valley sharing the same agro-ecological zone (according to IIAM's classification). All three districts border another country (Changara and Magoe border Zimbabwe). In Mutarara less than 10% used animal traction between 2002 and 2012 compared to 41-50% in Changara and Magoe. The trypanosomosis data for smallholder farmers show prevalence rates of 37.1% in Changara, 21.6% in Magoe, and 27.5% in Mutarara. This suggests that the limiting factor for the adoption of animal traction is not disease pressure since Changara has both high prevalence of trypanosomosis and high adoption of animal traction. In 2012 Mutarara had larger cattle stocks (61,135 heads) than Magoe (25,630 heads) yet lower adoption rates of animal traction.

7. ECONOMETRIC ANALYSIS OF ANIMAL TRACTION OWNERSHIP

Our primary interest in the following econometric analysis of the probability of animal traction ownership is on two explanatory factors. First, we expect trypanosomiasis prevalence to have a significant and negative effect on the probability of animal traction ownership. Second, we expect that the extent to which household access to technologies to prevent and/or treat trypanosomosis will have a positive effect on the probability of animal traction ownership by modifying (reducing) the hypothesized negative effect of trypanosomosis on the probability of animal traction ownership.

The sample we use for this analysis are n=620 TIA02-05 panel households that are within districts for which Specht (2008) provides empirical estimates of trypanosomiasis prevalence from 2003-2005. As per Table 10 above, although Specht (2008) has trypanosomiasis data from one district in Zambézia, we cannot include this district because in the TIA 2005 sample there is

[10] Personal communication with José Taimo, who led the restocking activities in the lower Zambezi between 1994 and 1999.

only one smallholder farmer that owns large livestock in Zambézia region. This also means that it is not possible to investigate the determinants of animal traction ownership in northern provinces or districts because (a) there is no data on trypanosomiasis (other than from 2000) prevalence in northern regions and (b) virtually no households own large livestock in the north. Thus, the best we can do is use results from the following analysis of the determinants of animal traction ownership in the center to assess what implications those results may imply for the promotion of animal traction in the north.

7.1 Determinants of household animal traction ownership

In our first LPM regression (column A, Table 12), we include total HH landholding and assume that it is exogenous (though we suspect it is not), and we do not include any measure of village access to vaccination for large livestock. As we would expect, the results show that an increase in trypanosomiasis prevalence has a negative effect on the probability of animal traction ownership. This effect is very nearly significant (p=0.105). Because a one unit change in this proportional variable (values for which range from 0 to 1) does not represent a marginal change, the standard approach to interpreting a marginal effect from such a variable is to multiply the 'one-unit' effect by a considerably smaller proportional movement, such as an increase in trypanosomiasis by 0.10 (an increase of 10%). Using this approach, we find that a 10% increase in trypanosomiasis prevalence reduces the probability of animal traction ownership by 8.7% (i.e. -0.0876).

Table 12 Linear Probability Model regressions of household animal traction ownership

	Depedent variable: 1= HH owns animal traction							
	OLS-CRE		OLS-CRE		OLS-CRE		2SLS	
Explanatory variables	(A)		(B)		(C)		(D)	
1=year 2005	0.644	***	0.640	***	0.644		0.588	**
1=village soil has nutrient retention problem	-0.002		0.024		0.018		0.069	
elevation (m)	0.000		0.000		0.000		0.000	
slope	0.036		0.034		0.033		0.037	
expected seasonal rainfall (mm)	0.000		0.000		0.000		0.000	
CV of exp seasonal rainfall	-0.081	**	-0.075	**	-0.080	**	-0.109	*
Trypanosomiasis prevalence (%), 2003-05	-0.876	*	-1.108	**			-1.748	*
1=village has vaccination access			0.195	*			0.398	
0=vaccination access * tryp prev %					-1.176	**		
1=vaccination access*tryp prev %					-0.696			
Expected maize price, oct-dec	-0.351		-0.352		-0.352		-0.216	
Expected small gnut price, oct-dec	-0.036	**	-0.036	**	-0.036	**	-0.035	**
Distance to fert retailer (km), 2002	-0.001		-0.001		-0.001		-0.001	
Distance to seed retailer (km), 2002	-0.001		0.000		0.000		0.000	
ln(village total # of large livestock)	0.084	***	0.048		0.062		-0.014	
ln(district total # of large livestock)	0.027		0.038		0.031		0.107	
1=village near watering hole, 2002	0.013		-0.020		-0.007		-0.052	
1=village near river/lake, 2002	0.105		0.079		0.090		-0.001	
1=vil. Received lstk promotion, 2002	0.162		0.149		0.150		0.280	
Distance to public transporation (km), 2002	0.000		0.000		0.000		0.000	
Travel time to nearest city 30k+ (2002)	0.000		0.000		0.000		0.000	
1=district borders coast	0.214	*	0.230	**	0.238	**	0.327	**
1=district borders other country	-0.137		-0.164		-0.139		-0.416	
HH total landholding (ha)	0.028	*	0.029	*	0.028	*	0.232	
HH medium/small TLU	0.035		0.036		0.036		0.022	
HH # of adults	-0.010		-0.009		-0.009		-0.045	
Head's age (years)	0.000		0.000		0.000		-0.002	
Head's education	0.034	***	0.033	***	0.033	***	0.030	**
HH maximum adult education	0.002		0.001		0.001		-0.004	
# children 0-4	-0.020		-0.019		-0.019		-0.042	
# of children 5 to 14	-0.031		-0.031		-0.030		-0.064	
Constant	-0.784	***	-0.900	***	-0.896	***	-1.356	**
Observations	1,240		1,240		1,240		1,240	
R-squared	0.198		0.202		0.199			

Notes: results presented for each explanatory variables are the scaled coefficient from the LPM; scaled standard errors were corrected for heteroskedasticity; ***, **, and * denote statistical significance at 0.01, 0.05, and 0.10. Only the second stage of the 2SLS is presented in column (4). All regressions are estimated using population sampling weights.

In column B, we add a binary indicator that =1 if the village has access to large livestock vaccination in that year, though we assume that it and total landholding are exogenous. The first result to note is that households that live in a village with access to vaccination services are 19.5% more likely to own animal traction. This suggests that although we know from Specht (2008) that each of the districts in this TIA sample had trypanosomiasis prevalence rates between 5 to 40% between 2003-2005, that during these same years, a household that lives in a village with access to vaccination enjoys a 19.5 increase in the probability of owning animal traction. This suggests that access to a technology that is known to prevent and/or treat trypanosomiasis has a large and significant positive effect on the probability of ownership of large livestock and thus animal traction.

The second result to note is that once we include a measure of village-level access to vaccination (treatment for trypanosomiasis), the magnitude of the effect of the trypanosomiasis incidence variable increases, and it becomes more significant. For example, in the model in column B, a 10% increase in trypanosomiasis results in an 11% *decrease* in the probability of owning animal traction (up from 8.7% in column A where we did not control for access to vaccination) – controlling for all other factors, including access to trypanosomosis prevention/treatment technologies. However, these results are based on the assumption that village access to vaccination and total HH landholding are exogenous. Yet, if either of those variables are correlated with an unobserved factor (i.e. something in the error term) and/or are simultaneously determined with the dependent variable animal traction ownership, then the coefficients on these variables may be biased (due to endogeneity from omitted variable bias or simultaneity bias).

We next run another LPM model (column C), again assuming that total HH landholding and village access to large livestock vaccination are exogenous, though this time we interact vaccination access with trypanosomiasis prevalence. The results are consistent with those of model B, in that trypanosomiasis prevalence has a large negative and significant effect on the probability of animal traction ownership in villages without access to vaccination. By contrast, in villages with vaccination, the coefficient on the trypanosomiasis prevalence variable is negative but the magnitude is almost the size of the other interaction effect, and the effect itself is not significant (p-value 0.268).

In order to address the concern we noted above about the potential endogeneity of household access to vaccination in the village, we next run a two-stage model in which the first stage is a probit of 1=village has access to vaccination, while the second stage is our regression of interest, an LPM of 1=household ownership of animal traction. This approach is similar to two stage least squares (2SLS) though is termed the control function (CF) approach (Rivers and Vuong (1988), as outlined by Wooldridge (2002)). We use 1=village has available land as an IV for total HH landholding and 1=village has a dip tank as an IV for 1=village has access to large livestock vaccination. Our results indicate that both IVs are significant in the first stage control function, thus we are confident that both are viable IVs due to this result and because neither variable would be assumed a priori to have a significant effect on the dependent variable of the structural equation – the probit or LPM of 1=household owns animal traction, for reasons explained in the methods section above. The second stage of the CF approach to testing the endogeneity of these two variables involves including the residuals from the first stage CFs in the structural equation, along with the potentially endogenous variable. We find that the residuals from each CF are significant, indicating that both are likely to be endogenous. For reasons explained in the methods section above, in column D, we thus return to the LPM estimator because it enables us to include these two endogenous variables in our preferred regression specification, while using population sampling weights and also correcting for the known heteroskedasticity of standard errors from an LPM.

In column D, we use two-stage least squares (2SLS) with an LPM, by which we formally recognize that both total HH landholding and 1=village has access to large livestock vaccination are endogenous to household ownership of animal traction. The result of explicitly controlling for the endogeneity of these two regressors (i.e. remove their bias) is that the magnitude of the negative and significant effect of trypanosomiasis prevalence on the probability of animal traction ownership is considerably larger. For example, a 10% increase in trypanosomiasis prevalence results in a 17% reduction in the probability of owning animal traction, controlling for all other factors, including access to technology that can prevent and/or treat trypanosomosis (vaccination). The magnitude of the positive effect of village vaccination on the probability of animal traction ownership doubles to be 39%, though the effect is no longer significant. The loss of significance is likely due to the fact that village vaccination access does not vary much at all over time and because 2SLS is well-known to inflate standard errors.

The coefficients for districts on the coast are surprisingly positive and statistically significant. This does not support our earlier arguments on livestock ownership and animal traction adoption being higher in the border districts. Only two coastal districts were included in the analysis – Buzi and Maganja da Costa – because cattle populations are usually negligible in coastal areas in the center and north of the country. The coefficients for coastal districts were significant because there has been a lot of investment in cattle rearing and animal traction use in Buzi. Otherwise the coefficients would most likely be negative as expected.

There are several important implications of the econometric results from these four models. First, we find a large negative and significant effect of trypanosomiasis on the probability of animal traction in these central zones (during the period covered by this data, from 2002 to 2005). Second, the negative effect of trypanosomosis on the probability of animal traction ownership is significantly reduced for households that live in villages with access to large livestock vaccination, by which trypanosomiasis can be prevented and/or treated. Taken together, these two findings, combined with the descriptive results in section six seem to clearly indicate that a key factor explaining the lack of large livestock (and thus lack of animal traction) in Sofala is the near absence of household or village access to technologies with which households could prevent and/or treat large livestock from trypanosomiasis. In addition, combining these results with the descriptive evidence from the north (section 6), this strongly suggests that trypanosomiasis is a key factor explaining the near absence of large livestock (and thus lack of animal traction) in northern provinces.

That said, this result does not mean that access to trypanosomosis prevention/treatment technologies is *sufficient* for large livestock to flourish in an area with this disease pressure, but it does imply that it is a *necessary* first step. For example, there is much more to household success in raising large livestock and deciding to make such a large investment than simply access to disease prevention for the animals. That is, intuitively it is clear that if very few households in Sofala and northern provinces have not raised large livestock between 2002 and the most recent IAI (2015), then livestock promotion and extension education on large livestock husbandry is a necessary condition for successful large livestock production in those areas (and thus access to animal traction).

8 Conclusions and policy implications

Tsetse flies are vectors of trypanosomes, a threat to animal health because animals suffering from trypanosomosis are weakened and therefore rarely used for draught power in agriculture. Low adoption of animal traction north of the Zambezi River is often attributed to trypanosomosis, which is carried by tsetse flies (Bias and Donovan, 2003; Walker et al, 2004; World Bank, 2006; Mather, 2009). Such adoption would very likely increase cultivated area, and labor productivity and reduce poverty. The importance of animal traction adoption cannot be stressed enough: agricultural productivity in Mozambique is among the lowest worldwide; human population continues to grow and migrate to urban centers; the average cropped area per smallholder farmer has declined in the last decade; history teaches us that it is easier to move from manual agricultural to animal traction, rather than jumping into motorized agriculture; and even though it may take longer to create the tradition of rearing oxen than to teach smallholders to use a two-wheel tractor, the former appears to be more sustainable over time.

Previous research show that farm power represents a major limiting factor to productivity growth in Mozambique, and that both tractors and draught animals available per area of agricultural land has been stagnating over the past three decades. The government of Mozambique recently acquired more than 500 tractors (mainly 80 HP) and created 47 tractor hire centers across the country. Power tillers may not be viable in dryland agriculture with relatively low population densities like Mozambique. Low horsepower (30-50 HP) four wheel tractors like those in India could be the most viable option for Mozambique. The low 30-50 HP Indian tractors may break down more than higher HP models but they should be more cost effective over time than US or European manufactured products. Mozambique seems to have acquired high horsepower tractors for its tractor hire centers, which raises sustainability questions. A follow up question in future research pertains also to the distribution of the tractor hire services across the country.

In this paper, we assess the relative role of disease pressure as compared with other potential determinants of animal traction use. Using data from 2003-2005 on trypanosomosis prevalence and household ownership of animal traction (an ox or donkey plus an animal-drawn plough) from a number of central districts our panel household-level econometric analysis clearly shows that trypanosomosis pressure is a large negative constraint to animal traction ownership by small or medium-holders. However, our analysis also finds that household access to vaccination services significantly reduces the negative effect of trypanosomiasis prevalence on the probability of household ownership of animal traction. Yet, our descriptive analysis suggests that while access to vaccination services (and other technologies such as dip tanks that can prevent and/or treat trypanosomiasis and other cattle diseases) appears to be *necessary* in order for households decide to purchase one or more animal traction units, it is very likely not *sufficient* by itself. For example, because cattle has essentially not been raised in most northern districts since at least 2002 (and probably earlier), households in those areas would require training (provided by livestock extension services) in order to understand both how to care for draught animals and how to use animal traction in land preparation. In addition, there may be problems of limited availability of quality pasture in northern provinces, as cultural barriers to keeping large livestock, and potentially low economic incentives to use animal traction to increase land sizes (in areas where very poor market access means that the incentives to produce surplus grain may be quite low). For example, it is possible that pasture availability and profitability issues explain why most cattle restocking prior to independence in 1975 occurred in the south and in Tete.

The absence of widescale testing in Sofala and the north since 2000 implies that prior to consideration of programs to promote large livestock keeping and animal traction in those areas, there first must be new and extensive field surveys of trypanosomosis prevalence there to establish the extent to which trypanosomosis is still a serious constraint (or not) to large livestock keeping. This kind of widescale trypanosomosis prevalence testing is required because it is quite likely that unless farmers have not only extension education and perhaps subsidized access to livestock and also access to vaccination and dip tanks, the enormous investment made by the government and households in large livestock could vanish in a year if trypanosomosis is still present in the north. Because there are currently no large livestock in the north, this implies that a survey would require that livestock be brought to extension stations and monitored over time to test for trypanosomosis incidence.

While tsetse flies should not take all the blame for low adoption of animal traction, Mozambique still lags behind other countries in the region in terms of animal health. Indeed, Mozambique was one of the latest to create the veterinary services in southern Africa in 1909 when its cattle were banned from entering in neighboring countries. It does not have enough dip tanks, and the coverage of yet compulsory vaccination misses at least one quarter of smallholder farmers' cattle. Veterinary services are poorly staffed. All these factors have a bearing on cattle ownership and adoption of animal traction.

Our econometric results also showed that the probability of cattle ownership is greater among smallholder farmers who are located in villages that border either Zimbabwe or Malawi, perhaps because there is a longer tradition of animal traction use in both those border areas and those countries. We also showed significant differences in animal traction adoption rates even between neighboring districts often sharing similar agro-ecological conditions. This merits additional studies that are more focused in exploring cultural barriers to technology adoption, which would require new data collection as this kind of analysis is not possible with the available data. We also note that the emphasis of animal traction projects in Mozambique has been on land preparation. Yet, this is a seasonal operation, suggesting that perhaps more emphasis should be placed on promotion of non-seasonal activities such as transportation. Such study would compare districts in terms of their use of draft power for transportation purposes and other activities, such as pulling water from wells for irrigation in replacement of the treadle pumps. Cattle can also be used for threshing, when the animals walk in circles over beans or cereals, separating the husks from the grains. Animal traction promotion projects should ideally include a package of all those activities. The fact that the people south of the Zambezi River are mainly Christians whereas people north of the Zambezi are mostly Muslims also deserves further investigation about the role of religion in shaping cattle ownership in the country.

References

African Development Fund, 2004. Mozambique Family Farming Livestock Rehabilitation Project: Project completion report.

African Development Fund, 1995. Foot and mouth disease control project: Project completion report. Agriculture and Rural Development Department, South Region.

Alderman, H., J. R. Behrman, H-P Kohler, J. A. Maluccio, and S. Cotts Watkins. 2001. Attrition in Longitudinal Household Survey Data. Demographic Research 5.4: 80-123.

Arnall, A., Thomas, D., Twyman, C., and Liverman, D., 2013. Flooding, resettlement, and change in livelihoods: Evidence from rural Mozambique. *Disasters*, 37(3): 468-488.

Barrett, V., Lassiter, G., Wilcock, D., Baker, D., Crawford, E., 1982. Animal traction in eastern upper Volta: A technical, economic and institutional analysis. MSU International Development Paper #4.

Baudron, F., Sims, B., Justice, S., Kahan, D., Rose, R., Mkomwa, S., Kaumbutho, P., Sariah, J., Nazare, R., Moges, G., and Gérard, B., 2015. Re-examining appropriate mechanization in Eastern and Southern Africa: two-wheel tractors, conservation agriculture, and private sector involvement. *Food Security*, 7(4): 889-904.

Bias, C, and C. Donovan. 2003. Gaps and opportunities for agricultural sector development in Mozambique. Research Report No.54E, Directorate of Economics, Ministry of Agriculture and Rural Development (MADER).

Bolaane, M., 2007. Tsetse and trypanosomosis control in the Okavango Delta, c. 1930s-1970s. *South African Historical Journal*, 58:91-116.

Castañeda, I., Werne, J., Johnson, T., and Filley, T., 2009. Late quaternary vegetation history of southeast Africa: The molecular isotopic record from Lake Malawi. *Palaeogeography, Palaeoclimatology, Palaeoecology*, 275: 100-112.

Chamberlain, G. 1984. Panel Data. In Handbook of Econometrics, Vol. 2, ed. Z. Grilliches, and M.D. Intriligator. Amsterdam, North Holland: Elsevier.

Chamberlin, J. 2013. Rural mobility and access to arable land in Sub-Saharan Africa. ASA 2013 Annual Meeting Paper.

Chamberlin, J. and T.S. Jayne. 2012. Unpacking the Meaning of "Market Access". World Development. Volume 41, January 2013, Pages 245–264.

Chapoto, Antony. 2006. The Impact of AIDS-related Prime-age Mortality on Rural Households: Panel Survey Evidence from Zambia. Ph.D. dissertation. Michigan State University. Available at: http://www.aec.msu.edu/agecon/theses/index.htm

CRU (Climate Research Unit), University of East Anglia. 2011. CRU-TS 3.1 Climate Database. CRU Time Series (TS) high resolution gridded datasets, NCAS British Atmospheric Data Centre. http://badc.nerc.ac.uk/view/badc.nerc.ac.uk__ATOM__dataent_1256223773328276.

Cunguara, B., and Darnhofer, I. 2011. Assessing the impact of improved agricultural technologies on household income in rural Mozambique. *Food Policy*, 36: 378-390.

Cunguara, B., Mudema, J., D. Mather, and D. Tschirley, 2012. Changes in cropping and input use in Mozambique, 2008-2012. Flash #60E. Maputo: Ministry of Agriculture.

de Janvry, A., and E. Sadoulet. 2006. "Progress in Modeling of Rural Household's Behavior Under Market Failures." In Poverty, Inequality and Development Vol. 2 ed A. de Janvry and R. Kanbur, 155-181. New York: Springer.

Deininger, K., and Byerlee, D., 2012. The rise of large farms in land abundant countries: Do they have a future. *World Development* 40(4):701-714.

Dias, J.A, Rosinha, J.A. 1971. Terão justificação os abates indiscriminados da caça como medida de luta contra a mosca tsé-tsé? Uma análise do caso de Moçambique. *Revista de Ciências Veterinárias*, 4:87-99.

DNEAP, 2004. *Poverty and wellbeing in Mozambique: Second national poverty assessment*. National Directorate of Studies and Policy Analysis, Maputo.

DNEAP, 2010. *Poverty and wellbeing in Mozambique: Third national poverty assessment*. National Directorate of Studies and Policy Analysis, Maputo.

FAO. 2007. Compendium of Agricultural - Environmental Indicators (1989-91 to 2000): Annex 2 Definitions.

Fischer, G., H. van Velthuizen and F.O. Nachtergaele. 2000. Global Agro-Ecological Zones Assessment: Methodology and Results. Interim Report IR-00-064. International Institute for Applied Systems Analysis and The Food and Agricultural Organization of the United Nations.

Hansen, M. C., P. V. Potapov, R. Moore, M. Hancher, S. A. Turubanova, A. Tyukavina, D. Thau, S. V. Stehman, S. J. Goetz, T. R. Loveland, A. Kommareddy, A. Egorov, L. Chini, C. O. Justice, and J. R. G. Townshend. 2013. "High-Resolution Global Maps of 21st-Century Forest Cover Change." *Science* 342 (15 November): 850–53. Data available on-line from: http://earthenginepartners.appspot.com/science-2013-global-forest.

Hargrove, J.W., Torr, S.J., Kindness, H.M., 2003. Insecticide-treated cattle against tsetse (Diptera: Glossinidae): what governs success? *Bulletin of Entomological Research* 93, 203–217.

HarvestChoice, 2015. "Cattle Density (head/sq. km, 2005)." International Food Policy Research Institute, Washington, DC., and University of Minnesota, St. Paul, MN. Available online at http://harvestchoice.org/data/ad05_catt.

Hocking, K.S., Lameron, J.F., and Lewis, E.A., 1963. Tsetse fly control and eradication. *Bulletin of the World Health Organization*, 28(5-6): 811-823.

Jamal, S., Sigauque, I., Macuamule, C., Neves, L., Penzhorn, B., Marcotty, T., van den Bossche, P., 2005. The susceptibility of *Trypanosoma congolense* isolated in Zambézia province, Mozambique, to isometamidium chloride, diminazene aceturate, and homidium chloride. *Onderstepoort Journal of Veterinary Research*, 72: 333-338.

Jayne, T., Yamano, T., Weber, M., Tschirley, D., Benfica, R., Chapoto, A., and Zulu, B., 2003. Smallholder income and land distribution in Africa: Implications for poverty reduction strategies. Food Policy, 28: 253-275.

Keyserlingk, A., 1999. The challenges of reintroducing animal traction in post-war Mozambique. in Starkey P and Kaumbutho P (eds), 1999. Meeting the challenges of animal traction. A resource book of the Animal Traction Network for Eastern and Southern Africa (ATNESA), Harare, Zimbabwe. Intermediate Technology Publications, London. 326p.

Lesorogol, C., 2009. Asset building through community participation: Restocking pastoralists following drought in northern Kenya. *Social Work in Public Health*, 24(1-2): 178-186.

Lischer, S., 2003. Collateral damage: Humanitarian assistance as a cause of conflict. *International Security*, 28(1):79-109.

Lovemore, D.F., 1987. Tsetse control by chemical means in Malawi, Mozambique, Zambia, and Zimbabwe. Proceedings of the Commission of the European Communities International Symposium, Ispra 4-6 March 1986.

Mapiye, C., Chomonyo, M., Muchenje, V., Dzama, K., Marufu, M., and Raats, J., 2007. Potential for value-addition of Nguni cattle products in the communal areas of South Africa: a review. *African Journal of Agricultural Research*, 2(10): 488-495.

Mather, D. and C. Donovan. 2007. The Impacts of Prime-age Adult Mortality on Rural Household Income, Assets, and Poverty in Mozambique. Background paper for the Mozambique Poverty, Gender and Social Impact Assessment, Africa Region, The World Bank, Washington, D.C. and MINAG Directorate of Economics Research Paper 65E, Maputo, Mozambique.

Mather, D., 2009. Measuring the impact of public and private assets on household crop income in rural Mozambique, 2002-2005. MINAG Research Report # 67E: Maputo.

Mather, D., Cunguara, B. and Boughton, D. 2008. *Household Income and Assets in Rural Mozambique, 2002-2005: Can Pro-Poor Growth Be Sustained?* MINAG Directorate of Economics Research Paper No. 66E. Maputo, Mozambique.

Mather, D., Cunguara, B., and Tschirley, D., 2015. Smallholder cropping and input responses to changes in expected prices and market access in central and northern Mozambique, 2008-2011. Ministry of Agriculture and Food Security Working Paper #75E: Maputo.

Maudlin, I., Green, C.H., Barlow, F., 1981. The potential for insecticide resistance in Glossina (Diptera: Glossinidae) - an investigation by computer simulation and chemical analysis. *Bull. Ent. Res.* 71, 691-702.

Mendes, C.B., 1974. A pecuária bovina Moçambicana. *Ind. Moçamb* 7(9):301-334.

Mercader, J., Astudillo, F., Barkworth, M., Bennett, T., Esselmont, C., Kinyanjui, R., Grossman, D., Simpson, S., and Walde, D., 2010. Poaceae phytoliths from the Niassa Rift, Mozambique. *Journal of Archaeological Science*, 37(8): 1953-67.

Mitchell, T. and P. Jones. 2005. An improved method of constructing a database of monthly climate observations and associated high-resolution grids. *Int. J. Climatology*, 25, 693-712.

Mukhebi, A., Perry, B., and Kruska, R., 1992. Estimated economics of theileriosis control in Africa. *Preventive Veterinary Medicine*, 12: 73-85.

Mundlak, Y. 1978. On the Pooling of Time Series and Cross Section Data. Econometrica 46: 69-85.

Newitt., M.D.D., 1968. The Portuguese on the Zambesi from the seventeenth to the nineteenth centuries. *Race and class*, 9(4):477-498.

Ngategize, P., 1982. Herd structure, production traits, cattle transactions and an economic analysis of alternative production systems of zebu cattle in N. Tanzania. MS Thesis, Michigan State University: East Lansing.

Pingali, P., Bigot, Y., and Binswanger, H., 1987. Agricultural mechanization and the evolution of farming systems in Sub-Saharan Africa. The John Hopkins University Press: Baltimore and London.

Pollock, J.N., 1982. Training Manual for Tsetse Control Personnel: Ecology and Behaviour of Tsetse. Volume 2. Food and Agriculture Organization of the United Nations: Rome.

Rivers, D. and Q.H. Vuong. 1988. Limited Information Estimators and Exogeneity Tests for Simultaneous Probit Models. *Journal of Econometrics* 39: 347-366.

Robinson, T., Rogers, D., and Williams, B., 1997. Mapping tsetse habitat suitability in the common fly belt of southern Africa using multivariate analysis of climate and remotely sensed vegetation data. *Medical and Veterinary Entomology*, 11(3):235-245.

Rodriguez, E., C.S. Morris, J.E. Belz, E.C. Chapin, J.M. Martin, W. Daffer, S. Hensley. 2005. "An assessment of the SRTM topographic products", Technical Report JPL D-31639, Jet Propulsion Laboratory, Pasadena, California, 143 pp.

Rogers, D.J., Hendrickx, G., and Slingenbergh, J.H.W., 1994. Tsetse flies and their control. *Rev. sci. tech. Off. int. Epiz* 13(4):1075-1124.

RTTCP, 2000. An update of the distribution of bovine trypanosomosis in Mozambique. Harare: Regional Tsetse and Trypanosomiasis Control Program.

Sadoulet, E., de Janvry, A., 1995. Quantitative Development Policy Analysis. The Johns Hopkins University Press.

Savadogo, K., Reardon, T., and Pietola, K. (1998). Adoption of improved land use technologies to increase food security in Burkina Faso: Relating animal traction, productivity, and non-farm income. *Agricultural Systems*, 58(3): 441-64.

Schofield, C., and Maudlin, I., 2001. Trypanosomiasis control. *International Journal for Parasitology*, 31: 615-620.

Scoones, I., 2014. The politics of trypanosomiasis control in Africa. STEPS Working Paper 57, Brighton: STEPS Centre.

SIMA. 2013. Sistema de Informação de Mercados Agrícolas. Ministério da Agricultura, Maputo.

Singh, I, L. Squire, and J. Strauss. 1986. Agricultural Household Models. Baltimore: Johns Hopkins University Press.

Specht, E.J.K. and Quembo, C.J., 2009. Report of the Mozambican Team in Enhancing Animal Health Services in Africa, Enhancing early disease detection, surveillance and prevention, ILRI Report.

Specht, E.J.K., 2008. Prevalence of bovine trypanosomosis in Central Mozambique from 2002 to 2005. *Onderstepoort Journal of Veterinary Research*, 75: 73 – 81.

Swap, R., Aranibar, J., Dowty, P., Gilhooly, W., Macko, S., 2004. Natural abundance of ^{13}C and ^{15}N in C_3 and C_4 vegetation of southern Africa: Patterns and implications. *Global Change Biology*, 10: 350-58.

Timberlake, J., and Dionísio, A., 1984. Review of the use of improved pasture species in Mozambique. Proceedings of a workshop on Pasture Improvement Research in Eastern and Southern Africa held in Harare, Zimbabwe, 17-21 September 1984.

Timberlake, J., and Reddy, S.J., 1986. Potential pasture productivity and livestock carrying capacity over Mozambique. INIA Research Report N. 49. Maputo, Mozambique.

Van den Bossche, P. 2001. Some general aspects of the distribution and epidemiology of bovine trypanosomosis in southern Africa. International Journal for Parasitology, 31: 592 – 598.

Walker, T., D. Tschirley, J. Low, M. Tanque, D. Boughton, E. Payongayong and M. Weber (2004) Determinants of Rural Income, Poverty and Perceived Well-Being in Mozambique in 2001-2002. Working Paper 57E. Maputo: Ministry of Agriculture.

Wooldridge, J.W., 2002. Econometric Analysis of Cross Section and Panel Data. Cambridge, Massachusetts: The MIT Press.

World Bank. 2006. Mozambique Agricultural Development Strategy: Stimulating Smallholder Agricultural Growth. Agriculture, Environment, and Social Development Unit: Africa Region.

Table A1 Cattle population by province, 1973 - 1998

Province/Year	1973	1974	1980	1985	1990	1992	1993	1995	1996	1997	1998
Niassa	15,566	14,192	9,471	7,768	3,515	3,930	3,633	3,699	4,013	4,530	3,838
C. Delgado	7,108	5,074	3,206	3,974	4,485	4,950	4,973	5,574	5,801	6,519	6,766
Nampula	71,826	71,826	41,000	34,000	12,705	6,742	5,536	6,386	6,796	9,141	10,364
Zambézia	177,074	183,953	140,598	57,339	18,653	19,625	19,942	19,200	19,000	19,099	19,320
Tete	141,624	121,106	112,465	110,816	39,990	32,885	38,309	78,278	93,179	119,350	113,552
Manica	69,023	63,777	45,956	29,769	31,394	22,356	23,839	29,382	39,397	41,117	47,087
Sofala	66,422	66,780	55,921	19,648	15,474	15,897	12,701	12,866	11,702	12,630	14,307
Inhambane	110,693	119,640	137,737	52,221	34,131	29,892	26,396	36,948	43,657	49,831	55,387
Gaza	343,968	374,046	381,654	246,404	143,913	95,821	58,750	73,631	97,909	108,827	126,167
Maputo	403,229	432,224	410,158	237,870	35,657	20,197	19,826	26,862	30,170	39,488	43,802
National	1,406,533	1,452,618	1,338,166	799,809	339,917	252,295	213,905	292,826	351,624	410,532	440,590

Source: *Arrolamento Pecuário*

Table A2 Mean cropped area in hectares by province, year, and tillage method

Province/tillage	Year	Niassa	C. Delgado	Nampula	Zambézia	Tete	Manica	Sofala	I'bane	Gaza	Maputo
Animal traction	2002			16.7		2.4	2.6	1.8	2.0	1.9	2.2
	2005			2.2	5.9	3.4	2.7	1.6	1.8	2.3	1.3
	2008				2.3	2.5	2.6	2.0	1.7	1.6	1.5
	2012		0.7	1.1		2.1	2.1	1.8	1.2	1.4	1.1
Animal traction + tractor	2002					2.8	1.7	1.7	1.8	2.7	1.9
	2005			3.9		1.6	5.5	4.1	4.5	2.1	2.9
	2008						2.4	1.8	11.9	2.4	2.5
	2012						4.2	0.8	1.9	1.6	1.7
Hand hoes	2002	1.7	1.2	1.0	1.2	1.6	1.9	1.8	1.3	1.2	0.9
	2005	2.2	1.7	1.4	1.7	2.3	2.2	2.0	1.2	1.3	0.9
	2008	1.9	1.5	1.4	1.4	1.8	1.5	2.0	1.1	1.3	0.8
	2012	1.6	1.1	1.4	1.2	1.4	1.6	1.4	0.8	0.8	0.3
Tractor	2002	2.0	2.9			2.3	3.0	2.4	2.2	1.9	2.0
	2005	0.4	2.0	5.2	4.8	2.5	2.5	2.9		1.4	1.5
	2008	3.2	2.1	2.5	1.1	5.6	1.3	2.6	1.3	0.8	1.2
	2012		2.5	3.6	1.4	0.8	1.9	2.2		0.7	0.6

Source: National Agricultural Surveys TIA 2002, 2005, 2008, and 2012

Table A3 Access to veterinary services by year and province

Province	HH vaccinated cattle (%)			HH used a dip tank (%)			HH own cattle (N)		
	2005	2008	2012	2005	2008	2012	2005	2008	2012
Niassa	10.6	27.3	100.0	3.5	0.0	100.0	1,044	317	254
C. Delgado	100.0		100.0	100.0		100.0	52	0	45
Nampula	93.9	89.1	63.5	92.6	81.7	72.5	2,054	19,150	23,570
Zambezia	100.0	10.6	19.4	100.0	4.7	83.1	129	2,106	3,669
Tete	21.2	56.8	46.7	11.1	24.1	15.9	61,026	77,198	57,248
Manica	79.1	92.3	85.8	63.4	90.1	75.2	20,954	32,855	49,700
Sofala	58.1	71.5	77.3	49.5	66.1	84.9	1,581	5,890	9,731
Inhambane	78.4	83.3	88.0	86.1	84.9	90.9	35,492	39,276	43,185
Gaza	85.4	73.3	78.1	63.7	66.5	70.1	58,188	56,748	48,208
Maputo	85.3	86.1	54.5	63.7	80.1	57.1	4,814	13,814	10,398
National	61.7	73.5	70.8	50.5	60.7	62.6	185,334	247,354	246,008

Source: TIA 2005, 2008, and 2012