Economic Analysis of Trypanocide Use in Villages under Risk of Drug Resistance in West Africa

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This thesis is dedicated to my kids Elvis, Farel and Marielle for their sacrificial love

"I believe that life is plenty of good things that people can benefit from them as long as enough energy and self confidence are put to overcome difficulties along the way"

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Zusammenfassung

Ökonomische Analysen können dazu beitragen, die Faktoren zu verstehen, die den Erfolg der Trypanosomosebekämpfung in der Rinderhaltung im so genannten Baumwollgürtel in Westafrika bestimmen. Die am weitesten verbreitete Methode der Krankheitsbekämpfung ist der Einsatz von Trypanoziden. Bisher ist wenig über deren kurz- und langfristige Produktivität unter Praxisbedingungen bekannt. Analysen zur Produktivität des Einsatzes von pharmazeutischen Produkten in der Tierproduktion müssen auch die Resistenz des Erregers gegenüber Trypanoziden berücksichtigen. Letztere kann ein wesentliches Hindernis für die Nachhaltigkeit dieser Krankheitsbekämpfungsverfahren darstellen. Generelles Ziel der Arbeit ist es die Methodik zur Messung der Produktivität von Maßnahmen zur Bekämpfung von Tierkrankheiten in der Viehhaltung in Westafrika weiter zu entwickeln. Dabei erfolgte auch die Ermittlung der Produktivität des Einsatzes von Trypanoziden und der durch die Krankheit verursachten monetären Verluste unter Praxisbedingungen. Darüber hinaus wurden in der Arbeit die Folgen einer abnehmenden Wirksamkeit der Trypanozide auf die Einkommen armer Rinderhalter abgeschätzt. Die Ergebnisse dieser Untersuchung können dazu beitragen, geeignete Strategien für die nachhaltige Bekämpfung der Trypanosomose beim Rind sowie zur Reduzierung nachteiliger Folgen der Trypanozidresistenz zu entwickeln.

Die Arbeit beruht auf einer umfangreichen Datenerhebung, die von Juni 2003 bis Mai 2004 in Burkina Faso und Mali durchgeführt wurde. Die Datenerhebung wurde von einem multidisziplinären Team bestehend aus Veterinären, Epidemiologen und Agrarökonomen durchgeführt. Insgesamt wurden über einen Zeitraum von 12 Monaten in 18 Dörfern von insgesamt 206 rinderhaltenden Betrieben die Rinderbestände mit einer Gesamtzahl von 3565 Rindern beobachtet. Aufwands- und Ertragsdaten wurden von in den Dörfern lebenden Projektmitarbeitern erhoben. Außerdem wurde eine Bewertung der epidemiologischen Bedingungen hinsichtlich Tierkrankheiten auf Dorfebene vorgenommen. Preisinformationen wurden auf lokalen Märkten, Schlachthöfen und in Fokusgruppendiskussionen gesammelt.

Die Untersuchungen haben gezeigt, dass die Rinderhaltung sowohl in Burkina Faso als auch in Mali eine wichtige Rolle spielt, wobei in Mali im Durchschnitt größere Herden zu beobachten waren. In Burkina Faso ist ein auch im Vergleich zu anderen Regionen Afrikas südlich der Sahara höherer Anteil von Zugtieren festzustellen. Daran zeigt sich, dass dort

die Bedeutung der Pflanzenproduktion höher ist und ein entsprechender Einsatz von Zugtieren in der pflanzlichen Produktion erfolgt.

Hinsichtlich der Einschätzung der Halter über die Ursachen und Formen von Rinderkrankheiten hat sich gezeigt, dass die Mehrheit die Trypanosomose für die wichtigste Rinderkrankheit hält. Auch war der Kenntnisstand über den Erreger dieser Krankheit vergleichsweise hoch gemessen an dem von Bauern in anderen Regionen Afrikas südlich der Sahara. Die Landwirte kennen durchaus alternative Strategien der Krankheitsbekämpfung; sie bevorzugen jedoch den Einsatz von Trypanoziden. Dabei wird die Behandlung vorwiegend nicht, wie in beiden Ländern gesetzlich vorgeschrieben, von Tierärzten, sondern von den Rinderhaltern selbst durchgeführt. Hierzu fehlen den Rinderhaltern aber oft die für eine erfolgreiche Behandlung notwendigen veterinärmedizinischen Kenntnisse.

Die Arbeit bedient sich eines methodischen Ansatzes, in dem die Rinderproduktion als Prozess modelliert wird, in dem sowohl lokale Ressourcen als auch zugekaufte Produktionsmitteln eingesetzt werden, um damit verschiedene Produkte und Leistungen zu erzeugen. Diese sind z.B. Milch, Fleisch, Zugkraft, organischer Dünger und indirekte Leistungen wie die Verbesserung der Finanzierungs- und Versicherungskapazitäten der ländlichen Haushalte. Kernstück des methodischen Ansatzes ist eine Produktionsfunktion, in die eine Schadensvermeidungsfunktion integriert ist. Dadurch wird es möglich die Verluste durch Krankheiten in der Rinderproduktion abzuschätzen. Gleichzeitig erfolgt eine Ermittlung der Grenzproduktivität des Trypanozideinsatzes unter verschiedenen epidemiologischen Bedingungen. Dabei wird zum einen eine konventionelle Cobb-Douglas-Produktionsfunktion verwendet, und zum anderen eine modifizierte Cobb-Douglas-Funktion mit integrierter Schadensvermeidungsfunktion spezifiziert. Um die Effekte verschiedener epidemiologischer Bedingungen, insbesondere von Krankheitsdruck und der Arzneimittelresistenz zu berücksichtigen, wurden entsprechende Variablen definiert. Drei unterschiedliche Spezifikationen der exponentiellen Schadensvermeidungsfunktion wurden untersucht. Die exponentielle Schadensvermeidungsfunktion, die zwei Schadensursachen, Trypanosomose und andere Krankheiten beinhaltet, weist die höchste Anpassungsgüte auf und wurde in der weiteren Analyse mit der Cobb-Douglas-Funktion verglichen. Die Produktivitätsschätzungen in dieser Studie zeigen, dass die Schadensvermeidungsfunktion konsistent höhere Grenzproduktivitäten für beide untersuchte Trypanozide (Isometamidium und Diminazen) in Gebieten mit hohem Befallsdruck und hoher Isometamidiumresistenz liefert. Die Ergebnisse des konventionellen Cobb-Douglas-Modells hingegen zeigen eine Abnahme der Trypanozidproduktivität in diesen Gebieten. Der Vergleich der beiden Modelle zeigt, dass das Schadensfunktionsmodell einen geeigneten Ansatz darstellt, die Grenzproduktivitäten des Einsatzes von Arzneimitteln in der Tierproduktion in Westafrika realistisch abzuschätzen. Hingegen zeigt sich, dass konventionelle Produktionsfunktionen möglicherweise zu falschen Schlussfolgerungen hinsichtlich der Grenzproduktivität von auf Schadensvermeidung ausgerichteten Produktionsfaktoren führen.

Allerdings müssen auch die Ergebnisse des Schadensfunktionsmodells mit der notwendigen Vorsicht interpretiert werden. Die Grenzproduktivitäten der beiden von den Rinderhaltern eingesetzten Trypanozide Isometamidium und Diminazen deuten darauf hin, dass die spezielle Intensität unter Praxisbedingungen unterhalb des ökonomischen Optimums liegt. In einer streng ökonomischen Interpretation bedeutet dies, dass unter den genannten Bedingungen Rinderhalter kurzfristig ihren Gewinn steigern könnten, wenn sie den Einsatz von Trypanoziden erhöhen würden. Dabei ist allerdings zu berücksichtigen, dass dies eine statische Betrachtungsweise darstellt, und die negativen externen Effekte, beispielsweise der Arzneimittelresistenz, vernachlässigt werden. Um die Entwicklung von Resistenzen zu verzögern oder bestenfalls umzukehren, wird das Konzept des rationalen Arzneimittelgebrauchs empfohlen. Rationaler Einsatz bedeutet, den Bedarf an Medikamenten durch Krankheitsvorbeugung zu reduzieren, die Trypanozide nach Möglichkeit durch alternative Behandlungsmöglichkeiten zu ersetzen, sicherzustellen, dass die Trypanozide nur bei medizinischer Notwendigkeit gegeben werden und der richtige Wirkstoff in angemessener Dosierung korrekt verabreicht wird.

Diese Untersuchung bestätigt, dass Trypanosomose eine bedeutende Krankheit im Baumwollgürtel Westafrikas ist. Beim derzeitig suboptimalen Einsatz von Tierarzenimitteln verbleiben immer noch Ertragsverluste in einem Bereich von knapp 10 bis über 20 %. Bei optimaler Bekämpfung ließen sich Verluste möglicherweise auf 1 bis 1.5 % reduzieren.

Die Kosten der Trypanosomose beim derzeitigen Niveau des Bekämpfungsaufwandes, die aus den Kosten der Krankheitsbekämpfung und den verbleibenden Ertragseinbußen zusammengesetzt sind, sind wesentlich höher als die Kosten bei für die jeweiligen epidemiologischen Bedingungen optimalem Isometamidiumeinsatz. Zur Zeit liegen die Kosten, die den Rinderhaltern durch die Krankheit entstehen bei € 13.30 bis € 26.00 pro

TLU und Jahr, sie könnten durch optimalen Trypanozideinsatz auf € 8.60 bis € 10.10 pro TLU und Jahr gesenkt werden, je nach epidemiologischen Bedingungen. Diese Kosten stellen im Durchschnitt 12% - 28% des Wertes der Rinderproduktion dar, abhängig von Befallsdruck und Resistenz. Durch die Optimierung können diese Kosten auf 7 bis 8% des Ertrages gesenkt werden. Niedrigere Kosten der Krankheit und die steigende Produktivität der Trypanozide im Falle hoher Resistenzniveaus können jedoch zu einer Situation führen, in der die Entscheidung der Rinderhalter über den Trypanozideinsatz vom Phänomen der Pfadabhängigkeit bestimmt wird. In einer solchen Situation würden die Möglichkeiten der Krankheitsbekämpfung stark beschränkt, entweder auf die Entwicklung neuartiger Arzneiwirkstoffe, die mit enormen Kosten verbunden wäre, oder die Ausrottung des Vektors der Krankheit, der Tsetsefliege, eine Strategie, die bisher niemals ohne externe Hilfe nachhaltig wirksam war. Die Aufrechterhaltung der Effektivität der Trypanozide ist daher von großer Bedeutung für landwirtschaftliche Produktionssysteme in Westafrika.

Insgesamt hat diese Arbeit gezeigt, dass es möglich ist, den Ansatz der Schadensvermeidungsfunktion auf die Messung der Produktivität von Krankheitsbekämpfungmaßnahmen in der Tierproduktion in Westafrika anzuwenden. Das hier entwickelte Modell beschränkt sich allerdings weitgehend auf die direkten Krankheitseffekte. Dynamische Aspekte der Resistenzentwicklung können nur in vereinfachter Form in das Modell einbezogen werden. Weiterer Forschungsbedarf ist deshalb erforderlich, etwa um ein bio-ökonomisches Modell entwickeln zu können, in dem der epidemiologische Krankheitsprozess einschließlich der Resistenzbildung und der Prozess der Entscheidungsfindung über die Auswahl von Tierbekämpfungsmaßnahmen in ein ökonomisches Haushaltsmodell integriert werden.

Keywords: Trypanosomose, Trypanozidresistenz, Produktivität, Ertragsverluste, Krankheitskosten.

Abstract

Economic analysis can assist in the understanding of the factors that determine the success of trypanosomosis control by cattle farmers in the cotton zone of West Africa. Trypanocides are the most widely used method of control, and determining their short- and long-term productivity provides important information. However, this must be interpreted in the light of emerging drug resistance, which poses a major obstacle to the sustainability of drug use. More generally, this research aims to advance the methodology of measuring the productivity of animal disease control inputs in West African cattle production. The study includes an empirical assessment of the productivity of trypanocidal drugs and the costs of trypanosomosis under village conditions. The analysis was extended to capture the implications for the livelihood of the poor cattle farmers of a declining susceptibility of trypanosomes to drugs. The results of this research can help decision-makers to put in place strategies for improved management of trypanosomosis and trypanocidal drug resistance.

The study was conducted in Burkina Faso and Mali from June 2003 to May 2004. Data were collected by a team of veterinary epidemiologists, technicians and agro-economists. In all, 206 herds with a total of 3565 cattle in eighteen villages were monitored during a period of twelve months. Input and output data were collected by enumerators posted in villages for which epidemiological conditions were assessed throughout the study period. Additional price information was collected in local markets, abattoirs and through focus group discussions.

It was found that cattle-keeping is important in both Mali and Burkina Faso; however, herds were larger in Mali. The smaller herd size in the study area compared to other parts of sub-Saharan Africa and the higher ratio of draught animals to male adult cattle, especially in Burkina Faso, indicate a farming system more oriented towards intensive use of draught animals in crop production. The majority of cattle farmers in the study area considered trypanosomosis the most important disease of cattle, and knowledge of the cause of trypanosomosis in the study zone was relatively high compared to other parts of sub-Saharan Africa. Farmers are aware of many strategies to control the disease. However, their preferred strategy is the use of trypanocidal drugs and the majority of treatments are given by cattle farmers, although this is not legal.

In the methodology developed, livestock production is modelled as a process in which local resources and external inputs are used to generate multiple outputs such as milk, meat, draught power, and manure, and indirect outputs including the finance and insurance functions of maintaining cattle stocks. The study applies a production function framework and integrates a damage control function to quantify cattle production output losses as well as the productivity effect of trypanocide use under different epidemiological conditions. For the estimation of the productivity of disease control inputs, a conventional Cobb-Douglas production function and a modified Cobb-Douglas function that integrates a damage abatement function were specified. Dummy variables were used to capture the effects of disease prevalence and drug resistance, thus taking into account different epidemiological conditions. Three different specifications of the exponential damage control function were tested. The specification that includes two sources of damage from diseases provided the best fit and was used for comparison with the Cobb-Douglas production function in the analysis. The productivity estimates of trypanocides in this study show that the damage control function provides consistently higher marginal productivity for both trypanocides (isometamidium and diminazene aceturate) in cattle production systems where disease is common and isometamidium resistance is high. However, the conventional Cobb-Douglas production function model shows that the productivity of trypanocidal drugs decreases in the situation where trypanosomosis disease prevalence and drug resistance are both high. The results suggest that treating the damage control inputs such as trypanocides in cattle production, as yield-increasing inputs in the conventional framework is likely to generate misleading results.

The marginal value products of isometamidium in all epidemiological conditions, and the marginal value product of diminazene in high-prevalence-high-resistance conditions, reveal an underuse of trypanocidal drugs. In a strict economic interpretation, this implies that in the short term cattle farmers could increase the profitability in those conditions if they increase trypanocide input beyond current levels. On the other hand, the static analysis applied in this study does not take into account the negative externality of trypanocide resistance in the future. If the use of trypanocide increases, cattle farmers will also be more likely to experience future losses from trypanocide resistance. To delay and even reverse the development of resistance the concept of “rational drug use” is recommended. Using drugs rationally entails: reducing need for drugs by disease prevention strategies; decreasing use of drugs by replacing with alternatives; ensuring

drugs are given only when clinically needed; giving the appropriate drug at the appropriate dose; and ensuring correct administration of the drug.

This study confirms that trypanosomosis is an important disease in the cotton zone of West Africa. Although drug resistance is increasing, trypanocidal drugs used are still effective against the disease. However, at the current sub-optimal level of isometamidium use, output losses are much higher – 9.8% to 22.7% of the value of output – than in a situation where isometamidium use is optimal for the epidemiological conditions. When disease control effort reaches the optimum level, output losses are much lower in all epidemiological conditions (1.3% to 1.5% of output). At the current use of trypanocidal drugs, economic losses due to trypanosomosis range from €9.50 to €22.00 per TLU[1] and year.

The costs of trypanosomosis at the current level of disease control effort, which include the control costs and the remaining loss after control are higher than they would be if isometamidium use was at optimal levels, in all epidemiological conditions. Currently, trypanosomosis disease costs cattle farmers €13.30 to €26.00 per TLU and year; however, at optimal disease control efforts, costs would be reduced to €8.60 to €10.10 per TLU and year, depending on epidemiological conditions. While the current costs of the disease represent on average 12% to 28% of the output derived from cattle production in the study area, costs of the disease at optimal drug usage would represent only 7% to 8% of output depending on disease prevalence and drug resistance levels. Lower costs of the disease and the increasing productivity of trypanocide in conditions of high drug resistance may create an intractable situation in which cattle farmers' choices for trypanosomosis control measures are guided by the phenomenon of path dependency. Once this occurs, the only options for controlling the disease would be the discovery of new drugs, for which the development is prohibitively expensive, or eradication of the tsetse vector of trypanosomosis – a strategy that has never been sustainable without considerable external support. Maintaining the effectiveness of trypanocides is hence a priority for farming systems in West Africa.

The study has demonstrated the feasibility of applying the damage control framework for measuring the productivity of animal disease control inputs at farm level in poor African countries. The model developed here concentrates on the direct effects of the disease,

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[1] TLU = Tropical Livestock Unit, corresponding to a bovine of 250 kg.

while the dynamic aspects of drug resistance are included in the model a simplified manner only. To capture these dynamic processes further research is required for example to develop a bio-economic model that integrates the impacts of trypanosomosis on cattle farmers' livelihoods and adequately captures the biological process of drug resistance.

Keywords: Trypanosomosis, trypanocidal drug resistance, productivity, output losses, disease costs.

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List of abbreviations

AAT	African Animal Trypanosomosis
AIC	Akaike’s Information Criterion
ANOVA	Analysis of Variance
BMZ	Bundesministerium für wirtschaftliche Zusammenarbeit und Entwicklung
CAHW	Community Animal Health Worker
CIRDES	Centre International de Recherche-Développement sur l’Elevage en Zone Sub-humide
CMDT	Compagnie Malienne de Développement des Textiles
CRRA	Centre Régional de Recherche Agronomique
DALY	Disability Adjusted Life Year
DDT	Dichlorodiphenyltrichloroethane
DIM	Diminazene
ELISA	Enzyme-Linked Immunosorbent Assay
EUR	Euro
FAO	Food and Agriculture Organisation
FCFA	Franc Communauté Française d'Afrique
GDP	Gross Domestic Product
GMM	Generalised Method of Moments
GTZ	Deutsche Gesellschaft für Technische Zusammenarbeit
HH	Household
IER	Institut d’Economie Rurale
IFAH	International Federation of Animal Health
ILCA	International Livestock Centre for Africa
ILRAD	International Laboratory for Research on Animal Diseases
ILRI	International Livestock Research Institute
ISCTRC	International Scientific Council for Trypanosomosis Research and Control
ISMM	Isometamidium
KAP	Knowledge Attitude and Practices
kg	Kilogramme
km^2	Kilometre square
LCV	Laboratoire Central Vétérinaire
LPEC	Livestock Productivity Efficiency Calculator
MRA	Ministère des Ressources Animales
MVP	Marginal Value Product
mg	Milligramme

mm	Millimetre
OLS	Ordinary Least Square
2SLS	Two-Stage Least Squares
OECD	Organisation for Economic Cooperation and Development
OMS	Organisation Mondiale de la Santé
PATTEC	Pan African Tsetse and Trypanosomosis Eradication Campaign
PSU	Primary Sample Units
SAS	Statistical Analysis System
SD	Standard Deviation
SIT	Sterile Insect Technique
TLU	Tropical Livestock Units
UBT	Unité de Bétail Tropical
ULAT	Unité de Lutte Anti-Tsetse
UNEP	United Nations Environmental Programme
UNDP	United Nations Development Programme
US	United States
VIF	Variance Inflation Factors
VSG	Variable Surface Glycoprotein
WHO	World Health Organisation

Chapter 1

Introduction

This thesis carries out an economic analysis of the use of drugs in controlling African Animal Trypanosomosis (AAT), a serious disease of cattle and small ruminants, in villages in Burkina Faso and Mali in West Africa that exhibit resistance to those drugs. It applies a production function framework integrating a damage control function to quantify cattle production output losses, as well as the productivity effect of trypanocide use under different epidemiological conditions. This chapter first describes the background and the research problem of the study. The objectives of the study are then presented, and the final section outlines the organisation of the thesis.

1.1 Background and research problem

Poverty is an important problem in West Africa, where the majority of countries are at the bottom of the Human Development Index (UNDP, 2004). The current focus of donors and governments on the first objective of the Millennium Development Goals (eradicate extreme poverty and hunger) has placed much attention on the rural economy (UNDP, 2003; Toulmin and Guèye, 2003). While the economy of West African countries is in a process of diversification, agriculture continues to play an important role in the reduction of poverty and is seen as the engine that will drive economic growth and development (FAO, 2004). Agriculture, defined as both crop and livestock[2] production, provides 30–50% of Gross Domestic Product (GDP) in most West African countries. It is the major source of income and livelihoods for 70–80% of the population and supplies food and revenue from the export of cash crops and livestock products (Toulmin and Guèye, 2003). Although the economies of the region are diversifying, farming is likely to remain of central significance to incomes and livelihoods for the foreseeable future (Fafchamps *et al.*, 2001). Hence, agriculture remains an increasingly dominant influence on the ecosystems of the region (Wood *et al.*, 2000) and great pressures are being placed on arable land, water, energy, and biological resources to provide an adequate supply of food while maintaining the integrity of those ecosystems. There are often significant trade-offs between the provision of agricultural outputs from agro-ecosystems and the conservation of the biological resources needed for food production (Pimentel *et al.*, 1997). However,

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[2] Livestock are farm animals such as cattle, sheep and chickens raised whether for home consumption or to generate income.

improvements to input productivity and returns gained from agriculture have been identified as a key means of reaching poverty reduction targets and at the same time protect the biological resources available (Pimentel *et al.*, 1997). Many factors, including livestock diseases such as AAT, jeopardize the ability of agriculture to achieve this important goal (Perry *et al.*, 2002). Trypanosomosis is controlled by different strategies; however the most important one, especially for cattle, remains the use of trypanocidal drugs. Cattle farmers' high reliance on drugs for the control of the disease makes them very vulnerable to the emergence of drug resistance. As stated by Hazell and Lutz (1998) modern inputs in farming systems can harm the environment and exacerbate poverty and food insecurity among rural people. The problem inherent in drug resistance can be conceptualised as one of optimal natural resource management where the resource stock is susceptible pathogens—which are trypanosomes in the case of trypanosomosis—ensuring the effectiveness of drugs (Laxminarayan, 2003). As resistance develops, the stock of susceptibility (effectiveness of drugs) can be augmented by creating new drugs. Unfortunately in the case of trypanosomosis, because of high development costs and small market volumes (Sones, 2001) no new drug is expected to reach the market in the foreseeable future. In such a situation it is important to search for interventions that extend the life span of the currently available drugs. However, one of the primary problems related to utilisation and protection of natural resources is the lack of supporting information for decision makers. In order to avoid divergence in policy goals between and among various decision makers that can lead to a negative impact, and to ensure that trypanocidal drug use satisfies the demand of sustained economic development, it is essential to introduce mechanisms based on economic principles. However, the problem of drug resistance is one that involves the community as a whole. Drug resistance affects all of the farming community: those who misuse the drugs and those who use them according to recommendations. Hence, solutions to the problem require decisions at local, national, and regional levels to ensure social welfare of the community, as well as private farm level actions where marginal value products of inputs drive economic decisions. This study focuses on farm level decisions on the use of trypanocidal drugs. Also, the study provides an opportunity to apply to animal disease control the damage control framework that has been widely applied to crop protection problems (Pemsl, 2005; Shankar and Thirtle, 2005; Huang *et al.*, 2002; Ajayi, 2000; Lichtenberg and Zilberman, 1986).

In order to find policy interventions for the sustainable use of drugs, it is necessary to perform as a first step an economic analysis of trypanocide use at farm level. This analysis of trypanocidal drug use is achieved through assessment of the productivity effect of drugs and will provide a better understanding of cattle farmers' decision-making for drug use. Also, the costs of the disease must be quantified under different epidemiological conditions, showing the magnitude of the economic implication of trypanosomosis at farm level.

1.2 Objectives of the study

Across much of West Africa, where trypanosomosis is the most important livestock disease and a major constraint on livestock development, drug use remains the most important strategy of control, and the economic performance of cattle production depends on the efficacy of disease control measures. This performance could be diminished by the declining susceptibility of trypanosomes to the available trypanocidal drugs.

This study aims to provide insights into the economics of trypanocide use and to generate information towards improving the management of trypanocide resistance in the cotton zone of West Africa. The main objective of the thesis is to advance the methodology for measuring the productivity of trypanosomosis control measures, with an emphasis on trypanocides in West African cattle production.

The specific objectives are:

(i) To test the damage control methodology as a tool for measuring the productivity of animal disease control.

(ii) To assess the productivity of trypanocide use at farm level under different epidemiological conditions.

(iii) To assess the direct costs of trypanosomosis at farm level.

The study was carried out as part of the regional interdisciplinary research project titled "Improving the management of trypanocide resistance in the cotton zone of West Africa" and funded by the German Ministry of Co-operation and Development (BMZ) and the Deutsche Gesellschaft für Technische Zusammenarbeit (GTZ).

1.3 Organisation of the thesis

The second chapter describes the trypanosomosis disease and the different methods for its control. The chapter is divided into three main parts. After a short introduction to the economic importance of the disease in the first part, the epidemiology of trypanosomosis is presented in the second part. The third part presents different methods of controlling the disease. Finally, there is a summary of the main issues discussed in the whole chapter. The chapter shows that drug use is the most important strategy adopted by cattle farmers in West Africa, and reliance on drugs has led to resistance that threatens the effectiveness of the continued use of trypanocides. Trypanocidal drugs are different from yield enhancing inputs in terms of their action on cattle output. Their distinctive contribution lies in their ability to increase the share of potential output that producers realise by reducing damage from damaging agents. Hence, the productivity analysis of such damage control inputs requires a different conceptual framework from that applied to yield increasing inputs.

Chapter 3 presents the conceptual framework and methodology used in the study of the economic analysis of cattle trypanosomosis control and the productivity assessment of trypanocides. The chapter is divided into seven main sections. The first section presents livestock diseases as an economic problem. In section two, the definition of livestock production losses due to diseases is discussed. Section three presents the production function approach in animal health economics. A review of methodology for assessing livestock productivity is presented. After discussing the literature related to the measurement of the productivity of livestock, the approach of valuing the output of cattle production for the study is given. The section ends by presenting the neoclassic concept of inputs productivity assessment. The framework of damage control in animal health economics is discussed in section four. The biological capital nature of trypanosome susceptibility and its impact on the productivity of trypanocide is discussed in section five. Concepts of user cost and path dependency of trypanocide use are discussed in section six. In the last section of the chapter the research hypotheses of the study are derived. In order to test the hypotheses through methodologies developed in this chapter 3, relevant epidemiological information and inputs/output data, as well as price information, are needed.

In chapter 4 the methods used for data collection are described. A procedure was designed that allowed the integration of socio-economic and biological data relevant to the analysis of the productivity effect of trypanocide use. The chapter is divided into four sections. In the first section the description of the study area is presented. The survey of household characteristics and knowledge, perceptions and practices of cattle farmers in the study area is given in section two. The third section describes the herd monitoring for inputs and outputs of cattle production. In section four the price data collection approaches are presented. The chapter ends with a summary that describes how data collected were organised and used to test the hypotheses and to achieve the objectives of the study.

In chapter 5, household characteristics and cattle farmers' knowledge, perception and practices of cattle production and trypanosomosis control are presented. The chapter is divided into four sections. The first section describes the characteristics of cattle farmers in the study area of Burkina Faso and Mali. In the second section, farmers' husbandry practices, knowledge, perceptions of trypanosomosis disease and its control, and farmers' practices of control, are discussed and comparisons made between farmers in Burkina Faso and Mali. The effectiveness of trypanocides as perceived by cattle farmers in both countries and factors contributing to trypanocide treatment failures as perceived by farmers are discussed in section three. The chapter ends by summarising the main findings.

Chapter 6 presents the results of cattle production analysis and the productivity of trypanocides and other cattle production inputs under different epidemiological conditions using econometric methods. The chapter is organised into six main sections. The first section presents cattle production function in the study area. The empirical models of production function used for the analysis are discussed and the specification of the functional form of the damage control function used is presented. In the second section, the variables that are included in the cattle production models and their relevance are discussed. In the third section the results of the regression models are presented and the coefficient estimates are discussed. In section four, after the mathematical derivation of the marginal productivity of inputs, the marginal value product of damage control inputs and the yield increasing inputs are computed. The marginal rate of substitution between trypanocides is discussed. In the fifth section cattle production output losses under different epidemiological conditions and the costs of trypanosomosis are computed and discussed. The key findings are summarised in the last section of the chapter.

Finally, chapter 7 summarises the thesis and presents conclusions derived from the findings as well as recommendations for policy and further research.

Chapter 2

Trypanosomosis in Africa and its control

This chapter describes the trypanosomosis disease problem in livestock production in Africa and reviews the available disease control technologies. The chapter therefore provides the biological and technical parameters that facilitate the economic analysis of the problem of trypanocide resistance. In the first part of the chapter the economic importance of the disease is analysed and in the second part, the epidemiology of trypanosomosis is presented. The third part describes different methods of control of the disease.

2.1 Economic importance

Trypanosomosis is a disease of humans and animals carried by the tsetse fly; it is classified as severe in the majority of the sub-Saharan countries affected, where it is ranked among the first three priorities for veterinary diseases (FAO, 1992). As an animal disease it severely affects African agriculture (Swallow, 2003) and consequently the livelihood of rural populations (Hendrickx et al., 2004). Tsetse flies infest an area of about 10 million km^2 stretching across 40 countries in sub-Saharan Africa (Kamuanga, 2003). It is estimated that about 50 million people (Kuzoe, 1991) and 45 to 60 million cattle are at risk of contracting trypanosomosis (Kristjanson *et al.*, 1999; Chadenga, 1994; Gilbert *et al.*, 2001). Out of the 45 to 60 million cattle at risk, three to seven million die each year (Hadjuk *et al.,* 1994; FAO, 2000) and the productivity of the survivors in terms of draft power, milk production, growth and birth rate is lowered by 10–40% (Swallow, 2003). Estimated total losses due to trypanosomosis range from US$1.3 to 4.5 billion depending on the methodology used, assumptions made and the type of loss estimated (Kristjanson *et al.*, 1999; Budd, 1999; ILRAD, 1994; de Haan and Bekure, 1991; Jahnke *et al.*, 1988), which would make annual losses from trypanosomosis equal to 10% to 33% the livestock GDP in sub-Saharan Africa. As a human disease, about 300,000 cases of human trypanosomosis, or sleeping sickness, are reported each year in Africa (WHO, 1998a) generating an estimated 1.5 million Disability Adjusted Life Years (DALY[3]) (WHO, 2004a).

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[3] The Disability Adjusted Life Year or DALY is a health gap measure that extends the concept of potential years of life lost due to premature death to include equivalent years of 'healthy' life lost by virtue of being in states of poor health or disability. The DALY combines in one measure the time lived with disability and the time lost due to premature mortality (WHO definition).

2.2 Epidemiology

African animal trypanosomosis (AAT) is a vector-borne disease of domestic livestock and wildlife in Africa. The epidemiology of the disease is determined by four biological factors: trypanosomes (pathogen), tsetse flies (vector), reservoir hosts (wild animals) and domestic animals such as cattle, small ruminants and camels living within the physical environment. The epidemiology of the disease is complex due to diverse farming systems in Africa, different cattle breeds varying in susceptibility, numerous hosts, and diverse tsetse fly species with varying ecological niches and host preferences.

The pathogen is a protozoan parasite of the family Trypanosomatidae and genus Trypanosoma (Levine *et al.*, 1980). *Trypanosoma congolense* is considered the most important cause of AAT in East Africa, and *Trypanosoma vivax* in West Africa (Stephen, 1986). Compared to *Trypanosoma congolense, Trypanosoma vivax* infections exhibit higher parasitaemia (presence of the parasites in the animals' blood), but with less severe anaemia (destruction of red blood cells). It is difficult to clinically distinguish diseases caused by different trypanosome species and mixed infections are common. An important biological feature of pathogenic trypanosomes is the Variable Surface Glycoprotein (VSG), a protein that forms a dense coat on the trypanosome surface. With time, the host develops an effective immune response against trypanosomes with a specific VSG coat, removing these but not other trypanosomes that have switched to a new (temporarily unrecognisable) VSG coat. These variants form the next wave of infection. The antigenic variation of the surface coat is unique to trypanosomes and is the basis of the epidemiological features of intermittent parasitaemia and failure to develop effective post-infection immunity. Also, because of the phenomenon of antigenic variation, there is still no prospect for effective control or eradication of the disease through the development and use of vaccines (Pays, 1995).

Tsetse flies are the primary vector of trypanosomosis and the only vector capable of transmitting trypanosomes cyclically. A tsetse can acquire a trypanosomal infection when feeding on a mammalian host with parasites in its blood. The trypanosomes undergo a cycle of development and multiplication in the digestive tract of the fly until the infective trypanosomes are produced. Thirty-one species and subspecies of tsetse have been identified (Patterson and Schofield, 2004). Tsetse flies are exceptional insects; their reproductive rate is low (Gooding and Krafsur, 2005), both sexes feed only on blood, and mortality is low. Their longevity, mobility, and frequent feeding make tsetse highly efficient vectors, but the low rate of population growth means even small increases in mortality rate can result in population decline and even elimination (Hargrove, 2003). However, "despite their low fecundity, tsetse flies demonstrate great resilience, which makes population suppression expensive, transient, and beyond the capacities of private and public sectors to accomplish" (Gooding and Krafsur, 2005).

Biting insects may transmit trypanosomes mechanically. Mechanical transmission is the transfer of the pathogen from an infectious source to a susceptible host by a vector, without any reproduction or developmental changes in the pathogen. According to Jordan (1986) and Leak (1999), there is little evidence that mechanical transmission of trypanosomosis is of importance in Africa under natural conditions. Congenital transmission of trypanosomosis, which is the transfer of pathogens from mother to foetus, can take place (Melendez *et al.,* 1993). In this case the calf will be born infected. Also, carnivores can be infected with *Trypanosoma brucei* by consuming infected meat; the importance of these transmission routes is not known, but is not likely to be high. On the other hand, transmission due to a medical procedure is also possible and may be important when poor needle hygiene is practised.

Trypanosome parasites circulate in a variety of wildlife hosts, which generally tolerate infections or have a state of pre-immunity. A host with pre-immunity has a resistance to a particular infection owing to the presence in the blood of specific antibodies prior to the infection; hence wildlife can have trypanosomes in their blood without developing the disease. Domestic animals: cattle, small ruminants, equines, pigs, dogs and cats are also susceptible to trypanosomes. The existence of wildlife reservoirs and alternative hosts complicates the epidemiology of the disease, making it difficult to manage and perhaps impossible to eliminate. Cattle-infective trypanosomes are the most economically important in Africa and the susceptibility of cattle to the disease depends on their breed. African cattle stem from the *in situ* domestication of a wild ox that inhabited northern Africa many years ago (Bradley *et al.,* 1996). In contrast, Zebus were mainly introduced from South Asia (Bradley *et al.,* 1998.) West African breeds are trypanotolerant; and therefore they can survive and be productive even if trypanosomosis is prevalent. Tolerance is highly heritable and involves the ability to control parasitaemia, maintain weight and resist anaemia (Murray *et al.,* 1990). Hosts have developed mechanisms to prevent or mitigate attack by tsetse flies. For example cattle can flick their tail or flick the ears (Torr, 1994). Host behaviour affects susceptibility to tsetse, with more defensive behaviour associated with less successful tsetse feeding (Torr *et al.,* 2002).

The environment in which susceptible hosts and tsetse flies live provides conditions for transmission to occur. The distribution of tsetse flies is related to climatic conditions (Rogers and Randolph, 1993). In West Africa, trypanosomosis is transmitted by savannah and riverine tsetse. The former are declining as the savannah habitat is changing due to human activities (Budd, 2002). High transmission risk areas include watering places and locations adjacent to agricultural areas (de la Rocque *et al.,* 2001).

West Africa covers an area of about 7.3 million km^2 divided into four principal agro-ecological zones: arid, semi-arid, sub-humid and humid on the basis of plant growth days and amount and distribution of rainfall. In the sub-humid zone where our study villages are located, the plant growing days per annum vary from 181 to 270, and the annual rainfall from 1000 to 1500 mm. Using criteria from Seré *et al.* (1996), Dixon *et al.* (2001), Manyong (2002) and Thornton *et al.* (2002), the livestock production system of the zone is described as a Cotton-Maize-Sorghum-Livestock system (Fernandez-Rivera *et al.*, 2004). The system covers an area of 110 000 km^2 of what has become known as the cotton belt of West Africa and has about one million cattle (Fernandez-Rivera *et al.*, 2004). The system has been described by Williams *et al.* (2000) as the archetype of crop-livestock systems in the sub-humid zone of Burkina Faso and Mali. After the crops are harvested, the remaining crop residues are fed to livestock and the manure from animals is used as fertilizer. Although agro-climatic and demographic conditions may be the primary drivers of the evolution of farming systems, the introduction of appropriate technologies plays an important role. In the cotton belt of West Africa, cotton production was promoted through the provision of inputs and animal traction. Between 1960 and 1999 these efforts resulted in quadrupled cotton yields, and the use of animal traction equipment rose from near zero to 50% in Burkina and to 90% in Mali (Follin and Deat, 1999). This change in the farming system has led to a change in the disease pressure as more susceptible Zebu cattle are introduced (Hendrickx *et al.*, 1999; Leperre and Claxton, 1994). Successful innovation of cotton production using draft cattle is a driver for a change in the disease control strategy at farm level and may be increasing the risks of cattle disease and drug resistance.

2.3 Control technologies

The control of trypanosomosis has included control of the vector, farming of trypanotolerant breeds and the use of prophylactic or curative medicines (McDermott and Coleman, 2001; Itty, 1992; Shaw, 1986). In West Africa, the recommended strategy for controlling the disease has been an integrated approach combining vector suppression in epidemiological hot spots and disease management at the herd level through the strategic use of trypanocides combined with the keeping of local trypanotolerant breeds (Hendrickx *et al.*, 2004). However, trypanocidal drug treatment used alone without any integration with other techniques remains the principal disease control method applied by all communities in the cotton zone of West Africa. Other methods are much less commonly employed (McDermott and Coleman, 2001).

2.3.1 Vector control

Many strategies of vector control have been used. Control of tsetse was initially through destruction of tsetse habitat or slaughter of wildlife hosts (Leak, 1999). Bush-clearing leads to ecological problems and is difficult to maintain, while destruction of wild animals has become unacceptable on conservation and animal welfare grounds. Biological control using predators or pathogens has had little success (van der Vloedt, 1991). The sterile insect technique (SIT) was used on Zanzibar, a small island with little risk of reinvasion; eradication was declared in 1997 and trypanosomosis has not recurred (Vreysen *et al.,* 2000). SIT is currently promoted as a means to eradicate tsetse from Africa, (PATTEC, 2001). However, fundamental questions on the feasibility, appropriateness and cost-benefit of this operation remain unanswered (Rogers and Randolph, 2002). The most important form of vector control has been the use of insecticides. Ground-spraying of tsetse sites with residual insecticide was widely used following the introduction of cheap persistent insecticides such as DDT and dieldrin fifty years ago; more recent campaigns have used less toxic synthetic pyrethroid insecticides. The method is labour intensive, logistically demanding, and potentially dangerous for the environment and the operators. More recently campaigns with aerial spraying have been carried out. The cost and potential side-effects of ground and aerial spraying stimulated interest in environment-friendly insecticide-treated traps/screens or baits. Hence, the method currently employed to control tsetse flies in West Africa is the use of synthetic pyrethroid insecticides to impregnate traps and screens, sometimes additionally baited with odour attractants. In addition, live animals treated with insecticide through spraying, dipping or by pour-on treatments have been used as live targets (Bauer *et al.*, 1992). In recent years interest has grown in community-managed and funded vector control (Barrett and Okali, 1998). The major drawback to the sustainability of this approach is that it requires the active participation of the community. Thus the approach requires economic incentives in order to be accepted by farmers as compared to methods of a more private nature, such as the use of curative or prophylactic drugs or disease tolerant livestock (Kamuanga, 2003). Tsetse control has been employed for more than 50 years with little long term success; vector control programs have cleared less than 2% of the tsetse habitat in the whole of Africa (Budd, 1999). Areas once cleared by vector control frequently become reinfested by immigrating flies, so that the overall distribution of tsetse flies has remained largely unaltered by man's interventions (Milligan and Baker, 1988).

2.3.2 Trypanotolerant breeds

Trypanotolerance has been defined as the relative capacity of an animal to control the development of the parasites causing trypanosomosis and to limit their negative effects (Murray and Dexter, 1988; Murray *et al.*, 1982). This capacity of some livestock species and breeds to survive, reproduce and remain productive under trypanosome risk was recognised and exploited by farmers, although there is a continued perception that because of their small size, trypanotolerant livestock are less productive than other breeds (Holmes, 1997). However, the International Livestock Research Institute (ILRI) demonstrated that in areas where the tsetse fly risk was low or zero, the productivity of trypanotolerant breeds (N'dama and the West African shorthorn) was equal to that of the physically larger trypanosusceptible Zebu breed (d'Ieteren *et al.*, 1998). In Africa as a whole, there are 12 million trypanotolerant cattle, or 5% of the total cattle population (Agyemang, 2000). Trypanotolerant cattle are used mainly in west and central Africa where they comprise 20% of the bovine population. Trypanotolerant cattle have other desirable characteristics including heat tolerance (Ferguson, 1987); resistance to helminths (Mattioli *et al.,* 1992); ticks (Mattioli *et al.,* 1993); and tick-borne diseases such as dermatophilosis (ILCA, 1979), anaplasmosis and babesiosis (Starkey, 1984); and lower nutritional and husbandry requirements. Despite these advantages, wherever Zebu can be raised they displace the trypanotolerant breeds. The slow increase in trypanotolerant cattle population compared to other breeds (Agyemang and Rege, 2004), and the lower price fetched in markets (Kamuanga *et al.,* 2001a) are the main reasons why these cattle continue to be less preferred by farmers. However, crossing trypanotolerant cattle with Zebus is widely practised by farmers and nearly all cattle in the study zone are to some extent trypanotolerant. Although trypanotolerant cattle can be economically productive even under conditions of high infection pressure (Itty, 1996), in areas with high risk of the disease, medicines (trypanocidal drugs) are generally required in order for animals to be sufficiently productive (Jordan, 1995).

2.3.3 Drug use

The use of modern trypanocidal drugs remains the most important strategy for controlling trypanosomosis. An estimated 70% of cattle at risk are treated each year (Agyemang and Rege, 2004; Allsopp, 1998). In West Africa, the drugs commonly used for trypanosomosis control at present are diminazene aceturate (DIM) and isometamidium chloride (ISMM). DIM has a short duration of action and is mainly used as curative trypanocide while ISMM can be used for prevention as well as for cure. Current trypanocides have been in use for more than 40 years. Because of the high price of new drug development, which is estimated at more than US$800 million (DiMasi *et al.*, 2003) per new compound, and the small African market for trypanocides (estimated at US$20 million per year) companies do not invest in the development of new drugs (Sones, 2001).

The use of trypanocidal drugs is common among livestock keepers is Africa and is expected to increase (Geerts and Holmes, 1998). The heavy reliance on trypanocides by livestock keepers has led to drug resistance. Resistance to trypanocides is the loss of sensitivity of trypanosomes to the antimicrobial effect of the trypanocidal drugs to which they were initially sensitive. Drug resistance is an outcome of natural selection. Trypanosomes, like all living populations, show variation and some are naturally more resistant to drugs than others. When a drug is used to treat a trypanosome infection, only the trypanosomes that are susceptible to the trypanocidal drugs are killed, while the small fraction of resistant trypanosomes survives. Therefore, the use of drugs gives a selection advantage to the resistant parasite, and over time, the trypanosome population becomes mainly composed of these resistant strains. Increased use of trypanocides leads to a cumulative build-up of adaptation processes within the biological system and trypanosomes become more adapted to the drugs and hence more resistant to them. There are increasing reports of trypanosome resistance, especially in East and West Africa (Diall *et al.*, 2003; Geerts and Holmes, 1998; Codjia *et al.*, 1993; Clausen *et al.*, 1992) and there is wide variation in levels of resistance or its risk factors from village to village in a given geographical area (Sinyangwe *et al.*, 2004; Twelde *et al.*, 2004). The sustainability of trypanosome resistance to trypanocides over time has been investigated in East Africa by

El Rayah *et al.* (1999), who showed in Sudan the continued presence of suramin[4]-resistant *Trypanosoma evansi*. The trypanocide suramin had not been used in Sudan for more than 20 years. They concluded that drug resistance in Sudanese *Trypanosoma evansi* appears to be a stable genotypic characteristic and persists in the absence of drug pressure. In Ethiopia, Mulugeta *et al.* (1997) showed that the drug-resistance of trypanosomes did not alter over a four-year period. Once developed, drug resistance in trypanosomes is a continuous process (Kaminsky and Zweygarth 1989a).

Based on experience to date, resistance can be expected to emerge within approximately ten years following the introduction of a trypanocide to the market (Waller, 1994; Geerts and Holmes, 1998). Drug resistance in trypanosomes is likely to be promoted by the same factors that cause bacterial resistance to antibiotics, such as large-scale drug use and sub-curative doses (Holmes *et al.*, 2004). The evolution of resistance is strongly influenced by the behaviour of individuals and institutions (Laxminarayan, 2003). Privatisation and liberalisation of veterinary services in West Africa has led to a situation in which drug administration is often in the hands of cattle farmers or extension workers, who may be unskilled in differential diagnosis (determination of which one of two or more diseases with similar symptoms is the one from which the animal is suffering) and lack of knowledge of appropriate drug use (Van den Bossche *et al.*, 2000). One study in East Africa found that trypanocidal drugs are used more frequently than trypanosomosis occurs (Machila *et al.*, 2003). Also, studies in West Africa revealed that there is a persistent tendency to use trypanocidal drugs despite the knowledge among livestock keepers of low trypanosomosis prevalence (Kamuanga *et al.*, 2001b; Bauer *et al.*, 1999). Practised in all cattle-keeping communities at either significant or low risk of trypanosomosis, drug use is the only control strategy that has proven sufficiently attractive to be adopted spontaneously. Shaw (2003) has shown that the benefit derived from tsetse fly control would never reach the level achieved by using trypanocide for controlling trypanosomosis. Also, as a result of the privatisation of animal health services, livestock owners in West Africa are increasingly responsible for animal disease control, which is thus limited by the amount of money individuals can afford to spend on drugs or other control measures to keep their animals alive and to maintain or to enhance their productivity. This militates against the adoption of strategies that are not in the perceived direct and immediate financial interests of cattle farmers, such as vector control. Hence, drug use is likely to

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[4] Suramin is a trypanocide used mainly for the treatment of *Trypanosoma evansi* in camels and for early stage sleeping sickness in humans. In the past, it was used in cattle, but no longer.

continue to be a major disease control strategy, even in the presence of resistance. Used properly, veterinary drugs prevent losses and permit higher levels of production. However, used improperly they promote drug resistance. While the costs of inappropriate drug use and lost production are met largely by the farmer who misuses the drug, the costs of drug resistance are met by society and future generations. In human health, there is abundant evidence that medicines are unnecessarily and improperly used in developing countries (Trostle, 1996; Hogerzeil *et al.*, 1993) and that this has contributed to high levels of resistance (WHO, 1998b). The reasons for this irrational drug use in human medicine have been well described by WHO (2001a) and many of these are likely to apply to the irrational use of veterinary medicines including trypanocides (Grace, 2003). In response to widespread concerns over the use of human medicines, the World Health Organisation (WHO) has been promoting the concept of “Rational drug use”. Rational drug use occurs when medicines appropriate for the disease are administered correctly for adequate time periods and at the lowest cost to the client and their community (WHO, 1987). As such, the concept of “Rational drug use” explicitly incorporates the externality of drug resistance. The successful application of rational drug use in human medicine is well documented (Radyowijati and Haak, 2003) and the approach seems to be well adapted to trypanocidal drugs use as applied in West Africa (Grace, 2006).

Although numerous estimates can be found in the literature indicating high returns of investment on trypanosomosis control using trypanocides (Shaw, 2003; Itty et *al*., 1995), hardly any scientific evidence exists on the productivity of trypanocides at the farm level in an environment where drug resistance is prevalent. In this study an economic analysis of trypanocide use under a range of epidemiological conditions is conducted. The research will generate information crucial to the development of strategies for improving the sustained effectiveness and efficiency of trypanosomosis control and the management of trypanocide resistance in the cotton zone of West Africa.

2.4 Summary

Trypanosomosis is transmitted by tsetse flies and is a major threat to animal and human health in sub-Saharan Africa. There are three main strategies for controlling the disease in cattle production: vector control, use of trypanotolerant cattle, and treatment with prophylactic or curative trypanocidal drugs. The use of drugs is the most important strategy adopted by cattle farmers in West Africa. However, the current trypanocides have been in use for many decades and the reliance on drugs has led to resistance that threatens the effectiveness of continued use of trypanocides. When resistance has developed, and in a situation where a new drug will not reach the market in the near future, strategies need to be developed that extend the life span of the currently available drugs. As a first step the benefits from current drug use by farmers must be characterised. This includes the assessment of losses in productivity due to the disease and the damage abatement effect of trypanocides under farm conditions. To assess the economics of livestock disease control, an analytical framework is required. The following chapter describes the economic concepts relevant to the study and the conceptual framework and methodology of the economic analysis of trypanocide use.

Chapter 3

Conceptual framework and methodology of the economic assessment of livestock disease control

To perform an economic analysis of livestock disease control methods, different theoretical concepts and approaches can be applied. Productivity assessment of trypanocide use, the major method of control as presented in chapter 2, requires analytical tools that are based on the concept of marginality. This chapter presents the conceptual framework and methodology used in the economic analysis of cattle trypanosomosis control and the productivity assessment of trypanocides.

The chapter is divided into seven parts. The first part conceptualizes livestock diseases as an economic problem. In section two, the definition of livestock production loss due to diseases is discussed. Section three presents the production function approach as applied in the economics of animal health. A review of methodology of assessing livestock productivity is then presented. After discussing the literature related to the measurement of the productivity of livestock, an approach for valuing the output of cattle production is given. The section ends by presenting the neoclassic concept of inputs productivity assessment. Recognition of the distinction between production inputs as yield enhancing or damage reducing, a framework for damage control in animal health economics is discussed in section four. The biological capital nature of trypanosome susceptibility and its impact on the productivity of trypanocide is covered in section five. The concept of user cost and its implications for a possible path dependency of trypanocide use are discussed in section six. In the last section of the chapter, the research hypotheses for the study are derived.

3.1 Livestock diseases as an economic problem

As stated by Van Dijk and Verkaik (1987), livestock production is an economic activity involving a technical transformation process in which resources are used to produce livestock products for the benefit of the consumer. The transformation process can be impaired by livestock diseases (Marsh, 1999; Putt *et al.*, 1987). “In economic terms, a livestock disease is a particular class of negative influences in the value creating processes based on using livestock as economic resources (McInerney, 1996).” The negative effects of diseases on animal production are variable. The loss in output from animal production due to diseases that are most widely recognised in the production sector of cattle farming

(Tisdell *et al.*, 1999) can be divided into the following categories: death, weight loss, reproductive loss, and lactation effects (Morris and Marsh, 1992; Morris and Meek, 1980). Chilonda and Van Huylenbroeck (2001) and McInerney (1996) describe the economic implications of disease on cattle production as follows:

(i) Diseases can destroy animals, which are the major inputs of the livestock production process.

(ii) Animal diseases lower the productivity of the inputs used in the livestock production process.

(iii) Animal diseases lead to mitigation costs to avoid or to reduce the incidence of diseases or to treat cases.

(iv) Animal diseases affect human well-being because many diseases can be transmitted between animals and man, causing severe or fatal infections.

(v) Animal diseases induce a sub-optimal exploitation of otherwise available resources (e.g. the use of trypanotolerant cattle of low production potential in tsetse infested areas) or the revenue forgone as a result of denied access to better markets.

Trypanosomosis can modify many different physiological processes related to the disease effects described above, leading to the impairment of production in affected animals. These functional derangements and negative impacts that lead to output loss can be translated into measurable economic effects affecting the productivity of inputs used in the production process. However, as observed by McInerney *et al.* (1992), in animal health economics, confusion is often caused because the terms “loss” and “cost” are used rather loosely, and even interchangeably. Therefore in the next section the use of terminology will be clarified.

3.2 Concepts of losses and costs

The quantification of the losses due to human, plant, or animal diseases follows on from the actual disease prevalence and the nature and magnitude of the losses experienced in infected subjects (Putt *et al.*, 1987). In human health economics, the Disability Adjusted Life Year (DALY) is the only quantitative indicator of burden of human disease that reflects the total amount of healthy life lost (World Bank, 1993). Losses due to plant diseases are calculated from yield reductions due to pathogens (Oerke and Dehne, 2004).

In animal health, diseases have a variety of biological effects on animals that can lead to loss in output (Perry and Randolph, 1999; Rushton et al., 1999). Output loss represents benefits forgone through, for example, the death of the animal, or milk that has to be discarded because of contamination due to a disease. At the same time, output loss represents a benefit that could be realised if effective control methods existed and were used. In the disease epidemiology context, different levels of livestock production output that determine output loss can be distinguished. This can be divided into unavoidable and avoidable loss. Applying the concept developed by Zadoks and Schein (1979) for plant diseases (see Figure 3.1), different definitions of production loss corresponding to different levels of livestock output can be illustrated.

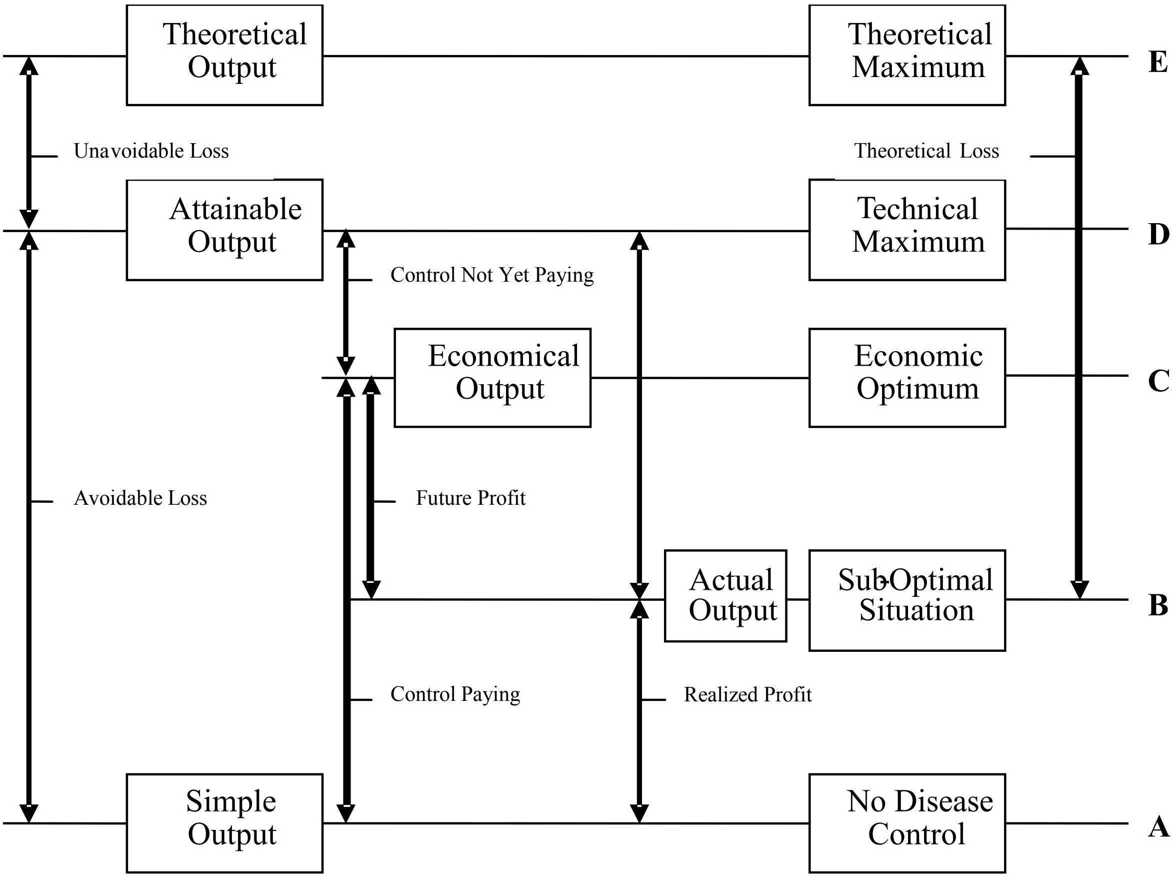

Figure 3.1: Livestock production output levels and losses

Source: Modified from Zadoks and Schein (1979)

The theoretical output level (E), which is the maximum output under ideal conditions with animals expressing their full potential of production, is of no interest here because we are dealing with real farm-level livestock output. Assuming that the attainable output (D) represents a level that can be attained by cattle farmers under real farm conditions, this corresponds to the output without trypanosomosis damage. If animals are infected by trypanosomes and there is no intervention, output is reduced to a minimum level (A), simple output. The economical output level (C) shows that intervention has a cost and can only be an economic option if at least a corresponding value of the output can be saved to balance the cost of the intervention. As a consequence, there is a loss (D-C) that should be accepted without further intervention because an intervention would be more costly than incurring the loss. Within the range between C and B, disease control efforts can reduce output losses and more profit can be realized. The difference between B and A is the realized profits from additional disease control effort starting from the simple output (A) where no intervention is applied. The actual output at point B is sub-optimal because it is lower than the economic output (C). Alternatively, a sub-optimal situation of too high an investment in disease control is possible. Then the actual output (B) would be above economic output (C) and economic losses would occur.

The negative effects of disease lead generally to extra inputs into livestock production. These extra inputs represent resources that have to be allocated to unplanned or non-preferred uses such as calling in the veterinarian for a sick animal, or taking measures to counteract a sudden disease threat. The term “cost” (e.g. “cost of the disease”) is defined as the combination of the value of output loss and expenditures related to the extra inputs used to mitigate the negative effects of disease; the expenditures to mitigate the effects of the disease are the control costs or the costs of intervention (Rushton *et al.*, 1999; McInerney, 1996; McInerney *et al.*, 1992).

3.3 Production function approach in animal health economics

The technical relationship between the quantity of inputs and the output produced is referred to as the factor-product relationship or the production function (Boehlje and Eidman, 1984). The relationship relates to the amount of products that can be produced for alternative combinations of inputs within a specified time interval, for example one year. It specifies the maximum output that can be produced with a given quantity of inputs and it is defined for a given state of technical knowledge (Samuelson and Nordhaus, 1998). The application of the production function framework in animal production has been less frequent than for crop production. Since the effect of animal diseases in a given production system is to reduce the efficiency with which inputs are converted into outputs (Rushton *et* *al.*,1999; Tisdell *et al.*, 1999), animal diseases can be treated within the production function framework, for which a well-developed set of concepts, economic principles and analytical procedures exists (McInerney 1996). This section is divided into three parts. In the first part, a review of methods of livestock productivity assessment is presented. The second part discusses the methodology applied in this study for the valuation of the output of cattle production in smallholder livestock production systems. In the third part, the concept and the method for assessing input productivity in cattle production are presented, together with a discussion of the neo-classical framework in which economic principles are assumed to guide decisions with regard to the optimal allocation of resources.

3.3.1 Review of methodologies of assessing cattle productivity

The major objective of this section is to present a review of the literature related to the measurement of the productivity of cattle in smallholder livestock production systems. In cattle production literature in general, three main approaches are used in assessing cattle productivity: the gross productivity based on calving rates and mortality (Putt *et al.*, 1987), the cow productivity index (FAO-ILCA-UNEP, 1980) and herd simulation approach (Konandreas and Anderson 1982).

3.3.1.1 Gross productivity based on calving rates and mortality

In livestock production systems producers continuously choose between future and present consumption. In the case of cattle production, the farmer can make this choice basically for two cattle production outputs:

(i) Milk can be sold or consumed by the household or, left to calves, thus increasing their nutritional intake with positive effects on survival and growth.

(ii) Cattle can be kept or slaughtered. Animals can be slaughtered at different ages i.e. as a calf, a young animal or an older animal before natural death. However, in the traditional systems, slaughtering occurs rarely. Cows and draught animals are slaughtered generally at a very old age; hardly any young animals are slaughtered or sold for slaughter.

The number of animals kept versus those slaughtered depends on production parameters such as calves' survival and adult animals' mortality. Gross productivity of a cattle herd can be expressed as births minus deaths. This shows the increase in the size of the herd from which cattle farmer can decide offtake (Putt *et al.*, 1987). Gross productivity is determined by calving rates and mortality without making any reference to other biological parameters of the herd. This productivity indicator is useful in making a crude estimate of the performance of the herd and provides the basis for assessing economic performance if prices capture the quality differences. However, the method cannot be used to economically assess the real productivity of smallholder cattle production systems since outputs that accrue to the cattle farmer in the system consist of more than a simple increase in the number of animals.

3.1.1.2 Cow productivity index

In 1980, The Food and Agriculture Organization of the United Nations (FAO), the International Livestock Centre for Africa (ILCA) and the United Nations Environmental Programme (UNEP) proposed a productivity index for comparing various breeds with respect to combined milk and meat production (Syrstad, 1993; FAO-ILCA-UNEP, 1980). The index considered reproductive rate (calving percentage), viability of cows and calves, weight of one-year-old calves, milk yield and body weight of cows. The scope of this productivity index is restricted to the production of milk and meat. Trail and Gregory (1981) used a similar index for comparing the merits of different cattle breeds and breed crosses in Kenya. They stated that “the index is the most meaningful way to compare the actual productivity of the breed types, given the level of information available”. Comparing productivity of indigenous cattle under traditional management in Sub-Saharan Africa, de Leeuw and Wilson (1987) stated that “although reproductive performance, overall mortality and growth of all stock are the main determinants of herd performance, it is the cow-calf unit that drives the system in the short term because of the milk supply, and in the long term because it is the number of calves, their mortality and growth that determine the sustained viability of the herd”. However, they pointed out that aggregate values of average herd productivity using the index ignore the variability that exists among individual producers within systems and among individual animals within herds. Although it is the cow-calf unit that drives the system in smallholder livestock production systems, the benefits that accrue to livestock keepers are more than milk and meat and also include manure, draught power and other benefits such as the insurance and financing benefits of keeping livestock. Cow productivity indices are of limited use because the common assumption that the effects of changes in parameters on performance do not interact is not necessarily valid; simulation models may perhaps be more appropriate (Bosman *et al.*, 1997).

Models of livestock systems can be positive or normative. Positive models use empirical data to test hypotheses, while normative models require some value judgments or assumptions. There are many different types of model used in livestock productivity studies, based on different techniques with varying degrees of complexity. Models may be either dynamic or static. A dynamic model will show the behaviour of a system over time, whereas a static model will only describe the steady-state situation representing the equilibrium that the system should eventually reach (Hary, 2004; Upton, 1989). Models may also be deterministic or stochastic. A deterministic model will describe the situation that would arise if all the variables had average values (Dijkhuizen *et al.*, 1991), while a stochastic model allows the variables to take values from a range according to some probability distribution (Konandreas and Anderson, 1982). As described by Pittroff and Cartwright (2002) models of livestock systems can be synthetic (including spreadsheet models and simulation models) as opposed to statistical models. Both types of models apply an interpretation framework to observed data. The following section describes the herd simulation models of livestock systems.

3.1.1.3 Herd simulation models

The main purpose of herd simulation models is to predict the future herd structure and production levels. The models can be animal performance driven or nutrient supply driven. Animal performance driven models evaluate the offtake of livestock by supplying, among other input variables, data for actual animal performance (Pittroff and Cartwright, 2002). The nutrient supply driven models evaluate the offtake of livestock production or processes determining livestock production as a function of nutrient supply to animals (James and Carles, 1996). The inputs of animal performance used in the herd model are herd structures, calving, culling and mortality rates. Given estimates of the production traits and offtake rates, the future herd structure and production levels can be predicted. The essential idea is that herd size at date $t + 1$ must equal herd size at date t plus births minus mortalities and net offtake (Upton, 1989). The most important herd simulation models currently in use include the Livestock Productivity Efficiency Calculator (LPEC) (Pan Livestock Services, 1991; James, 1984) and the International Livestock Centre of Africa (ILCA) Bio-Economic Herd Simulation Model (von Kaufmann *et al.*, 1991). The ILCA

Bio-Economic Herd Simulation Model was used by Itty in 1995 to compare the biological and economic performance of alternative management strategies for village milk production and in 1992 by the same author to study the control of trypanosomosis using trypanotolerant cattle and chemotherapy in Ethiopia, Kenya, Côte d'Ivoire, The Gambia, Zaire and Togo. It was also used by Kristjanson *et al.* (1999) in the estimation of the costs of African Animal Trypanosomosis and by Mulatu *et al.* (1999) in the assessment of the economic benefits of application of an insecticidal "Pour-on" to control tsetse in Ghibe in Southwest Ethiopia. The LPEC was used by James and Carles (1996) in measuring the productivity of grazing and foraging livestock. The LPEC index can be used to compare the efficiency with which different production systems utilize a foraging resource. The model is designed to express productivity per unit of forage intake; however, in situations where inputs like labour or drugs are the limiting factors, it might be inappropriate to assess production per unit of energy intake (Upton, 1993). Models should always be a good reflection of reality in order to obtain meaningful results for supporting decision-making in real-world situations (Dijkhuizen *et al.*, 1991).

As described above, more work on livestock productivity has been done using simulation models. However, herd simulation models that predict the output of biological processes based on a set of empirical observations are limited in the range of input combinations that can be considered. Since all methods have their limitations it is argued that a combination of several models may be a useful approach for the economic analysis of trypanocide use and the assessment of the impact of trypanocide resistance. Such an integrated approach is likely to provide more insights into factors that drive farm-level use of trypanocides.

In cattle production, the term "productivity" is frequently used inappropriately (James and Carles, 1996; Baptist, 1992). In this study the economic definition of productivity is used. Productivity is commonly defined as a ratio of a volume measure of output to a volume measure of input use (OECD, 2001). There are different productivity measures; usually productivity is expressed in one of three forms: partial factor productivity, multifactor productivity, and total factor productivity. The standard definition of productivity is actually what is known as a partial factor measure of productivity, in the sense that it only considers a single input in the ratio. Partial factor productivity measures are easier to relate to specific processes. A multifactor productivity measure utilizes more than a single factor, for example, both labour and capital. Hence, multifactor productivity is the ratio of total output to a subset of inputs (OECD, 2001). A broader gauge of productivity, total factor productivity is measured by combining the effects of all the resources used in the production and dividing it into the output. Different from crop production, where productivity is generally calculated per unit of land, cattle productivity is usually expressed in terms of production per animal (James and Carles, 1996). The Tropical Livestock Unit (TLU), corresponding to a bovine of 250 kg (Jahnke, 1982; Whiteman 1980; Boudet, 1975; Heady, 1975), allows comparison of production when animal size varies.

3.3.2 Valuation of cattle output

To measure productivity of cattle production systems using the production function approach, it is necessary to identify an appropriate indicator that can describe the different outputs of the system.

Under the conditions of small-scale cattle producers in West Africa there are six types of outputs considered in the valuation of cattle production. These can be divided into direct outputs, i. e. milk, meat, draught power, plus manure as a by-product, and indirect outputs including financing and insurance functions of keeping cattle.

Evaluating the output of livestock production raises some complex issues of measurement and imputation. First, the output produced by a cattle herd includes marketable outputs like milk and meat, and non-marketable outputs such as manure and draught animal power — although there may sometimes be imperfect local markets for manure and draught power (Lawrence and Pearson, 2002). Second, a cattle herd is an asset that generates changes in stocks over time, which can alter the value of the herd. Changes in stocks occur through live weight changes, births and deaths, sales and purchases as well as gifts (donated or received) of animals. Changes due to herd growth from animal reproduction and maturation are viewed as direct outputs. Animal maturation is defined as embodied production that is not consumed or sold but kept in animals, and animal reproduction leads to offspring. The value of the embodied production becomes available when animals are slaughtered, sold or given away (Moll, 2005). If, for example, an animal is still in the household’s possession at the end of any time period, then changes in the value of that animal need to be considered in total output. To capture these processes, the procedure adopted is to measure cattle output on an annual basis employing inputs and to produce outputs. For animals leaving the herd before the end of the monitoring period, or for animals entering the herd during the monitoring period, the contribution to total output can be estimated according to the total number of months spent in the herd.

In order to find common measure for production inputs and cattle outputs, it is necessary that these be measured using a common unit. As discussed above, a variety of productivity indices have been used. The difference in indices is due to differences in the purpose of the analysis. The majority of indices have specified output (often confined to meat and/or milk) in terms of value, mass or energy (James and Carles, 1996). In the production function framework, many productivity studies use models in which the dependent variable (output) and some of the input variables are expressed in monetary terms. The same approach will be followed in this study because it allows a direct interpretation of the marginal productivity estimates of the various inputs as marginal returns to a unit of input.

Some outputs of cattle production systems are difficult to value in economic terms when the product is not traded or there are imperfect markets. Generally, the valuation starts with the identification of the physical production obtained, thereafter following the valuation within the farming system.

To formalize valuation of cattle outputs it is useful to distinguish between recurrent production and embodied production (Moll, 2005). The recurrent products are milk, manure and draught power. Embodied production refers to change in body weight and changes in number of animals per herd. The embodied production is measured by subtracting the embodied production at period **t** from the embodied production at the end of period **t + 1**.

For the valuation of the recurrent production, no distinction was made between marketed and non-marketed outputs.

The value of the recurrent production $\mathbf{Q_r}$ during the monitoring period is defined as:

$$Q_r = \sum_{i=1}^{n} \sum_{j=1}^{3} q_{ji} p_j \qquad (3.1)$$

where q_{ji} is the quantity of recurrent production **j** produces by animal **i** and p_j the price for the recurrent output **j** (three recurrent products are considered), **n** is the number of animals in the herd.

The value of the embodied production Q_e during the monitoring period is calculated by summing the embodied production of individual animal **i** in the herd. The embodied production of the individual animal is obtained by subtracting the sale price of the animal **i** at the end of the monitoring period $P_{i(t+1)}$ from the sale price p_{it} at period **t** which is the start of the monitoring. The sales price is the total weight times the price per kg liveweight. The embodied value at the end of the monitoring period can be negative due to loss of body weight.

$$Q_e = \sum_{i=1}^{n} (p_{i_{(t+1)}} - p_{i_t}) \qquad (3.2)$$

The benefits that accrue to livestock keepers also include socio-economic benefits in the form of assets and security. Older animals may be kept in the herd for insurance or financing motives, thereby reducing the output of the production and the return to resources used.

In the study zone, cattle are among the most important traditional sources of status and prestige (Doran *et al.*, 1979). The cultural function of livestock is defined as “a value that goes beyond economic value” (Jahnke, 1982). In many cases, these cultural functions are closely associated with the type and importance of other livestock functions (Steinfeld, 1988). However, in this study only the asset (financing) benefit and the insurance (security) benefit are taken into consideration. The social and security benefits of livestock keeping are of special importance[5] in developing countries, where financial markets function poorly and opportunities for risk management through formal insurance are generally absent (Moll *et al.*, 2001). Therefore, to provide a more realistic valuation of cattle productivity, as many of the livestock functions as possible should be taken into consideration and should be aggregated into a single unit (monetary value) and related to the resources used, irrespective of whether these products are marketed, home-consumed or maintained in the herd for later use. Hence, a combination of techniques is required in evaluating the benefits of livestock keeping in smallholder livestock production systems (Behnke, 1985).

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[5] The absence or ill-functioning of markets for finance and insurance in developing countries, especially in rural areas, has been documented by Von Pischke *et al.* (1983), Binswanger and Rosenzweig (1986), Bosman and Moll (1995) cited by Moll (2005). The functions of cattle as security (insurance) and as a means of financing are significant in communities where it is difficult or impossible to fulfill these functions by other means. The consequence is that to cope with the vagaries of life, people in rural areas search for alternatives. Among the possibilities are keeping cattle, hoarding gold and jewelry, and investing in tree crops (Moll, 2005).

The benefit in financing: In the study area, it is common to use cattle as collateral in order to obtain loans, and the benefit of keeping cattle and selling them to meet specified requirements has a number of advantages. As described by Moll (2005), it provides: a hedge against inflation, as the real value of livestock generally remains fairly stable; the presence of cash is avoided, thereby averting possible claims from others that are difficult to refuse for social reasons; avoidance of storage losses if animals are exchanged for goods; and avoidance of the costs involved in borrowing for consumption or investment purposes. However, the sale of animals when there is a need, and not at the optimal moment as determined by the physical production or prices, implies a trade-off between the benefit from financing and the maximal cash returns. Also, transaction costs for animal sales may be in some cases higher than the benefits of other financing means. However, due to the lack of information they are not considered in the present study.

The benefit from financing can be estimated based on the concept proposed by Bosman *et al.* (1997) that in a subsistence economy the opportunity of using the value in animals for specific purposes at the desired time without having to pay in the form of interest confers measurable benefits. Hence, the benefit of financing during an observation period is calculated as shown in equation 3.3. The factor $\mathbf{b^f}$ is a proportion of the sale price and can be estimated by considering the cost incurred in alternative ways of financing (Ayalew, 2000; Bosman *et al.*, 1997). For the study zone the factor $\mathbf{b^f}$ was estimated from the opportunity cost of credit using the commercial interest rate of 10% generally applied for agricultural credit in the zone. The benefit of financing $\mathbf{B^f}$ derived from the herd of animals during the monitoring period is the sum of the benefits of financing derived from each animal **i** in the herd. The benefit is related to the sale price $\mathbf{p_i}$, which is the animal weight times the price per kg liveweight adjusted by the time the animal remains in the herd during the monitoring period.

$$B^f = \sum_{i=1}^{n} b^f p_i \tag{3.3}$$

The insurance function of livestock results from the potential of being able to sell animals in case of emergencies. Hence, having animals is comparable to having insurance and the absence of the need to pay a premium can be considered the tangible benefit. The insurance benefit involves the maintenance of a capital stock embodied in cattle as a guarantee for offsetting shortfalls in earnings and unforeseen expenses in the future (Moll, 2005; Ouma *et al.*, 2003; Ayalew, 2000; Bosman *et al.*, 1997). The insurance benefit can be estimated by assuming that the whole stock is available to provide household security through liquidation at any time when the need arises (Ayalew, 2000; Bosman *et al.*, 1997). It is quantified as a product of the insurance factor $\mathbf{b^s}$ (estimated from the opportunity cost of insurance) and the monetary value of the annualised current stock (weighted average body weight of the whole herd). Ayalew (2000) has discussed informal group insurance in the Ethiopian highlands and estimated the insurance benefit of goats to be 0.083 of the average value of the stock. Moll (2005) stated that if alternative options are not present, a guesstimate is required, and a range from 0.05 for stable situations without major risks to a factor of 0.20 for situations with severe risks, seems justifiable. In this study a conservative factor of 0.05 is used in the computation. The insurance premium for an animal **i** considered in this study covers a specified limit that is the period of monitoring or the time the animal spends in the herd during the monitoring period. The benefit of insurance $\mathbf{B^s}$ is therefore related to the average value of the animal for the period in consideration. The sum of individual animal insurance premiums gives the insurance benefit for the whole herd.

$$B^s = \sum_{i=1}^{n} b^s * \left[p_{i_{(t+1)}} + p_{i_t} \right] / 2 \qquad (3.4)$$

Summing up recurrent and embodied production and the estimated values of the benefits in insurance and financing, the value of output **Q** of cattle production expressed per TLU is defined as:

$$Q = Q_r + Q_e + B^f + B^s \qquad (3.5)$$

where:

(i) Q_r is the recurrent production, the flow product value gained from the animal as living resource.

(ii) Q_e is the embodied production, the increase in stock value through liveweight gain.

(iii) B^f and B^s are the benefit in financing and insurance functions of livestock.

3.4 Animal disease control in a damage control framework

3.4.1 Damage control framework

In crop and animals production, three production levels are distinguished: potential, attainable, and actual level (van de Ven *et al.*, 2003; van Ittersum *et al.*, 1997) to which a fourth level can be added as discussed in section 3.2 (simple output). These correspond to the matching growth conditions defined by a hierarchy of three groups of growth factors: growth-defining, growth-limiting, and growth-reducing factors. The growth-defining factors determine potential growth and production levels; they include the genetic characteristics of plant or animal and climatic factors that are beyond the farmer's control. The potential output or theoretical output as presented in Figure 3.1 is the highest production level achievable within the given physical environment and the genetic characteristics of plant and animal and assuming no growth-limiting or growth-reducing factors. Growth-limiting factors include shortage of water and nutrients. When these factors occur, the resulting output is defined as attainable output. The farmer can control the level of water and nutrients by irrigating, fertilizing and supplementing feed to animals to attain a certain output level. The attainable output level assumes no growth-reducing factors, defined as weeds, pests and animal diseases. Growth-reducing factors lower the production level further to the actual output level. However, when no action is taken to control the growth-reducing factors when they actually occur, the output is reduced to the simple output.

To integrate the growth conditions developed above with economic analysis, inputs in agricultural production are divided into two types: yield enhancing and damage reducing inputs. Yield enhancing inputs are directly involved in the biological process of crop or animal growth. They help to express the genetic potential of a crop or an animal and their use increases output. Damage control inputs are not directly involved in the basic biological processes of crop or animal growth. Their distinctive contribution lies in their ability to increase the share of the attainable output that producers realise by reducing damage from damaging agents. They are dependent on the occurrence of damage factors in order to show productivity effects. If the factor that causes the damage is not present, then the damage control input has no effect on quality or quantity of production (Fox and Weersink, 1995).

Damage control has come to play an important role in agriculture, where productivity growth is largely the result of enhanced use of damage control inputs (Babcock *et al.*, 1992). However, inputs that mitigate damage perform conditionally or indirectly on output. The role of damage control input in production processes relies on two hypotheses concerning the structure of production:

(i) the separability of the input vector with respect to a partition of inputs into direct inputs and damage control inputs.

(ii) a sub-function of damage control inputs that is different to that of the direct inputs. This sub-function is consistent with disease control decisions to apply damage control inputs to abate externally originating damage processes affecting potential production associated with direct input applications.

The separability allows distinction between the productivity of direct and damage control inputs. The sub-function of damage control inputs is conditional on the severity of the disease and other environmental factors (Carpentier and Weaver, 1997).

Generally, economic analysis of damage control inputs involves a single damage agent and a single damage control input. However, specifications can be extended to the case of multiple diseases and multiple disease control inputs, assuming the independence of damage by different diseases, and disease control inputs to be disease specific (Babcock *et al.*, 1992).

In earlier damage control input productivity studies such as the estimation of the productivity of agricultural pesticides by Headley (1968), pesticides were treated as direct yield-increasing inputs in the production function framework, leading to an overestimation of their productivity effect (Lichtenberg and Zilberman, 1986; Babcock et al., 1992; Carrasco-Tauber and Moffit, 1992). Instead, Lichtenberg and Zilberman (1986) proposed a model in which the actual output is considered as a combination of the attainable output and losses that are caused by the damaging agents. Therefore a distinction must be made between other direct production inputs ($\mathbf{Z}_i$) and the damage control inputs ($\mathbf{X}_i$) in the model specification. In order to take into consideration the distinct roles of direct versus damage control inputs, they suggested incorporating into the production function an abatement function that gives the proportion of loss eliminated by the control inputs. So far the damage control model has been widely applied to crop protection problems (Pemsl, 2005; Shankar and Thirtle, 2005; Huang *et al.*, 2002; Ajayi, 2000).

Based on the separability of the input vector and the sub-function of damage control inputs, which is different to that of the direct inputs, the actual livestock output **Q** can be expressed as a function of the potential output and a damage control function (**G**):

$$\mathbf{Q} = F(\mathbf{Z_i})*[\mathbf{G}(\mathbf{X_i})] \qquad (06)$$

Where the attainable output is a function of direct inputs, and the term $\mathbf{G}(\mathbf{X_i})$ is the damage control function.

The modelling framework is illustrated in Figure 3.2. In this framework, the direct inputs (animals and feed) take the central position and define the attainable output through animal growth function $F(\mathbf{Z_i})$ under a specific biophysical environment. The damage control function $\mathbf{G}(\mathbf{X_i})$ is generally defined on the [0 1] interval and possesses the properties of a cumulative probability distribution with $G(\mathbf{X_i}) = 1$ denoting complete eradication of damaging factors and $G(\mathbf{X_i}) = 0$ denoting zero elimination of the destructive capacity of damaging factors (Lichtenberg and Zilberman, 1986; Babcock *et al.*, 1992). This suggests that, when the growth conditions are optimal, the value of $\mathbf{G}(\mathbf{X_i})$ reaches 1 and the output **Q** attains its maximum: the attainable output. Under non-optimal conditions, the actual output is downscaled by the factor $\mathbf{G}(\mathbf{X_i})$.

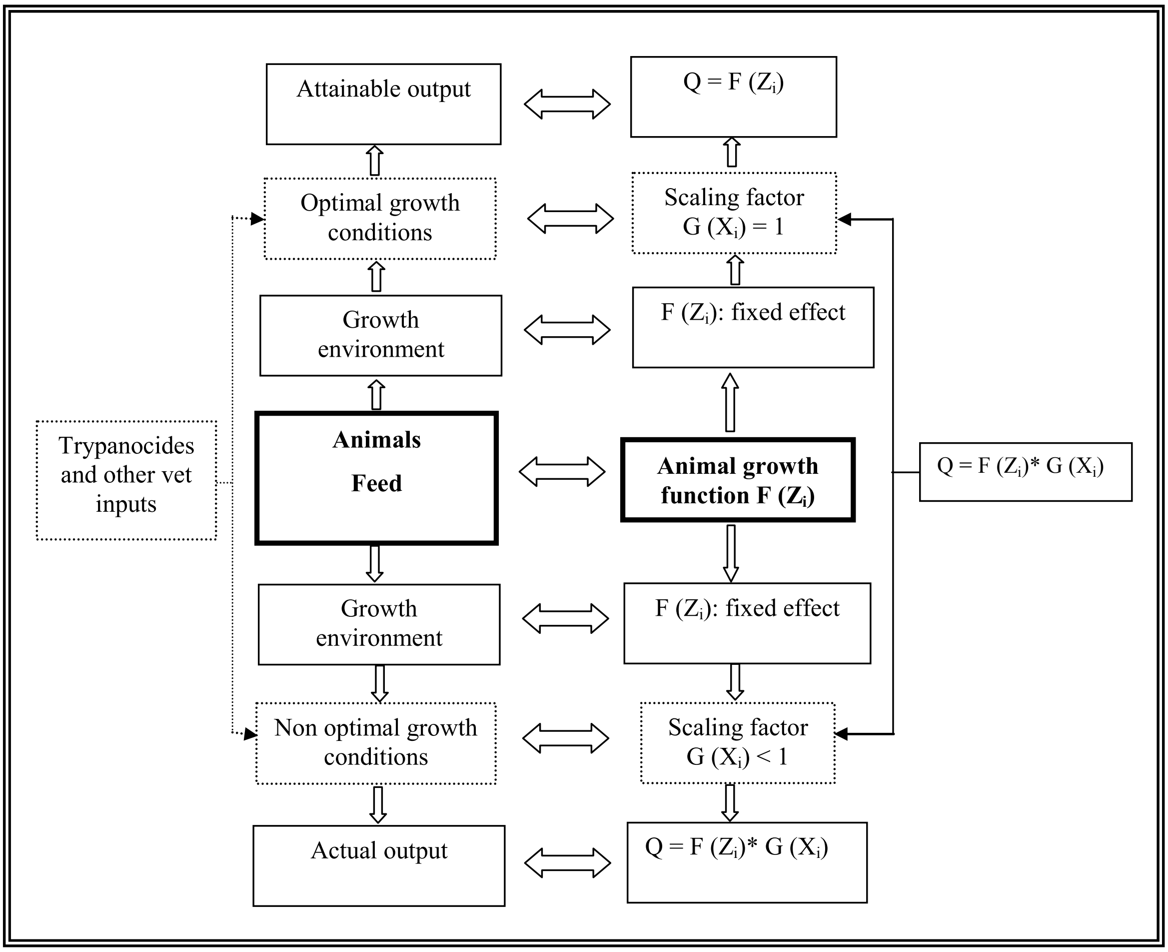

Figure 3.2: The modelling framework of damage control function

Source: Modified from Zhengfei *et al.* (2006)

The damage control function can be expressed in econometric form and then tested empirically. Different specifications[6] of the damage control function have been used and there is no particular reason to prefer one form to the others (Pemsl, 2005; Ajayi 2000; Babcock et al., 1992; Carrasco-Tauber and Moffit, 1992; Lichtenberg and Zilberman, 1986). However, in many cases, the estimated coefficients differ depending on the type of specification (see Carrasco-Tauber and Moffit, 1992). One of the important determinants of the modelling framework of the damage control function presented in Figure 3.2 is the environment in which the production processes being studied are taken place. Applying the damage control framework to cattle production with trypanosomosis disease in an environment characterised by drug resistance for example, requires the incorporation of drug resistance into the model specification, hence, the damage control is a function of the

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[6] The most important specifications used in damage control inputs productivity studies include: exponential, logistic, Weibull and Pareto.

disease prevalence, disease control intervention (trypanocide use) and trypanosome resistance to drugs. Controlling disease damage in non-optimal growth conditions has an impact on actual output by reducing output loss.

The impact of disease control on output loss is represented graphically in Figure 3.3, where Q_{max} represents the total herd output obtainable assuming that trypanosomosis is under control or that it does not occur at all (optimal growth conditions, see Figure 3.1 & 3.2). Output level O is zero production or complete output loss at maximum damage from trypanosomosis. Total output loss is an exception rather than the rule and in most cases; the actual minimum of output that a cattle farmer may obtain from his herd is greater than zero. The output level Q_{min} represents the output obtained when no direct[7] disease control inputs are used (simple output in Figure 3.1). This level of output is determined by many factors, such as the immune system of animals or the presence of disease tolerant animals in the herd as well as the nutritional status of animals (the state of animals' health in terms of the nutrients in their diets). Animal sensitivity to diseases is known to be affected by feed and minerals intake. In almost all cases if intake is reduced animal productivity may be impaired (Hawkins and Morris, 1978). The productivity of disease control inputs is not independent of the processes within the ecosystem being studied. Rather, they are inseparable. The heterogeneity of the ecosystem and the multiple and complex input-output interactions that may exist in the ecosystem might influence the productivity of damage control inputs (Carpentier and Weaver, 1997).

The difference between Q_{max} and Q_{min} is the potential output loss. This corresponds to a measure of the limit of the productivity of disease control inputs in terms of the maximum of output loss avoided due to the use of trypanocides. If for example, the animal is immuno-suppressed due to lack of feed or water or if the number of disease tolerant animals in the herd is low, the actual output Q_{min} may tend towards zero and the potential output loss will increase.

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[7] There may be measures that control disease as a by-product, such as improving nutrition. These are called indirect measures

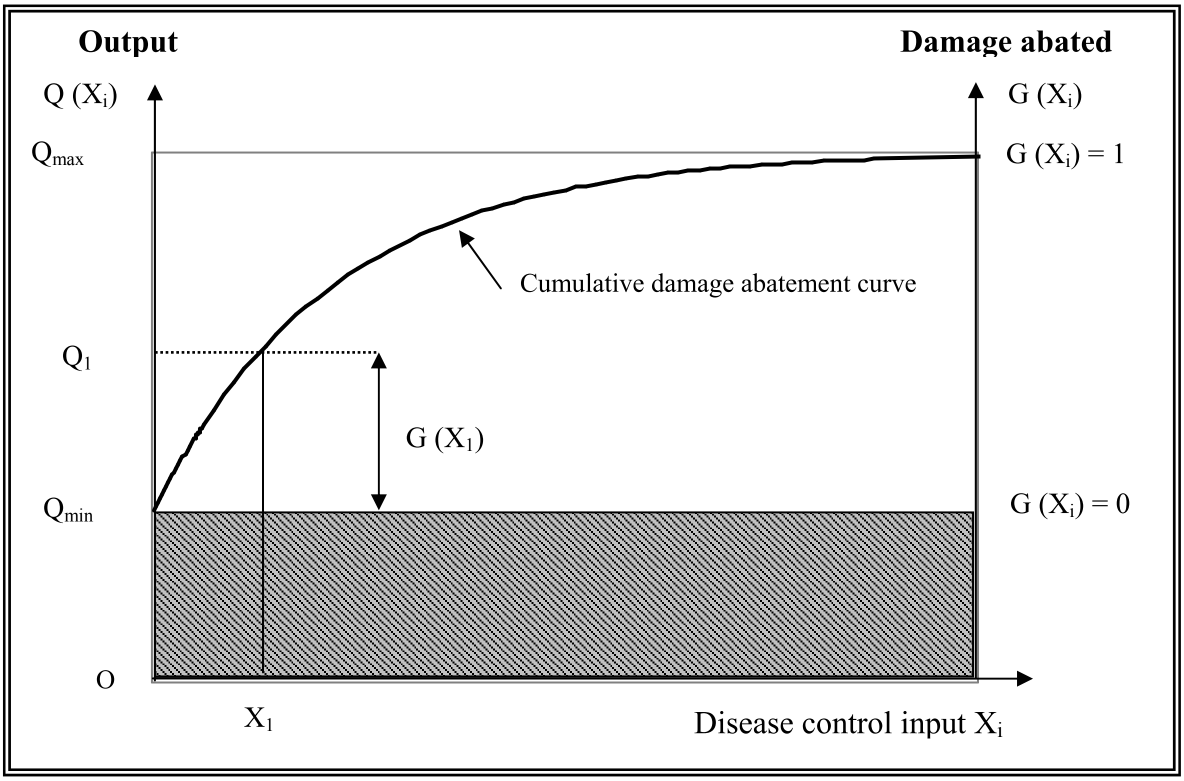

Figure 3.3: The impact of disease control on output loss: damage abatement

Source: Adapted from Ajayi (2000)

The modelling approach presented above has the merit of treating animal disease control in a damage control framework. The main reason of using such a model is the possible explanation of eventual overestimates of trypanocide productivity (Lichtenberg and Zilberman, 1986). However, the approach has some limitations. The estimation results are in most cases different depending on the type of model specification used (Pemsl, 2005; Ajayi 2000; Babcock et al., 1992; Carrasco-Tauber and Moffit, 1992). Also, determining the optimal damage control input use requires knowledge of the production function, the damage function and the control function (Chi *et al.*, 2002). Although knowledge in these areas is improving accurate estimates of the effects of disease on output, the effectiveness of treatment strategies on disease levels is to some degree limited due to large epidemiological data requirements.

3.4.2 Defining the optimal disease control

Neo-classical theory suggests that the productivity of production factors in a production function framework can be analysed based on the principle of marginal productivity. The principle of marginality states that an input is used until its marginal cost equals its marginal value product. In the case of animal disease control, the optimal level of disease control input is attained when the cost of an additional unit of the input can be recovered by the additional value of output saved. The general relationship between the disease control input cost and the value of output saved can be described as shown in Figure 3.4. In the absence of any control, losses would amount to L_1. With progressive increase in control costs, losses will decline but at a diminishing rate because of diminishing marginal returns to the disease control effort. The line L_1L_2 is an efficiency frontier if it defines the lowest output losses attainable for any level of control cost, or the least possible control costs for restricting losses to a specified level (McInerney, 1996). Since the economic cost of disease is the sum of the value of output loss and the cost of disease control, optimal management is concerned with reducing the cost incurred due to the disease to its lowest level. The line AB is the iso-cost line, indicating output loss and control cost combinations that amount to the same cost of the disease. The management strategy indicated by point M is the lowest cost that can be achieved in this situation, incurring control cost of C_m and accepting losses of L_m since it is not worth trying to lower them further. At this point the principle of marginality is fulfilled and the optimal disease control input can be derived.

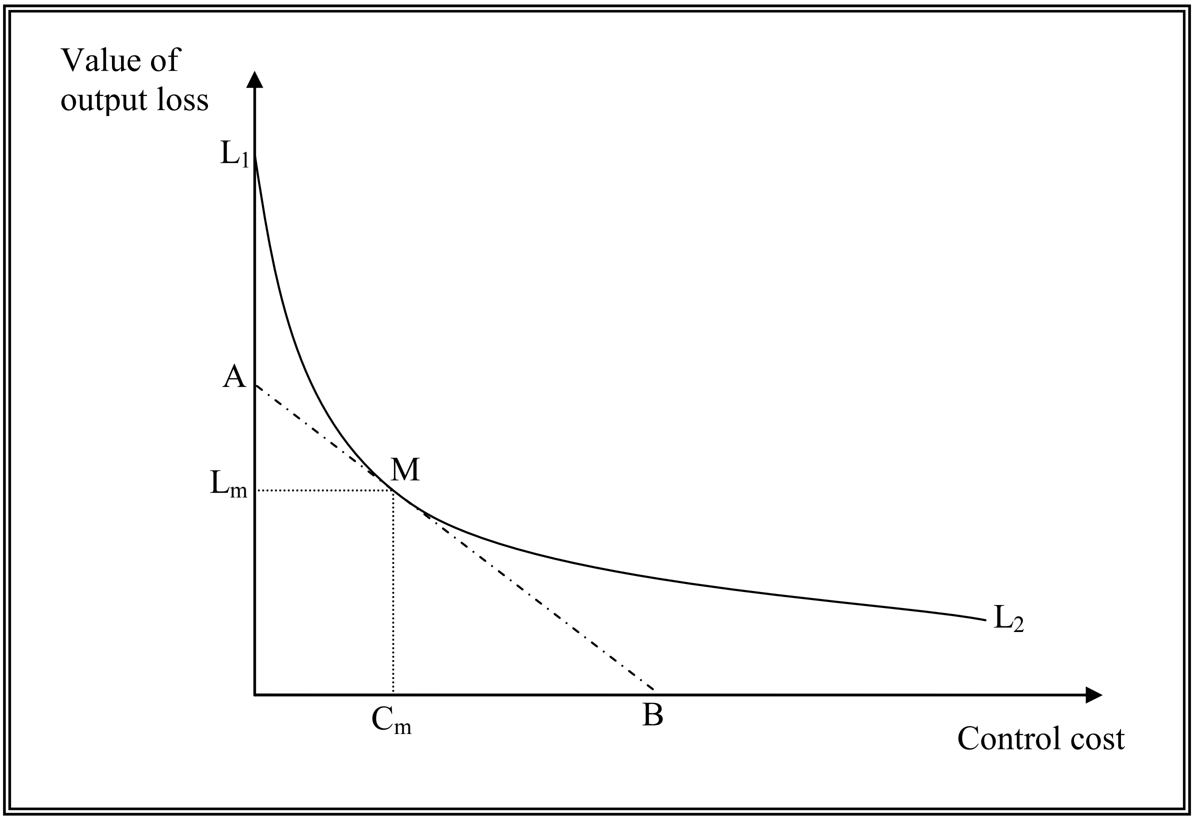

Figure 3.4 The relationship between output losses and control costs: optimal disease control level

Source: Adapted from McInerney (1996)

3.5 Trypanosome susceptibility and the productivity of trypanocide usage

Generally, the use of damage control inputs tends to subject producers to certain difficulties that do not arise in connection with the use of conventional or direct yield-increasing inputs. The most important problem is that in many cases the damaging agents (pest, weed, trypanosome etc.) involved adapt to the damage control measures taken as time passes, rendering the latter increasingly ineffective (Lichtenberg and Zilberman, 1986). The incorporation of the concept of pest resistance into a pest management model in order to illustrate the relationship existing between the economics of pest resistance and the economics of exhaustible resource, for example, has been extensively developed by Hueth and Regev (1974). As discussed in chapter 2, the susceptibility of trypanosomes can be considered as an exhaustible biological capital that is viewed as the total susceptibility of trypanosomes to currently used trypanocides, susceptibility being defined as the opposite of resistance. It is, then, a natural resource stock subject to management in a manner analogous to resource stocks in other extractive industries, extraction in this case being the use of trypanocides. Optimal trypanocide use implies conjunctive management of both the parasite and its associated stock of susceptibility (Hueth and Regev, 1974). Thus, any realistic model of optimal management of trypanosomosis must recognize this phenomenon. If trypanosomes develop a complete resistance to a type of trypanocide, that drug is comparable to an asset that has reached the terminal point of its service life. However, when the resistance is not complete, or when alternative strategies are not accepted and adopted by cattle farmers, the ongoing depletion of trypanosome susceptibility requires adjustment in the quantity of trypanocide use (dose adjustment) or prompts the switch to new and usually more expensive trypanocidal drugs. Unfortunately there is no immediate prospect of new compounds for commercial use (Sones, 2005). Hence, the adjustment is the increase in the quantity of trypanocide use, leading to high costs of the disease control. Also, as described for pesticide by Feder (1979), the quantity of trypanocide used may increase due to the uncertainty regarding drug effectiveness. In Burkina Faso and Mali, farmers tend to increase the standard dosage, and the practice is also used by veterinary professionals as an empirical response to emerging drug resistance (Grace *et al.*, 2006a).

The problem of growing resistance to damage control inputs has important economic consequences (Lichtenberg and Zilberman, 1986) that are crucial for the interpretation of damage abatement inputs productivity estimates (Ajayi, 2000). The impact of the changing levels of the effectiveness of trypanocides in a given livestock production system is represented graphically in Figure 3.5. As shown in the figure, Q_{min} represents the simple output when no disease control measures are applied. When trypanocides are used and resistance to the drug develops, the effectiveness of trypanocides becomes less and less. As a result, the cumulative damage abatement curve in a low resistance situation is above the cumulative damage abatement curve in a high resistance situation. The actual output Q_1 in a low resistance situation will be higher compared to actual output Q_2 in high a resistance situation. With the same quantity of trypanocide, more damage will be abated in a low resistance situation compared to high resistance, i.e., $G_1(X_1) > G_2(X_1)$ in Figure 3.5.

As depicted in Figure 3.5, the value of $G_1(X_1)$ and $G_2(X_1)$ on the scale [0 1] reduces output by $[1 - G_1(X_1)]$ and $[1 - G_2(X_1)]$ respectively. For the same amount of damage control input (X_1), $[1 - G_2(X_1)]$, which represents the remaining or uncontrolled damage in the high resistance situation, will be higher than $[1 - G_1(X_1)]$, representing the uncontrolled damage in the low resistance situation. As a result the cost of the disease, which is the sum of the value of output loss and the cost of disease control, will be greater in a high-resistance situation than a low-resistance situation.

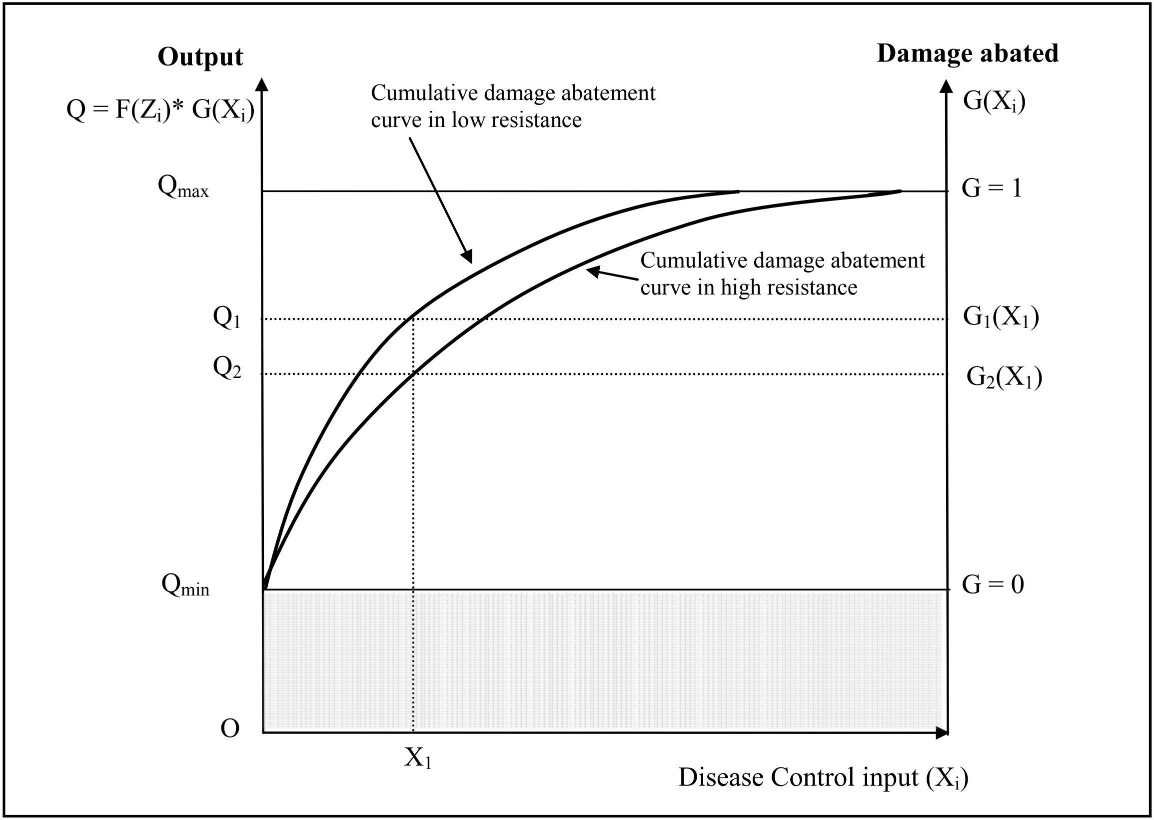

Figure 3.5: Impact of resistance on trypanocide productivity

Source: Adapted from Ajayi (2000)

3.6 User cost and the productivity of trypanocide usage over time

3.6.1 Impact of user cost

The economic definition of non-renewable or exhaustible resources such as trypanosome susceptibility states that the inter-temporal sum of the services provided by a given stock of an exhaustible resource is finite (Dasgupta and Heal, 1979). A non-renewable resource is depleted when used as an input in a production process and at the same time its rate of growth is nil; thus the flow of services obtainable from an exhaustible resource must necessarily decline to zero in the long run, especially for trypanocides when they continue to be used. The central problem is how to allocate the amount of the resource inter-temporally, that is between different points over time or between different generations. If the susceptibility of trypanosomes is supposed to decrease, this implies that the effectiveness of trypanocides will be less in the future. This means that in addition to trypanocide costs there are “user costs” that result in a reduced level of future benefits due to the decreasing susceptibility of trypanosomes. User costs reflect the scarcity of the resource and must be taken into account when deciding on any exhaustible resource use (Fleischer, 2000). Where user costs are involved, there is often a linkage between production decisions and outcomes in two different time periods. Optimal decisions on the use of trypanocides are only made when the management of the direct costs of trypanocides use and the associated indirect costs on biological capital (trypanosome susceptibility) are simultaneously optimised. Hence, if the marginal value of trypanocides’ contribution to livestock output is less than the sum of the marginal cost of trypanocides and the marginal cost of their use in reducing the stock of trypanosome susceptibility, then trypanocides should not be used.

The evaluation of the productivity effects of damage control inputs should not be restricted to only the private benefits accruing to producers, but should also consider externalities (Waibel *et al.*, 2003; Zadoks and Waibel, 2000). Externalities occur when the activities of one economic agent affect the activities of another agent in ways that are not taken into account by the operation of the market. Some of the externalities, such as drug resistance, that affect common property resource (trypanosome susceptibility) may be difficult to internalise because they only occur in the long run (Waibel *et al.*, 2003). These long term externality costs are borne by the actors — the cattle farmers using trypanocides. However, in addition to the users of the drug, others farmers, non-users and the society as a whole are also affected. The development of resistance as the consequence of drug use can have significant impacts on damage control inputs productivity, as was the case in pesticide use (Capalbo and Antle, 1988). This holds true for trypanocides. If livestock keepers include in their production decisions trypanocide “user costs”, the discounted present value of future net returns from trypanocide would certainly be less. Therefore, the exclusion of negative externalities associated with trypanocide use can result in an overstatement of productivity gain (Waibel *et al.*, 2003; Zadoks and Waibel 2000; Archibald, 1988).

The common property nature of trypanosome susceptibility implies that unlike other resource inputs, trypanosome resistance cannot be easily managed by individual livestock keepers. As the biological capital cannot be appropriated by an individual producer, the outcome will depend on the common decision taken with regards to trypanocide use by all farmers in the geographical area. This creates problems for the optimisation of trypanocide use because the individual livestock keeper, when aware of the problem of drug resistance, will consider only the level of resistance in his own herd. In the absence of external influence, there is a disincentive for a private producer to consider the implication of his current trypanocide use decisions on the development of drug resistance in the future. Hence, from a private economic point of view, there is no relationship between the amount of the natural resource consumed and the costs paid. This is also applicable to those users of trypanocides who are not aware of the negative externality created by drug resistance. As a result, individuals tend to use up as much of the resources, as possible leading to further degradation of natural biological capital. It then becomes increasingly necessary to use higher doses of trypanocide, which in turn further depletes the natural trypanosome susceptibility. This sets off a chain of events that makes livestock production more dependent on trypanocide and may lead to a phenomenon known as path dependency.

3.6.2 Path dependence and trypanocide use

There are a number of specific mechanisms that, in the context of certain behavioural and knowledge conditions, can produce path dependency. However, little is known about the relative importance and prevalence of these potential mechanisms (Martin and Sunley, 2006). A process of economic allocation is path dependent when the history of the process has lasting effects on subsequent allocation. In its loosest sense, path dependency means that current and future states, actions or decisions depend upon the path of previous states, actions or decisions, suggesting that past events and choices can influence and in some cases determine the outcomes of economic processes (David, 1985; Page, 2005). Generally, four causes are related to path dependency: increasing returns, self-reinforcement, positive feedbacks, and lock-in (Page, 2005). There are differences among these four. Increasing returns means that the more an outcome occurs, the higher the relative return to that outcome, and therefore it is more likely to occur in the future. This means that the more a choice is made or an action is taken, the greater its benefits. Self-reinforcement means that making a choice or taking an action puts in place a set of forces or complementary circumstances that encourage that choice to be sustained. Positive feedbacks suggest that an action or choice creates positive externalities with that same choice if made by other people. Positive feedbacks create something like increasing returns, but they differ. We might think of increasing returns as costs or benefits that rise smoothly as more people make a particular choice and of positive feedbacks as little bonuses given to people who have already made that choice and who will make that choice in the future. Finally, lock-in means that one choice or action becomes better than any other just because everyone else has made that choice or taken that action. Applied to trypanosomosis control, use of trypanocidal drugs and choice of cattle breed represent two control strategies that may lead to path dependency of drug use. Trypanotolerant breeds are less preferred by cattle farmers and when Zebu cattle which are trypanosusceptible can be raised they displace the trypanotolerant breeds (Grace, 2006). Increasing introduction of trypanosusceptible breeds increases the use of trypanocidal drugs which in turn increases drug resistance. The more the choice of drug use is made, the greater its benefits to cattle farmers leading to increasing return. One of the causes of drug path dependency may be found in the higher returns of the drugs (Shaw, 2003). However, the negative externality (drug resistance) created by drug use is more appropriately seen as the driving force behind path dependency (Page, 2005). The replacement of trypanotolerant breeds by susceptible cattle encourages the choice of trypanocidal drug use to be sustained (Self-reinforcement). Self-reinforcement factors lead to a lock-in which is extremely difficult to reverse (Liebowitz and Margolis, 1995). Although trypanotolerant breeds can be economically productive even under conditions of high infection pressure of trypanosomosis (Itty, 1996), livestock production may be kept on a trypanocide path, as was demonstrated for pesticide use by Cowan and Gunby (1996).

3.7 Summary and research hypotheses

From the theoretical framework presented above the following issues can be highlighted:

- A production function framework based on the concept of marginal productivity can be applied to assess the productivity effects of trypanocide.

- Due to the damage control nature of trypanocide, its productivity effect can be assessed in a damage control framework, where a distinction is made between other direct cattle production inputs and the damage control inputs by incorporating into the production function an abatement function that gives the proportion of loss eliminated by trypanocides.

- The growing resistance to damage control inputs has economic consequences that are important for the interpretation of trypanocide productivity estimates. In the case of trypanosomosis control, the damage control is a function of trypanocide use, the disease prevalence, and drug resistance.

Based on the problem analysis presented in chapter 1, and the analysis of different methods of control of the disease, as well as the theoretical aspects discussed above, the following hypotheses are identified:

(1) The productivity of trypanocidal drugs in cattle production at the farm level differs under different epidemiological conditions.

(2) The development of drug resistance contributes significantly to the higher costs of trypanosomosis in the small-scale cattle production system in West Africa.

In order to test these hypotheses, an integrated data collection procedure is used as presented in the next chapter. A collaborative approach has been applied, with direct responsibility for specific tasks assigned to veterinary epidemiologists and agricultural economists.

Chapter 4
Methodology of data collection

Chapter 4 describes the methods used for data collection. A procedure was designed (Figure 4.1) that allowed the integration of socio-economic and biological data relevant to the analysis of the productivity effect of trypanocide use. The chapter is divided into four sections. In the first section a description of the study area is presented. The survey of the knowledge, perceptions and practices of cattle farmers in the study area is presented in section two. The third section describes the herd monitoring for inputs and outputs of cattle production. Finally in section four the price data collection approaches are presented.

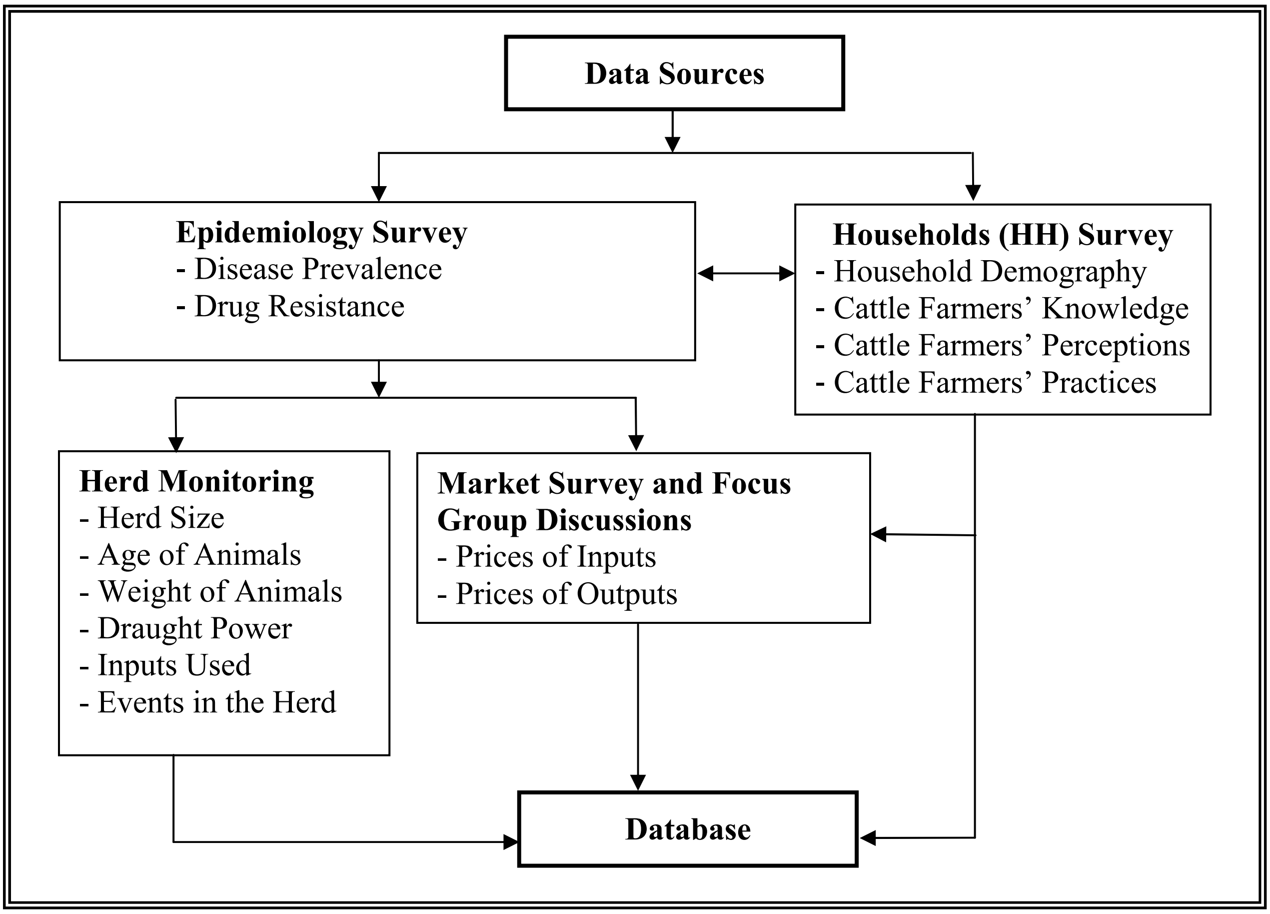

Figure 4.1: Data collection organisational chart

Source: Own presentation

4.1 Description of the research area

The study zone was identified as the cotton zone of Kénédougou (Figure 4.2), a region of approximately 15600 km^2 common to Burkina Faso and Mali (south-western Burkina Faso and south eastern Mali). The region has a sub-humid climate with two main seasons: a dry season from November to May and a wet season from June to October. The natural vegetation is wooded savannah with important patches and small strips of gallery forest along the river network.

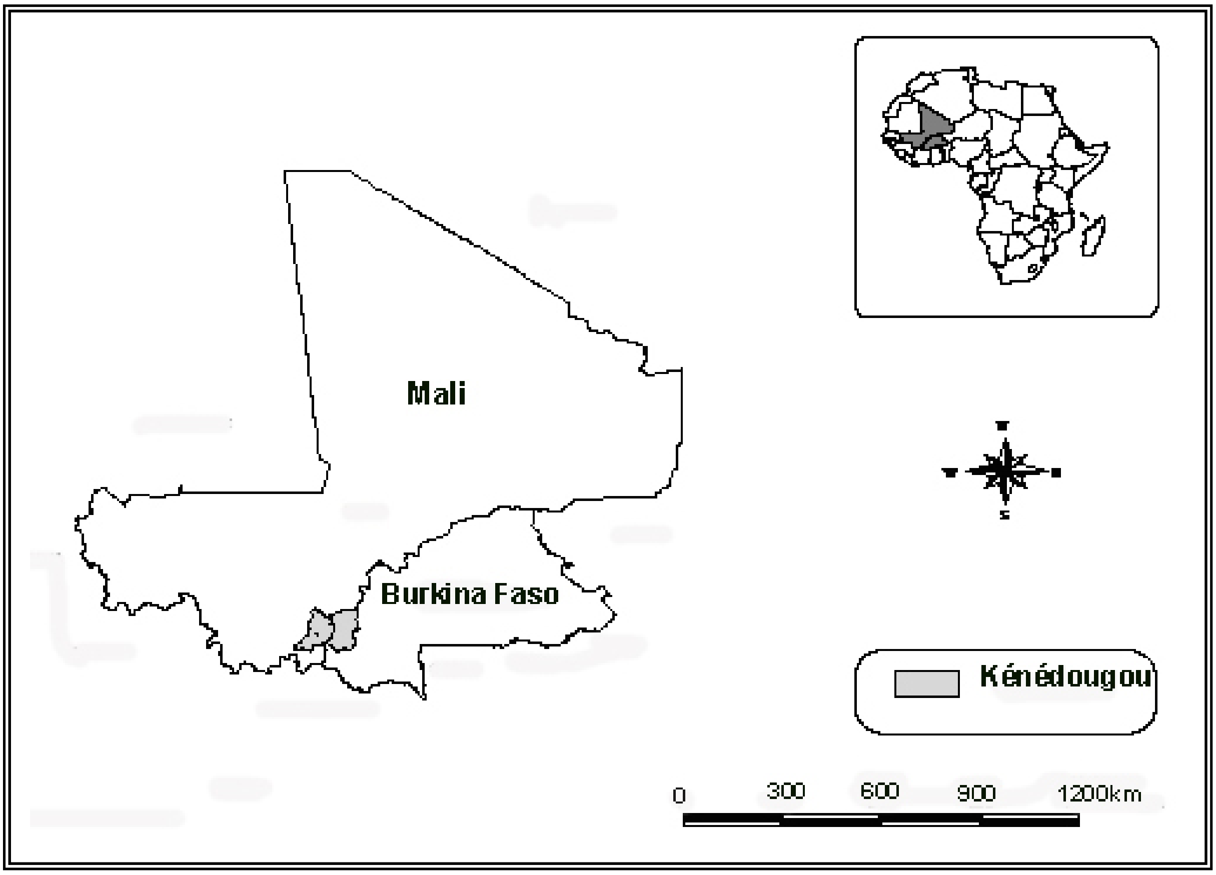

Figure 4.2: Map of the study zone Kénédougou Burkina Faso – Mali

Source: ILRI/BMZ project document (non-published)

4.1.1 Description of the study area in Burkina Faso

The study area in Burkina Faso is located in the Kénédougou province, one of 45 provinces of Burkina Faso. Kénédougou occupies 3% of the total land area of the country (MRA, 2000) and is on the border of Mali. Benefiting from a sub-humid climate and fertile soil, Kénédougou is considered a region of high agriculture potential. In the north of the province, cotton and cereals are the main cash crops; the south is widely known for orchards and root-crop production, and farming is more diverse. Other crops cultivated for subsistence and sale include sorghum, rice, maize, millet, groundnuts and legumes. Uncultivated land occupies 20% of the area; mainly exploited by women, this provides firewood, herbs, shea nut (*Vitellaria paradoxa*) and honey (MRA, 2000). There are two main systems of cattle-keeping: pastoral and agro-pastoral. For pastoralists, cattle-keeping is their central livelihood strategy; milk is a major dietary component and sale of cattle the main source of income. Herds are large; the system is extensive and low external input. Many pastoralists practise transhumance, grazing cattle in the north during the rainy season and moving south after the harvest, but there is an increasing trend towards permanent settlement. Generally the relations with agro-pastoralists are good and complementary, with pastoralists providing expertise, livestock products (milk, but more importantly, manure) and sale cattle, while benefiting from crop residues and grazing during the months when there are no standing crops. In the agro-pastoralist system, cattle are kept mainly for their contribution to crop production. Animal traction is used in land preparation, weeding and transport; manure is a valuable fertiliser. Zebu cattle are kept, as well as trypanotolerant “Baoulé”. However, Métis, which are stable crosses between Zebu and “Baoulé” are more common. Agro-pastoralists keep fewer cattle than pastoralists but inputs per animal in terms of nutrition and veterinary treatments are higher. The province of Kénédougou (see Figure 4.2) is divided into four animal health (zoo-sanitary) districts (MRA, 2000) of which two districts: Orodara and Koloko are included in the study.

4.1.2 Description of the study area in Mali

The study area in Mali is the southeast of the circle of Sikasso, which is on the border of Burkina Faso. The zone is also called Kénédougou because of common agro-ecological conditions and a shared history with Kénédougou in Burkina Faso. With annual rainfall between 1000-1200 mm, Sikasso is the most agriculturally productive region of Mali. Agriculture is the main source of employment and food, and the basis of the local economy. The main subsistence crops grown are maize, sorghum, millet and rice; in most years a surplus is produced, which is sold outside the area. Cotton and groundnut are important cash crops. Most farmers use cattle to cultivate these crops. Of secondary importance are root crops, legumes and fruit, and small-scale market gardening. There are again two main systems of cattle-keeping; pastoral and agro-pastoral. Cattle-keeping is the principal activity of pastoralists. For agro-pastoralists, cattle are kept mainly for animal traction, manure, savings and social obligations and only secondarily for milk and meat production. During the dry season when fodder and water become scarce in the north and when at the same time tsetse challenge is reduced in the more humid areas, pastoralists move south with their herds. There is also a tendency of pastoralists to settle. Whether the penetration is seasonal or permanent, complementary and competitive relationships develop between cropping agriculture and livestock production, which sometimes lead to conflicts between pastoralists and agro-pastoralists. In this zone also, Zebu cattle are kept as well as trypanotolerant “N’dama”. However, “Méré”, which are crosses between Zebu and “N’dama”, are more common. Agro-pastoralists keep fewer cattle than pastoralists but inputs per animal in terms of nutrition and veterinary treatments are higher. With technical and institutional support from cotton parastatal there has been rapid adoption of draft cattle in the last few decades (Williams *et al.*, 2000).

4.2 Knowledge, perceptions and practices survey

The knowledge, perceptions and practices survey is a formal data collection method, which uses survey techniques (formal questionnaires) and qualitative approaches (focus and key informant interviews) (Warwick, 1993). It is the most widely used method in health-seeking behaviour research and is increasingly applied to other sectors, such as education and natural resource management. The aim of the survey was to understand the cattle farmers’ knowledge, attitude and practices of cattle disease diagnosis and treatment, their perceptions of the importance of trypanosomosis and their assessment of the effectiveness of trypanocide. The decision to adopt trypanocides for AAT control is strongly influenced by the livestock keepers’ perception of the effectiveness of drugs. Also, livestock keepers’ perceptions are influenced by the knowledge they have about the disease and different methods of its control. The current state of knowledge, attitude and practices of trypanocide use evaluates the perception that livestock keepers have about drugs and also provides insight into their likely reactions to alternative technologies such as tsetse control and the use of trypanotolerant breeds.

A survey using a questionnaire (see the French version of the questionnaire in Appendix L) was carried out in the study zone. All the villages included in the survey are located in the area called Kénédougou, common to Burkina Faso and Mali (see map in Figure 4.2). The farm households were selected in two steps: first a selection of villages, eight in Burkina Faso and sixteen in Mali. Some of the villages were from previous trypanocide resistance studies (Diall *et al.* 2003; McDermott *et al.* 2003) and the rest were selected from the same sample frame of villages used in the previous trypanocide resistance studies. Then in second step, farm households willing to collaborate and participate in the study and provide animals for blood sampling were selected within each village. A total of 595 households were selected and included in the survey. According to the sampling procedure, the sample size per village in each country is as follows (Table 4.1):

Table 4.1: Sample size per village included in the knowledge, perception and practices survey

Countries	Villages	Number of Households	% of total sample
Burkina Faso	Diéri	39	6.55
	M'Bié	25	4.20
	Kotoura	48	8.07
	Ouolonkoto	40	6.72
	Samogohiri	33	5.55
	Sokoroni	68	11.42
	Sokouraba	85	14.29
	Toussian Bandougou	10	1.68
Mali	Badiassa	18	3.03
	Bamadougou	11	1.85
	Diassadiè	19	3.20
	Bogotiéré	5	0.84
	Farako	11	1.85
	Finibougou	8	1.34
	Finkolo	20	3.36
	Kafoziéla	20	3.36
	Kapala	19	3.19
	Niankorobougou	8	1.34
	Niangassoba	20	3.36
	N'Ténébougou	14	2.35
	Samogossoni	18	3.03
	Tiogola	20	3.36
	Wahibéra	22	3.70
	Zangaradougou	14	2.35
Total		**595**	**100**

Source: Own survey

The questionnaire was focussed on technical aspects of cattle keeping and disease control. Sensitive questions on purchase and administration of medicines were placed at the end. The questionnaire was administered in the local language. Picture cards and open questions were used in order to minimise affirmation bias. The questionnaire was field-tested in each country to ensure that questions were comprehensible, unambiguous and acceptable. Modifications were made according to the different conditions in each country. Questionnaires were checked soon after completion and any inconsistencies or gaps corrected by a follow-up interview with the cattle farmers.

4.3 Herd monitoring

Herds were selected for monitoring from nineteen villages included in the knowledge, perceptions and practices survey (6 in Burkina Faso and 13 in Mali). The six villages of Burkina Faso were selected as follows: in earlier phase of trypanocidal drugs resistance project, 25 villages had been randomly selected from the sampling frame of 73 villages in the south west Burkina Faso (McDermott *et al*. 2003). The six villages with highest prevalence participated in the present study. In Mali, 25 villages were also randomly selected from the sampling frame of 100 villages. Of these, five with high prevalence were selected along with eight which were adjacent to these high prevalence villages. The eighteen villages included in the present study had been subject to new epidemiology studies from June 2003 to May 2004.

The criteria used to select herds in the villages were as follows:

(i) Cattle farmers should be from villages where data on trypanocide resistance exists. The methodology used by epidemiologists for field assessment of trypanocide resistance is presented in Appendix A.

(ii) Cattle farmers should be willing to provide information and participate in the study.

(iii) Herds selected should stay in the village for the whole monitoring period (12 months).

Farmers in one of the 19 villages withdrew from the study after six months because they were no longer willing to allow their cattle to be blood sampled. There were no farmer dropouts in the remaining 18 villages. A total of 208 herds, equivalent to 208 cattle farmers (households), initially selected, comprising 3565 animals (696 in Burkina Faso and 2869 in Mali) were monitored from June 2003 to May 2004, the end of the monitoring period. Table 4.2 shows the distribution of herds and the number of animals per village.

Table 4.2: Distribution of herds and number of animals

Countries	Villages	Number of Herds	Number of animals
Burkina Faso	Diéri	11	141
	M'Bié	9	45
	Kotoura	16	180
	Sokoroni	11	208
	Sokouraba	9	74
	Toussian Bandougou	8	48
Mali	Bamadougou	17	144
	Bogotiéré	8	211
	Diassadiè	9	132
	Farako	12	537
	Finibougou	8	330
	Finkolo	21	252
	Kafoziéla	13	193
	Kapala	11	212
	Niangassoba	6	115
	Niankorobougou	5	175
	Tiogola	13	419
	Wahibéra	21	149
Total		**208**	**3565**

Source: Own survey

Data on animal production inputs and outputs were collected monthly by trained enumerators using data collection sheets (Appendix M). In Mali, due to the high number of animals, the weights of adult cattle were measured bi-monthly using the cattle girth measurement. Cattle girth[8] was measured in centimetres using a tailor's measuring tape. The conversion tables of Bosma (1992), developed for south Mali, were used to convert centimetre girth to kilogram body weight. Calves were weighed each month using a spring balance, which is a weighing scale often used to measure force. The device consists of a coiled spring fixed to a support at one end, with a hook at the other to which the body to be weighed is applied. In Burkina Faso all adult and young animals were measured each month; this means that, while the average weight is derived from 12 measurements for all calves in the study, it is derived for adult animals from 12 and 6 measurements in Burkina Faso and Mali respectively. The milk obtained from the cows in lactation in each herd was measured monthly and the number of

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[8] Numerous studies have been conducted in Sub-Saharan Africa to develop methods of estimating live body weight of cattle using formulae derived from body measurements (Goe *et al.*, 2001). For the girth measurement, a plastic tape marked in centimetres (cm) was drawn around each animal directly behind the front legs and the base of the hump to measure the girth that is then converted into body weight in kilograms.

times the cow was milked per month was recorded. Details of births, stillbirth, abortions, deaths and disposal were collected. For manure production data, it was assume that an animal of 250 kg liveweight produces on average 600 kg of available manure per year (Landais *et al.*, 1990). All management decisions were made by the owners of the herd, without external interference.

4.4 Price data collection

Cattle price was recorded from 425 animals in local cattle markets in Orodara (Kénédougou Burkina Faso) and Sikasso (Kénédougou Mali) in order to derive the kilogram liveweight price of cattle. The survey was carried out in collaboration with the slaughterhouse of each locality at different periods of the year. A total of 425 prices were recorded and the mean price was used to compute the value of the livestock embodied production and components of output related to the liveweight. For the recurrent production, milk price was collected from the local markets and its average value in the study zone was used in the computation. Although manure can be sold and bought in the study area, there is no well-established market for it. To estimate the value of manure, farmers were asked in focus group discussions to estimate the amount of money they would have paid if they have to buy manure, taking into account the importance of manure for crop production in their village. A focus group consists of a small number of people who provide information during a directed and moderated interactive group discussion. A total of 18 focus group discussions were carried out in the 18 villages included in the study, with an average of 12 cattle farmers participating in each group discussion. For draught power, prices of animal day work were recorded during the focus group discussions and an average daily animal rental was used to value the opportunity cost of draught power. Different prices used for the computation of the gross output of cattle production are presented in Appendix B.

4.5 Summary

The methodology described above has as its first step the collection of household level data in 24 villages, including those of known epidemiological conditions (disease prevalence and drug resistance information). The knowledge, perception and practices data encompass socio-economic household characteristics, knowledge, perception, and practices relevant for the identification of factors contributing to trypanocide treatment failures at farm level. For the second step, quantitative input and output data and price information for the cattle production function analysis are collected through herd monitoring, market survey and focus group discussions.

The data collected were organised in such a way that further analyses would be made to test the hypotheses (see chapter 3) and to achieve the objectives of the study as presented in chapter 1. Before undertaking the actual economic analysis of trypanocide use in villages at risk of drug resistance, a descriptive analysis of household characteristics was conducted in order to find out differences among villages at each country level. Then, the analysis of cattle farmers' knowledge, perceptions and practices of cattle production and trypanosomosis control was performed at country level. It is assumed that unmeasured variables associated with the policy environment and access to services in each country may affect farmers' knowledge and practices and levels of input use. Relevant biological and socio-economic data were integrated into a production function framework with a damage control function (see section 3.4 in chapter 3) for the analysis of the productivity of trypanocide use and the costs of trypanosomosis in order to assess its magnitude at farm level under different epidemiological conditions.

Chapter 5

Household characteristics and farmers' knowledge and perception of trypanosomosis and control practices

This chapter has two purposes. First, it presents a descriptive analysis of a survey among 595 households (see chapter 4) in Burkina Faso and Mali, covering twenty four villages (eight in Burkina Faso and sixteen in Mali). The survey results aim to characterise cattle producer households, including their level of knowledge, which may help to explain differences in their cattle production and disease control practices and the efficacy of trypanocides in the treatment of trypanosomosis. The latter aspect is subjected to an in-depth analysis by developing a model that helps to explain the reasons for failures of treatments of cattle against trypanosomosis disease, as perceived by cattle farmers. The results of the model allow the identification of constraints at farm level that can limit the implementation of economically optimal use of trypanocidal drugs for the control of the disease in West Africa.

5.1 Household characteristics

In West Africa, as in sub-Saharan Africa in general, there is wide diversity of livestock systems (Fernandez-Rivera *et al.*, 2004). Each system is characterised by general agro-ecological, social and economic features (see chapter 2 and 4). Socio-economic variables determine the characteristics of households and in turn can be considered as factors affecting cattle farmers' adoption of technologies and the efficiency of their use. In this study, a household is defined as a person or group of persons living in the same house, homestead or a compound, usually sharing a community life, and bound together primarily by pooling resources and sharing income. The purpose of this section is to analyse major household characteristics and assets at village and country levels in order to detect possible differences that may affect household resource allocation for cattle production and the productivity of production inputs used. The household characteristics include:

- The age of the household head; the household head is the person in the household who has primary authority and responsibility for household agricultural activities, including crops and livestock.
- The number of years the head of household has attended a formal school.

- Size of the household: The term "size of household" is the total number of all the people living in the household; a household includes related family members and all unrelated people, if any, such as those living in the household working, for the household and eating in the household.

- The number of household active members: a household active member is defined as any person in the household who provides labour for the production and contributes directly to household production activities for income generation.

- The number of children in the household: this is the number of persons in the household who are under 14 years of age.

- The number of children at school: is the number of children who are between 6 and 14 years old and going to school.

The household assets considered in the analysis are limited to the number of cattle owned by farmers and the means of transport, the latter being the number of bikes and/or scooters at disposal of the household. Means of transport and cattle ownership are taken as proxies for wealth, and bikes and scooters play an important role in crop production and animal health provision (Ouédraogo *et al.*, 2004).

5.1.1 Household characteristics and asset ownership

Table 5.1 shows the household characteristics in villages of Burkina Faso. The analysis of variance shows that differences exist among villages. However, only a few comparisons show a significant difference at the 5% level. For example, out of the 28 comparisons performed for the number of years of formal education of the household head, only two showed significant difference between means. The biggest number of differences was found for the size of household (10 out of 28) and none of the villages is consistently different from all others. The mean age of the household head ranges from 35 to 51 with Kotoura presenting the lowest household head average age. The number of years of formal education is low in all villages with averages between 0.3 and 2.3 years. The largest average size of household is observed in Kotoura. However, households in Diéri present the biggest average number of active household members. The average number of household active members is significantly correlated with the size of the household. In M'Bié households present the lowest size of household and the lowest number of household active members. The average numbers of children in the villages are similar except for Kotoura where the average number of children is significantly different from other villages. This may be explained by the difference found in the sizes of the households. The number of children going to school is positively correlated with the number of children in the household. Ouolonkoto and Kotoura have the highest number of children at school.

Table 5.1: Household (HH) characteristics in villages of Burkina Faso

Villages	Average household characteristics (N = 348)					
	Age of HH head	Years of formal education	Size of the Household	Number of actives in the HH	Number of children in the HH	Number of children at school
Diéri	47.1bc (14.4)	0.6ab (1.8)	16.7c (9.8)	12.3c (7.0)	3.6a (3.0)	2.7a (2.6)
M'Bié	42.2ab (15.6)	2.3b (3.9)	8.1a (4.2)	4.7a (2.2)	2.3a (1.7)	2.2a (1.5)
Kotoura	35.5a (9.0)	1.7ab (2.8)	17.6c (9.9)	8.9b (5.5)	6.0b (4.2)	5.3c (3.6)
Ouolonkoto	48.8bc (14.1)	0.3a (1.4)	15.6bc (8.1)	9.9bc (6.6)	4.00a (2.8)	3.6bc (2.5)
Samogohiri	54.8c (17.5)	1.6ab (2.5)	11.7ab (5.1)	7.4b (3.1)	3.2a (2.6)	2.9a (2.3)
Sokoroni	48.7bc (13.7)	1.0ab (2.0)	11.9ab (4.5)	7.1ab (2.8)	3.28a (2.08)	2.9a (1.9)
Sokouraba	46.1ab (15.1)	0.5a (1.6)	11.3ab (6.8)	6.6ab (3.5)	3.1a (3.1)	2.8a (2.7)
Toussian Bandougou	50.5bc (14.1)	1.9ab (3.2)	12.1abc (3.6)	7.1ab (2.5)	3.1a (2.5)	1.7a (1.7)
F-test	6.51***	3.56***	7.66***	9.76***	6.58***	5.84***

Note: *** Significant at 1%. Means in columns followed by different letters are significantly different at 5%. Figures in brackets are standard deviations of the means.

Source: Own field survey

The household cattle ownership in Burkina Faso shows no difference between villages (Table 5.2) although the average number of cattle is small in M'Bié. There are differences between villages in terms of the number of bikes and scooters (see the significance of the

F-test in Table 5.2). However, only two villages, Kotoura and M'Bié showed significant difference in terms of the average number of bikes owned. The average number of scooters per village is small, with only households in Samogohiri having on average more than one scooter. The average number of scooters owned by households in Samogohiri is significantly different from the four villages M'Bié, Sokouraba, Sokoroni and Ouolonkoto respectively. Comparisons between other villages show no significant difference.

Table 5.2: Household (HH) assets in villages of Burkina Faso

Villages	Average household assets (N = 348)		
	Number of cattle	Number of bikes	Number of scooters
Diéri	7.7 (11.0)	2.9ab (2.1)	0.8ab (1.0)
M'Bié	4.9 (4.6)	2.0a (1.3)	0.4a (0.6)
Kotoura	14.4 (20.5)	3.5b (1.9)	0.8ab (0.7)
Ouolonkoto	18.9 (38.3)	2.9ab (1.9)	0.5a (0.8)
Samogohiri	17.2 (24.5)	3.1ab (1.8)	1.4b (1.9)
Sokoroni	14.8 (22.2)	2.6ab (1.5)	0.5a (0.6)
Sokouraba	15.5 (30.4)	3.3ab (1.7)	0.5a (0.7)
Toussian Bandougou	9.9 (14.3)	2.0a (1.0)	0.8ab (0.4)
F-test	1.22	2.90***	5.17***

Note: *** Significant at 1%. Means in columns followed by different letters are significantly different at 5%. Figures in brackets are standard deviations of the means.

Source: Own field survey

Table 5.3 shows the analysis of the household characteristics in the villages of Mali. Except for the number of years of formal education, which shows no difference between villages, there are some differences between villages in terms of other household characteristics (see the F-test in Table 5.3). In the majority of the villages, farmers have no formal education. The average age of the household head is between 48 and 64 and only Niangassoba shows differences with Wahibéra, Badiassa, and Farako respectively. The average sizes of the household range from 10.3 to 52.0 with Bogotiéré presenting the biggest of household. Comparisons show that only Niangassoba is different from Badiassa, Zangaradougou and Bogotiéré respectively. In Mali, the number of household active members is also correlated with the size of the household, with Bogotiéré presenting the biggest number of active members in a household and Niangassoba the lowest. Differences are observed only between Niangassoba and three other villages, namely Kafoziéla, Samogossoni and Bogotiéré. The average numbers of children are similar for fifteen villages out of sixteen and only one village shows a difference from five other villages. The average number of children going to school is high in Finkolo, which is different from seven other villages (see Table 5.3).

Table 5.3: Household (HH) characteristics in villages of Mali

Villages	Average household characteristics (N = 247)					
	Age of HH head	Years of formal education	Size of the Household	Number of actives in the HH	Number of children in the HH	Number of children at school
Badiassa	64.2b (8.6)	0.0 (0.0)	35.4bcd (15.1)	17.4ab (11.7)	9.4b (4.5)	1.4a (1.2)
Bamadougou	53.5ab (18.4)	0.4 (1.3)	28.8abcd (28.2)	13.4ab (11.5)	8.1ab (6.4)	1.6ab (1.1)
Bogotiéré	49.0ab (7.3)	0.0 (0.0)	52.0d (22.5)	20.4b (7.6)	11.4b (7.8)	3.4abc (3.2)
Diassadiè	57.8ab (11.3)	0.0 (0.0)	24.6abcd (20.2)	14.0ab (13.9)	4.5ab (3.1)	1.9ab (2.3)
Farako	64.2b (10.5)	0.0 (0.0)	25.8abcd (24.7)	13.7ab (15.9)	5.9ab (7.3)	3.5abc (3.3)
Finibougou	59.7ab (12.8)	0.0 (0.0)	12.5ab (4.9)	5.7ab (2.5)	3.6ab (2.3)	2.4ab (1.8)
Finkolo	60.7ab (13.5)	0.3 (1.4)	26.6abcd (18.3)	12.9ab (8.4)	6.8ab (4.6)	6.0c (5.1)
Kafoziéla	58.4ab (10.3)	0.3 (1.3)	33.3abcd (18.3)	18.9b (9.9)	8.6b (7.3)	3.8abc (2.3)
Kapala	58.0ab (17.5)	0.0 (0.0)	22.3abc (12.6)	10.2ab (7.2)	5.9ab (3.5)	2.8ab (2.5)
Niangassoba	47.8a (11.6)	0.1 (0.4)	10.3a (11.2)	5.6a (8.4)	2.7a (2.4)	1.2a (1.4)
Niankorobougou	59.0ab (13.0)	0.0 (0.0)	22.5abcd (8.4)	11.0ab (8.9)	5.4ab (2.5)	3.5abc (2.3)
N'Ténébougou	51.5ab (10.5)	0.0 (0.0)	23.0abcd (16.9)	11.8ab (9.2)	7.1ab (6.0)	3.6abc (4.1)
Samogossoni	58.3ab (12.7)	0.0 (0.0)	30.5abcd (12.7)	18.9b (10.9)	9.2b (5.2)	4.9bc (3.4)
Tiogola	51.0ab (11.8)	0.0 (0.0)	15.8ab (9.1	8.9ab (5.2)	3.1ab (3.1)	1.2a (1.0)
Wahibéra	62.4b (13.6)	0.0 (0.0)	30.1abcd (22.3)	17.0ab (13.2)	6.1ab (3.8)	3.2ab (3.1)
Zangaradougou	51.5ab (12.6)	0.3 (1.1)	46.1cd (50.9)	17.4ab (15.4)	10.8b (10.1)	3.6abc (3.9)
F-test	2.63***	0.71	3.30***	2.63***	3.12***	4.70***

Note: *** Significant at 1%. Means in columns followed by different letters are significantly different at 5%. Figures in brackets are standard deviations of the means.

Source: Own field survey

The household cattle ownership in the villages of Mali shows that there are differences between villages (see the F-test in Table 5.4). However, only Zangaradougou shows significant differences from the rest of the villages. This village was excluded from the production function analysis because all cattle farmers in that village practise long-distance transhumance for seasonal grazing and water supplies. Many cattle farmers in the study area with large herds practise long-distance transhumance. Transhumance involves short or long distance movements of livestock, in some cases over as much as hundreds of kilometres. The duration of the transhumance may be as long as 8 to 10 months. Transhumance may occur at any time during the whole dry season and part of rainy season or vice versa.

Table 5.4: Household (HH) assets in villages of Mali

Villages	Average household selected assets (N = 247)		
	Number of cattle	Number of bikes	Number of scooters
Badiassa	27.3a (34.0)	3.3abc (1.9)	2.6bcd (1.5)
Bamadougou	18.6a (27.2)	3.0abc (2.4)	3.4cd (3.5)
Bogotiéré	32.2a (29.3)	3.4abc (1.8)	4.2d (2.4)
Diassadiè	10.1a (9.5)	2.3abc (1.6)	1.0ab (0.7)
Farako	27.9a (25.0)	1.45ab (1.37)	1.36abc (0.92)
Finibougou	26.9a (21.3)	1.6abc (0.7)	0.9ab (0.3)
Finkolo	11.6a (15.7)	2.4abc (1.8)	0.8a (0.8)
Kafoziéla	20.1a (19.2)	3.9c (2.2)	1.7abc (1.1)
Kapala	16.5a (12.1)	2.1abc (2.2)	1.6abc (1.0)
Niangassoba	10.7a (7.1)	1.2a (0.4)	0.4a (0.5)
Niankorobougou	11.6a (17.7)	1.4ab (1.3)	0.9ab (1.1)
N’Ténébougou	32.5a (32.1)	1.9abc (1.3)	1.3ab (1.1)
Samogossoni	14.8a (16.2)	3.1abc (2.1)	1.6abc (1.3)
Tiogola	21.0a (23.4)	2.1abc (1.1)	1.7abc (1.1)
Wahibéra	14.5a (22.0)	2.4abc (1.9)	1.2ab (1.2)
Zangaradougou	65.9b (48.5)	3.6bc (2.8)	2.9bcd (1.9)
F-test	4.91***	3.08***	6.23***

Note: *** Significant at 1%. Means in columns followed by different letters are significantly different at 5%. Figures in brackets are standard deviations of the means.

Source: Own field survey

Table 5.4 shows that there are differences between villages in terms of the average number of bikes and scooters owned by households. The average numbers of bikes range from 1.2 to 3.9. The average number of bikes in Niangassoba is significantly less than in Kafoziéla and Zangaradougou. Also, the average number of bikes owned by households in Niankorobougou is significantly different from those of Kafoziéla. The biggest average number of scooters is found in Bogotiéré, which shows no difference with only three villages. Households in Niangassoba own on average fewer scooters and the average number of scooters owned is significantly different from Badiassa, Bamadougou, Bogotiéré, and Zangaradougou respectively.

Although there are some differences among villages (see F-test in Table 5.1, Table 5.2, Table 5.3, and Table 5.4), there is no village consistently different across many household characteristics and household asset ownership. However, Niangassoba appears as the village presenting the lowest average value across some variables. The same was observed for the village Bogotiéré, which has the biggest average value in terms of the size of the household, the number of children, the number of active members, and the number of scooters owned by the household. From the perspective of livestock production function analysis in the study area, household characteristics and asset ownership are compared across the two countries in order to assess possible difference that might be taken into consideration in the production function model specifications.

5.1.2 Countries comparison of household characteristics and asset ownership in the study area

Farmers are poorly educated in the study zone of both countries. Low levels of education and high illiteracy rates are typical in many developing countries such as Burkina Faso and Mali (UNDP, 2005). The overall number of years of formal education received on average by the household head in the study zone is less than one. However, the percentage of educated farmers is significantly higher in Burkina Faso compared to Mali. Also, farmers in the study area of Burkina Faso have more years of formal education. Cattle farmers in Burkina Faso were 10 years younger on average than their neighbours in the study area of Mali (Table 5.5).

The size of households is large as in rural West Africa in general (Goody, 1989). Households in the study area of Mali have significantly larger households, more active household members and more children than those in Burkina Faso (Table 5.5). Although the fact that they have more children may be explained by the difference in age of the household head and the size of household, there is no significant difference in the average number of children at school. However, the difference in the percentage of children at school between the study areas of the two countries is highly significant, with households in Burkina Faso having a higher proportion of children at school.

Table 5.5: Comparison of household characteristics in the study area

Characteristics of household (N = 595, Burkina = 348 and Mali = 247)	Countries		Differences
	Burkina Faso	Mali	
Mean age of household head (years)	46.7	57.0	10.3***
Mean size of the household	13.8	26.7	12.9***
Mean number of active members	8.0	13.4	5.4***
Mean number of children per household	3.9	7.4	3.5***
Percentage of HH head educated (formal)	19.1	3.6	15.5***
Mean years of formal education (HH head)	1.1	0.1	1.0***
Mean number of children at school	3.2	2.9	0.3
Percentage of children at school	82.6	39.7	42.9***

Note: *** Significant at 1%, ** Significant at 5%, * Significant at 10%. Percentage data were compared using Chi-square and T-test for the rest.
Source: Own field survey

Table 5.6 shows that households in the study area of Mali have significantly more cattle. The majority of households in both country study areas owned bikes and scooters. However, the percentage of households with scooters is significantly higher in Mali compared to Burkina Faso. Also, households in the study area of Mali own significantly more scooters (Table 5.6) but fewer bikes. The difference between the countries in the average number of bikes per household in the study zone is only significant at 10%.

Table 5.6: Comparison of asset ownership in the study area

Asset ownership (N = 595, Burkina = 348 and Mali = 247)	Countries		Differences
	Burkina Faso	Mali	
Mean number of cattle per household	12.9	21.1	8.2***
Mean number of scooters per household	0.7	1.6	0.9***
Mean number of bikes per household	2.9	2.5	0.4*
Percentage of households with scooters	53.2	78.9	25.7***
Percentage of households with bikes	97.1	94.3	2.8

Note: *** Significant at 1%, ** Significant at 5%, * Significant at 10%. Percentage data were compared using Chi-square and T-test for the rest.
Source: Own field survey

Table 5.7 shows that the structure of the herds is different across country study zones. A recent review of studies on herd size and structure in sub-humid sub-Saharan Africa found an average herd size of 38, ranging from 7 to 77 cattle, with cows making up the largest group (Otte and Chilonda, 2002). Households in Mali have significantly more male adult cattle, more cows and more young animals compared to Burkina Faso. However, the percentage of households owning only adult male cattle is significantly higher in Burkina Faso. Although households in the study area of Mali have more cattle and significantly more oxen (adult male castrated used as draught animals), draught orientation is more important in Burkina Faso, with the mean oxen to bull ratio significantly higher (Table 5.7).

Table 5.7: Comparison of herd structure in the study area

Herd structure (N = 595, Burkina = 348 and Mali = 247)	Countries		Differences
	Burkina Faso	Mali	
Mean number of male adult cattle	4.8	7.1	2.3***
Mean number of cows	3.8	6.7	2.9***
Mean number of heifers	2.5	3.4	0.9**
Mean number of calves	1.8	3.9	2.0***
Mean number of oxen	3.8	4.5	0.7**
Percentage of households with only male cattle	54.7	26.1	28.6***
Mean oxen to male adult cattle ratio	0.8	0.6	0.2***

Note: *** Significant at 1%, ** Significant at 5%, * Significant at 10%. Percentage data were compared using Chi-square and T-test for the rest.
Source: Own field survey

The comparisons show that cattle farmers in the study area of Burkina Faso and Mali are different in their household characteristics; their asset ownership, and the structure of their herds is also different. The structure of a herd influences its health status. It has been shown in the study area that female animals presented more trypanosome infections than males and there were significantly more heavy infections in younger animals (Grace, 2006). Those differences may play a role in explaining cattle farmers' knowledge and management practices of trypanosomosis and the efficacy of trypanocides in the treatment of the disease.

5.2 Cattle farmers' knowledge, perceptions and practices of trypanosomosis control

5.2.1 Husbandry practices

The grazing system is communal, with individual users having free access to the grazing land. Farmers practise transhumance over short distances, and the percentage of farmers practising transhumance is significantly higher in Mali than Burkina Faso (Table 5.8). This may be explained by the fact that farmers in Mali have significantly more cattle and farmers with large herds are more likely to practise transhumance than those with small herds. The practice of transhumance was one of the criteria used in choosing household herds monitored for the production function analysis. Households willing to move for long distance transhumance were excluded.

Table 5.8: Practice of transhumance by cattle farmers

	Burkina Faso	Mali	Difference
Percentage of farmers practicing transhumance	7.2	34.0	26.8***
Average distance (km) of transhumance	12.4	15.1	2.7
Number of days of transhumance per year	30.1	128.5	98.4***

Note: *** Significant at 1%. Data were compared using Chi-square for the percentage of farmers practicing transhumance and T-test for the rest.
Source: Own field survey

Table 5.9 shows that most of the farmers give nutritional supplementation, which is intended to supply feed and nutrients that are missing or not consumed in sufficient quantities in the cattles' diet. The proportion of farmers in Mali giving salts is significantly higher than that in Burkina Faso. Agricultural by-products (mainly cotton seed cake, bran and hulls) are given by more farmers in Burkina Faso. Harvest residues (straw, and the leaves and stalks of maize, legumes and groundnuts) are used significantly by more farmers in Burkina Faso. Only in Mali do farmers give cultivated fodder (S*tylosanthes)*, cowpea *(Vigna unguiculata)* and dolic (*Lablab prupureus*). Fodder cultivation had been introduced by the cotton parastatal (CMDT) as part of a package whereby farmers received two oxen and a plough on credit and in turn undertook to grow fodder.

Table 5.9: Nutritional supplementation

Percentage of farmers giving:	Burkina Faso	Mali	Difference
Salt	93.4	97.6	4.2**
By-products	64.9	50.6	14.3***
Harvest residues	92.8	50.2	42.6***
Food from uncultivated bush	82.8	61.9	20.9***
Cultivated fodder	0.0	25.1	25.1***

Note: *** Significant at 1%, ** Significant at 5%. Data were compared using Chi-square.
Source: Own field survey

5.2.2 Cattle farmers’ knowledge on trypanosomosis and its control

This section describes the extent of knowledge of cattle farmers in the study areas of Burkina Faso and Mali. Farmer-level interventions for trypanosomosis control depend on the knowledge they have of the disease. Increased knowledge is linked to better animal disease management (Grace, 2006; Machila *et al*., 2003). The majority of cattle farmers in Burkina Faso know tsetse flies as the first cause of trypanosomosis, while cattle farmers in Mali are significantly less likely to be aware that tsetse flies are the first cause of the disease (Table 5.10). This evidence for the widespread ability of cattle farmers in Burkina Faso to recognise tsetse flies as the first cause of the disease may be explained by the intensive research work on the control of the flies carried out previously by the Centre International de Recherche-Développement sur l’Elevage en Zone Sub-humide (CIRDES) in the study area in Burkina Faso (Kamuanga *et al*., 2001b). Also, the greater knowledge of the cause of the disease in Burkina Faso may be because the average prevalence of trypanosomosis is higher in this country compared to Mali. In general, knowledge of the cause of trypanosomosis (almost 65% of cattle farmers in Burkina Faso) is greater for the study zone than that in other studies in Africa. In The Gambia in West Africa only 35% of cattle farmers knew the cause of the disease (Snow, 1995). A study conducted in Busia and Kwale districts of Kenya in East Africa revealed that 44% of farmers said tsetse flies were the cause of trypanosomosis (Machila *et al*., 2003). Cattle farmers are aware of the following strategies to prevent the disease: use of trypanocidal drugs —either ISMM or repeated doses of DIM, avoiding high-risk areas by watering animals at pumps or grazing where flies are fewer, use of trypanotolerant cattle, use of different methods of vector control and use of traditional medicines. The number of strategies known by cattle farmers is not significantly different between the countries (Table 5.6). The most important strategies cited are: use of trypanocidal drugs (45% of farmers), followed by avoidance of high-risk areas (33.4% of farmers). Farmers in Burkina Faso are better informed about the signs of trypanosomosis. However, although the number of trypanocides recognised by cattle farmers in Mali is higher, the difference between the countries is not significant.

Table 5.10: Cattle farmers' knowledge on trypanosomosis and its control

	Burkina Faso	Mali	Difference
Percentage of farmers knowing tsetse as first cause of trypanosomosis	64.82	21.86	42.96***
Percentage of farmers knowing tsetse as first or second cause of trypanosomosis	81.34	40.89	40.45***
Number of strategies[a] of trypanosomosis prevention known	4.62	5.40	0.78
Number of signs[b] of trypanosomosis known	3.1	2.9	0.2**
Number of trypanocides known[c]	1.4	2.6	1.2

Note: *** Significant at 1%, ** Significant at 5%. Data were compared using Chi-square for percentage of farmers and T-test for number of signs and number of trypanocides known.

[a] Trypanosomosis prevention strategies were listed and cattle farmers were asked for identification.

[b] Only the signs that are related to the disease are taken into consideration in the analysis.

[c] Different trypanocides were presented to cattle farmers to be recognised as curative or preventive.

Source: Own field survey

5.2.3 Cattle farmers' perception of trypanosomosis

Higher level knowledge generally influences perception (Laver *et al.*, 2001). The knowledge cattle farmers possess about trypanosomosis disease and its control may influence how they perceive the disease and the related strategies of control. Due to the imperfect knowledge and understanding of farmers about the causes and effects of cattle diseases, their attitudes, beliefs and perceptions are important determinants of their behaviour in dealing with such threats. For example, cattle farmers relating the cause of trypanosomosis to idiosyncratic beliefs such as dirt, poisoning, coldness or overwork will certainly not choose an adequate and timely strategy for control. The present section compares the perception of cattle farmers in the study areas of Burkina Faso and Mali.

The majority of cattle farmers in both countries considered trypanosomosis the most important disease. Cattle farmers in Burkina Faso put slightly more importance on the disease than those in Mali. This is confirmed by the prevalence studies, which show that the average prevalence of trypanosomosis is 13% and 10% in Burkina Faso and Mali respectively (Grace, 2006). Prevalence is the proportion of animals that are found to be infected with trypanosomosis at a certain point in time. Many prevalence surveys can be conducted during a period of one year and the average of the results gives the annual average prevalence. There is no significant difference in perceived morbidity (the state of being diseased) due to trypanosomosis among cattle farmers of the two countries, but there is a large and significant difference in terms of mortality. However, the difference between cattle farmers of the countries in perceived case fatality, which is the rate of death among sick animals, is only significant at 10% (Table 5.11).

Table 5.11: Farmers’ perception of trypanosomosis

	Burkina Faso	Mali	Difference
Proportion of farmers considering trypanosomosis as priority disease	90.22	84.52	5.7**
Percentage herd sick of trypanosomosis	27.7	26.3	1.4
Percentage herd died of trypanosomosis	11.2	6.5	4.7***
Case fatality	35.4	25.0	10.4*

Note: *** Significant at 1%, ** Significant at 5%, * Significant at 10%. Data were compared using Chi-square.

Source: Own field survey

5.2.4 Cattle farmers’ practices of trypanosomosis control

The section above presents the comparisons of the perception of cattle farmers in the study areas of Burkina Faso and Mali. Knowledge of trypanosomosis guides perceptions of cattle farmers, which are linked to farmers’ behaviour and practices of the disease control. For a cattle farmer to adopt and practise a disease control measure, three broad conditions are necessary: awareness and knowledge of the measure, the perception that the control measure is feasible and worthwhile to try, and the perception that the measure promotes the cattle farmer' objectives (Pannell, 1999). It is important to stress here that the information presented above emerged from what cattle farmers report they do and may not necessarily reflect what they actual do. However, farmers' behaviour and practices may influence the level of different inputs used for cattle production.

Because of limited knowledge of the cause of the disease, cattle farmers in Mali seek significantly more advice for sick animals compared to those in Burkina Faso (Table 5.12). Cattle farmers in both countries report using a range of drugs to treat trypanosomosis. In general the first-choice drug reported is diminazene (DIM) followed by isometamidium (ISMM). Farmers in Burkina Faso are significantly less likely to use ISMM as the first choice for treatment, and have a higher tendency to use DIM as the first choice compared to cattle farmers in Mali, although the difference is not significant. A minority of farmers in both countries report using non-trypanocidal drugs to treat the disease. In Mali, cattle farmers are significantly more likely to use traditional medicines for the treatment of sick animals than their neighbours in Burkina Faso (Table 5.12). Cattle farmers in Burkina Faso buy more trypanocides in the informal sector and are more likely to treat animals themselves or use more untrained fellow farmers to treat sick animals, and consequently are less likely to use services provided by veterinarians and Community Animal Health Workers (CAHW) compared to their neighbours in Mali (Table 5.12).

Table 5.12: Cattle farmers' veterinary care practices

Cattle farmers' practices	Percentage of cattle farmers		
	Burkina Faso	Mali	Difference
Seeking advice for sick animal	7.47	84.21	76.74***
Using DIM as the first-choice drug	76.5	64.0	12.5
Using ISMM as the first-choice drug	2.8	34.4	31.6***
Using traditional medicines	33.62	42.10	8.48**
Using non-trypanocidal drugs	0.2	0.9	0.7
Using veterinary and CAHW services	44.79	57.45	12.66***
Buying drugs in the informal sector	77.91	20.65	57.26***
Using untrained farmers to treat animals	66.04	57.45	8.59**
Experience drug treatment failures	29.62	27.53	2.09

Note: *** Significant at 1%, ** Significant at 5%. Data were compared using Chi-square.
Source: Own field survey

Large informal sectors and provision of services by untrained personnel are characteristics of systems in developing countries. The majority of human medicines are sold without prescription (Radyowijati and Haak, 2003). This is also true for veterinary medicines. Where human drugs cannot be effectively controlled and regulated, the same conditions can be expected in the veterinary drugs sector. Most trypanocides are given by cattle farmers and their fellow farmers; widespread drug use by farmers and untrained service providers and the buying of drugs in the informal sector are risk factors for the development of drug resistance. There is no difference in the perceived drug treatment failures between cattle farmers in Burkina Faso and Mali (Table 5.12). To understand factors that contribute to treatment failure as perceived by cattle farmers, a logistic regression was performed and the results are presented in the following section.

5.3 Household characteristics, knowledge, perceptions, and practices contributing to treatment failure

In the previous section, it was shown that the percentage of cattle farmers experiencing drug treatment failure was not significantly different between the countries. However, household characteristics and asset ownership (see section 5.1.2); cattle farmers' knowledge, perceptions, and practices related to trypanosomosis and its control (see section 52) are different when comparing the study areas of Burkina Faso and Mali. In the present section, a logistic regression is used to investigate the relationship between the perceived drug treatment failure by farmers and the household characteristics and asset ownership and knowledge, perceptions, and practices of cattle farmers. This may reveal a determinant of the likelihood of a household to experience drug treatment failures.

5.3.1 Logistic regression model

Logistic regression is used to investigate the relationship between binary outcomes; in this case, the experience of drug treatment failure and the explanatory variables, which are factors assumed to contribute to treatment failure at farm level. Logistic models are a special case of the more general log linear model and can thus be used for the analysis of binary responses. However, the distributional assumptions required for standard methods of analysis of log linear models are violated when applying those methods to data involving clustering (Bland, 2004; Carlson, 1998; Kish and Frankel 1974). Generally, the estimation of the population parameters and their associated variances are based on assumptions about the characteristics and underlying distribution of the observations (binomial probability distribution is assumed for logistic regression). These include the assumptions that the observations are selected independently and all observations have the same probability of being selected. Data collected through stratified sampling design (country level and then village level see chapter 4.2) with households clustered within villages, deviate from these assumptions. Hence, clustering was taken into account for the analysis, using robust standard errors (Bland, 2004; Carlson, 1998; Huber, 1967).

In the basic model, let $\mathbf{Y_i}$ be the binary response of a household head and can take one of two possible values: $\mathbf{Y = 1}$ if the household head experiences treatment failure and $\mathbf{Y = 0}$ if not. Suppose $\mathbf{x}$ is a vector of explanatory variables (household characteristics) contributing to treatment failure and $\boldsymbol{\beta}$ a vector of slope parameters, measuring the impact of changes in

x on the probability of the household head experiencing treatment failure. The model can be written as follows:

$$Y_i = \alpha + \beta_i x_i \qquad (5.1)$$

where α and β_i are the unknown constant term and vector of regression coefficients to be estimated respectively.

Once the coefficients in equation (5.1) are estimated one can calculate the probability that a household head experiencing treatment failure can be found in the population of cattle farmers with a specific household characteristic introduced in the model. The probability of the binary response is defined as follows:

$$\text{If} \quad Y_i = 1; \qquad P(Y_i = 1) = \pi(x) \qquad (5.2)$$

$$Y_i = 0; \qquad P(Y_i = 0) = 1 - \pi(x) \qquad (5.3)$$

where $\pi(x) = E(Y|x)$ represents the conditional mean of **Y** given certain values of **x**.

The probability of experiencing treatment failure is then expressed as (Agresti, 2002; Hosmer and Lemeshow, 2000):

$$P(Y_i = 1) = \pi(x_i) = \frac{1}{1 + \exp[-(\alpha + \beta_i x_i)]} \qquad (5.4)$$

5.3.2 Description of variables and results of the logistic regression

The logistic model was constructed using all variables identified as relevant in the preliminary analysis of household socio-economic characteristics and farmers' knowledge, perceptions, and practices of trypanosomosis control. To identify relevant variables, it was assumed that perception of treatment failure has two components: the actual level of treatment failures and farmers' ability to detect failures. Information on the actual level of treatment failures at individual household level was not available but will be influenced by the quality of drug treatments (WHO, 2004b). Therefore all variables related to treatment were included in the model. Farmers' ability to detect treatment failures is assumed to relate to a farmer's knowledge, experience and attitude; and these in turn are influenced by socio-demographic characteristics (Sheeran and Abraham, 1996; Becker et al., 1977; Becker and Maiman, 1975). Farmers’ knowledge of the cause, signs and treatment of trypanosomosis were included as indicators of experience, and farmers’ attitude towards the disease in terms of how important and common they considered the disease. Variables relating to household characteristics were also included, except when these involved overlapping categories. A dummy variable for country was included as the policy environment was known to be different in each country and this is likely to influence practices of trypanosomosis control. Also, in the villages of Burkina Faso, but not Mali, farmers had participated in previous studies on trypanosomosis and trypanocide resistance, which are likely to have had some influence on knowledge, attitude and practice. The variables included in the model are presented in Table 5.13.

Table 5.13: Definition of variables used in the logistic regression model

Group of factors	Variable name	Definition
Dependent variable	Treatment failure	Binary variable: 1 for households that experienced drug treatment failure and 0 otherwise
Independent variables		
Location	Country	Dummy = 1, if cattle farmers are from Burkina Faso, 0 otherwise
Treatment related factors	Advice	Dummy = 1, if cattle farmers seek advice, 0 otherwise
	Vet agent/CAHW	Dummy = 1, if cattle farmers use veterinary agent and CAHW (Community Animal Health Worker) service, 0 otherwise
	Self treatment	Dummy = 1, if cattle farmers treat the cattle themselves, 0 otherwise
	Informal sector	Dummy = 1, if cattle farmers buy drug products in the informal sector, 0 otherwise
Knowledge, attitude, experience related factors	Trypanosomosis	Dummy = 1, if cattle farmers consider trypanosomosis top priority disease, 0 otherwise
	Sick	Number of animal sick of trypanosomosis according to farmers
	Signs trypanosomosis	Number of signs of trypanosomosis known by cattle farmers
	Cause trypanosomosis	Dummy = 1, if cattle farmers know tsetse flies as first cause of trypanosomosis, 0 otherwise
	Trypanocide	Dummy = 1, if cattle farmers know that isometamidium and diminazene are the drugs used to treat trypanosomosis, 0 otherwise
Socio-economic and demographic factors	Age	Age of household (HH) head in years
	Education	Dummy = 1, if cattle farmers participated in formal education, 0 otherwise
	Children at school	Number of children at school in the household
	Actives	Number of household active members
	Cattle	Number of cattle in the household
	Bikes	Number of bikes in the household
	Scooters	Number of scooter in the household

Source: Own presentation

The diagnostic of the model (see Appendix C) shows that the “linktest” is not significant, meaning there is no specification error. Also, the average VIF (Variance Inflation Factors) is less than 10, showing no collinearity problem. Table 5.14 shows that the logistic model is statistically significant. Hosmer and Lemeshow's goodness-of-fit test yields a Chi-square with a large P-value indicating that the model fits the data well. Results show that cattle farmers in Burkina Faso are more likely to experience drug treatment failure compared to their neighbours of Mali (Table 5.14). The fact that cattle farmers seek advice implies they know little about the disease and its control and hence may be more likely to experience drug treatment failure. Those who use less veterinary and CAHW services are significantly more likely to experience treatment failures, which is predictable given that these professionals and para-professionals are likely to have more knowledge and skills than cattle farmers. Also, cattle farmers who know the cause of the disease and the appropriate drugs to treat it are less likely to experience treatment failures; however, buying drugs in the informal sector has no significant effect in contributing to drug treatment failures. The laboratory quality analysis at Free University of Berlin of trypanocidal drugs sampled in the study area shows no difference in quality between formal and informal sectors (P-H. Clausen, pers. com. 2006). The model shows that cattle farmers who know more signs of trypanosomosis are more likely to experience drug treatment failure. This is surprising; however, knowledge of more signs of the disease in the model may be confounded by other factor that was not included in the model. For example, high disease prevalence may be associated with more opportunities for drug failure and also more opportunities for becoming familiar with disease signs. Table 5.14 shows that only the age of the household head is significant among all the socio-economic and demographic factors included in the model. This may be explained by the fact that socio-economic and demographic factors are generally indirect factors in health seeking behaviour (Rosenstock, 1990). The model shows that older farmers are significantly less likely to experience drug treatment failures, and the association is substantial. A cattle farmer with an additional decade of experience will have 20% less risk of experiencing treatment failures. This is not surprising, as older farmers are likely to have more experience.

Based on the results of the model, knowledge of the disease and knowledge of the appropriate trypanocidal drugs for its control, as well as the quality of treatment provided either by the cattle farmers themselves or the veterinary agent and the CAHW, are determinants that may decrease the level of drug treatment failures. This may enable cattle farmers in the study area to use trypanocidal drugs more efficiently.

Table 5.14: Results of the logistic regression with robust standard error of factors contributing to drug treatment failure

Treatment failure	Odds Ratio	Robust Std. Err	95% Confidence Intervals	Z	P > | Z |
Country	3.07	1.73	1.01-9.26	1.99	0.047
Advice	4.09	1.89	1.66-10.11	3.06	0.002
Vet agent/CAHW	0.24	0.16	0.07-0.86	-2.19	0.029
Self treatment	0.74	0.18	0.47-1.18	-1.26	0.207
Informal sector	1.25	0.35	0.72-2.16	0.79	0.428
Trypanosomosis	1.40	0.42	0.78-2.52	1.11	0.266
Sick	1.01	0.02	0.97-1.04	0.38	0.700
Signs trypanosomosis	1.27	0.10	1.08-1.48	2.96	0.003
Cause trypanosomosis	0.50	0.12	0.31-0.82	-2.77	0.006
Trypanocide	0.09	0.04	0.03-0.24	-4.75	0.000
Age	0.98	0.01	0.97-1.00	-2.12	0.034
Education	0.59	0.21	0.29-1.20	-1.46	0.143
Children at school	0.99	0.04	0.92-1.07	-0.21	0.830
Actives	0.99	0.02	0.95-1.03	-0.55	0.584
Cattle	0.99	0.01	0.98-1.01	-0.69	0.490
Bikes	1.08	0.08	0.94-1.24	1.09	0.275
Scooters	1.07	0.12	0.86-1.33	0.64	0.521

Summary statistics

Number of observations = 540
Log pseudo-likelihood = -273.9531
Pseudo R2 = 0.1716
Wald chi2 = 67.81 Prob > chi2 = 0.0000
Hosmer-Lemeshow chi2 = 1.97 Prob > chi2 = 0.982

Source: Own field survey

5.4 Summary

From the results of the household characteristics and assets ownership and cattle farmers' knowledge, perceptions, and practices analysis presented above, the following points can be highlighted:

Households in the study area show demographics typical of traditional West African farming societies, with extended families representing the central units of production. In general, cattle farmers are poorly educated in the study area of both countries. However, the percentage of cattle farmers educated is higher in Burkina Faso than Mali.

The herd size in the study area is smaller than that found in a recent study in sub-humid sub-Saharan Africa. Cattle farmers in Mali have more cattle compared to Burkina Faso, with a different herd structure. The smaller herd size in the study area and the higher proportion of draught animals to male adult cattle, especially in Burkina Faso, indicate a system oriented towards draught. This may lead to differences in cattle production output between farmers in Burkina Faso and Mali.

The majority of cattle farmers in the study area considered trypanosomosis the most important disease. Knowledge of the cause of trypanosomosis in the study area is relatively high compared to other parts of sub-Saharan Africa. Farmers are aware of many strategies to control the disease. However, the primary strategy is the use of trypanocidal drugs. The first-choice drug reported by cattle farmers is diminazene (DIM) followed by isometamidium (ISMM). In the study area, the majority of trypanocide treatments are given by cattle farmers and their fellows. In Burkina Faso, cattle farmers buy most of the trypanocides in the informal sector and are more likely to treat animals themselves or use more untrained fellow farmers to treat sick animals compared to farmers in Mali.

The results of the logistic regression show that advice-seeking behaviour is an indication that cattle farmers are experiencing drug treatment failures. Also, the country of origin of cattle farmers in the study area contributes to treatment failures. Cattle farmers in Burkina Faso are more likely to experience trypanocidal drug treatment failures. The use of veterinary and CAHW services contributes significantly to a reduction in treatment failures. Knowledge, perceptions and practices related factors such as the knowledge of the cause of the disease and the knowledge of the appropriate drugs for control make a significant contribution towards a reduction in treatment failures. Older farmers are less likely to experience trypanocidal drugs treatment failures.

The household characteristics and asset ownership, as well as the knowledge, perception and practices of trypanosomosis control — including the perception of the effectiveness of trypanocidal drugs — influence the adoption of methods for animal disease control and the way inputs are used for cattle production at farm level. The perceptions and practices of disease control are captured in the amounts of different damage control inputs allocated by farmers to cattle production in different epidemiological conditions. In the following chapter (6), input usage and the production function of cattle production in the study area are discussed, together with the productivity analysis of inputs.

Chapter 6

Cattle production function analysis and the productivity of trypanocide

The previous chapter presented a descriptive analysis of household characteristics and socio-economic conditions of cattle production in the study area. The analysis also included the farmers' perceptions of trypanosomosis disease and its control, and their assessment of the effectiveness of trypanocides. The current chapter presents the results of cattle production function analysis and the productivity of trypanocides and other cattle production inputs using econometric methods. The chapter is organised into six main sections. The first section presents the results of production function analysis to describe the input-output relationship for cattle production in the study area. The production function models and the specification of the functional form of the damage control function are discussed. In the second section, the variables that are included in the models are discussed against the background of the relevant literature and production conditions in the area. In the third section the model results are assessed using statistical standards. In section four the marginal productivity and the marginal value product of trypanocides and other production inputs are computed. In the fifth section the following figures are computed and discussed: the proportion of the attainable output realised due to the use of damage control inputs; actual output loss; output loss at optimum level of disease control under different epidemiological conditions; and the costs of trypanosomosis. The chapter ends with a summary of the key findings.

The epidemiological context of cattle production in the study area was analysed in collaboration with veterinary epidemiologists, and additional epidemiological information was collected from a previous resistance study in the zone (McDermott *et al.*, 2003). The results of the disease prevalence study and the experimental field survey of isometamidium resistance in the villages included in the production function analysis are summarised in Table 6.1 (see details of the analysis in Appendix A). Veterinary epidemiologists consider a prevalence of trypanosomosis of 10% to be high (McDermott *et al.,* 2003; Woitag, 2003) and assuming a threshold of 25% for drug treatment failure in cattle treated with isometamidium (Grace *et al*. 2006b, OMS, 2003), a maximum risk reduction less than 75% reveals evidence for drug resistance (see Table 6.1). No village has shown evidence for diminazene resistance at the threshold of 25% of drug treatment failure. Hence, for the economic analysis of trypanocide use in this study, trypanocidal drug resistance refers only to resistance to isometamidium. Four different epidemiological conditions: (i) low-prevalence-low-resistance, (ii) low-prevalence-high-resistance, (iii) high-prevalence-low-resistance, and (iv) high-prevalence-high-resistance were identified, based on the prevalence of the disease and the severity of drug resistance characterising the epidemiological context of productivity analysis of cattle production in the study area.

Table 6.1: Evidence of isometamidium resistance in the study villages

Country	Village	Average disease prevalence [%]	Maximum [%] risk reduction	Evidence of resistance
Burkina Faso	Diéri	15.8	57	Yes
	M'Bié	23.8	89	No
	Kotoura	3.9	73	Yes
	Sokoroni	4.6	74	Yes
	Sokouraba	12.7	50	Yes
	Toussian Bandougou	23.8	90	No
Mali	Bamadougou.	5.7	81	No
	Bogotiéré	3.1	NA	No
	Diassadiè	14.7	69	Yes
	Farako	7.5	70	Yes
	Finibougou	8.1	74	Yes
	Finkolo	10.4	82	No
	Kafoziéla	2.7	76	No
	Kapala	11.9	60	Yes
	Niangassoba	7.0	87	No
	Niankorobougou	14.9	72	Yes
	Tiogola	12.4	75	Yes
	Wahibéra	20.7	79	No

Note: NA = no analysis possible because of too few cases.

Source: Data from the epidemiological surveys (Grace *et al.* 2006b) and (McDermott *et al.* 2003)

6.1 Cattle production function model

As suggested by McInerney (1996), one possible way to assess the productivity of animal disease control measures is to estimate a livestock production function. This concept has been used extensively in crop production (Heady and Dillon, 1961; Tokrisna *et al.*, 1985). Applying this concept to cattle, the unit of production is usually the herd, assuming that a well defined relationship between total output and inputs can be specified. It is further assumed that cattle farmers are producing at the efficient level, i.e. with the technology available, achieving the maximum output given the resources they employ. In the process of formulating a cattle production function model that well represents the technical and economic conditions, the choice of the model specification and the exogenous variables is crucial. Of course, the variables included in the model should reflect the underlying mechanics of the production process. Often however, only imperfect knowledge of these relationships exists and the underlying production logic can only be hypothesized (Heady and Dillon, 1961). This may lead to specification errors and therefore methods must be applied that allow biases inherent in the model to be identified, evaluated and corrected. It must also be recognized that the estimation of production functions from farm level data is more problematic than if these were derived from experimental conditions.

As pointed out by Heady and Dillon (1961) in their seminal work, cattle input-output relationships are better studied under experimental conditions because some special difficulties arise in the estimation of the farm level cattle production function. Most importantly in the smallholder livestock production system is the problem of feed inputs. Under grazing conditions cattle obtain the bulk of their feed by free grazing on communal land. Availability of feed from natural pasture depends on a set of factors comprising soil conditions, climate, vegetation, and grazing pressure (Steinfeld; 1988). There may be differences between villages in grazing area and the quality of the pasture, which may affect the feeding of animals, with significant effect on production. As discussed in chapter 3.3.2 cattle production is a multi-product enterprise and the distinction between the animal itself as product (meat production) and the situation where the product is a flow over time from the animal (milk, manure, and power production) has to be taken into consideration (Heady and Dillon, 1961).

To specify the form of the cattle production function, it would be desirable to build on the prior empirical literature on the economic production of cattle. Unfortunately, very limited application of production function theory to livestock production and animal disease can be found in the livestock production literature. Tung and Rasmussen (2005) have used a Cobb-Douglas production function analysis for smallholder semi-subsistence and semi-commercial poultry production in Vietnam. They pointed out the difficulties of getting reliable information on feed intake. However, the model parameters estimated were compatible with field observation (Tung and Rasmussen, 2005). McInerney *et al.* (1992) have applied the “loss-expenditure frontier” to the economic analysis of mastitis in the UK national dairy herd. They reached the conclusion that the “loss-expenditure frontier”, which relates output losses following disease occurrence and expenditures made to treat disease or prevent its occurrence, successfully defines the economically optimal level of disease costs. However, the framework of the damage control function discussed in chapter 3 was applied in detail only in one study of dairy production in the UK (IJpeelar, 2005). Using the Cobb-Douglas function for productive inputs and an exponential damage control function, IJpeelar (2005) showed that veterinary inputs productivity could be successfully analysed in a damage control framework. However, he pointed out that the coefficient of veterinary inputs was barely significant. He argued that this is probably caused by the variation between farms and years with respect to disease incidence and the use of treatment and/or control methods. In production function analysis literature, there is no specific form of production function for cattle. Therefore, the decision was made to start the analysis in this study with the Cobb-Douglas production function, which is widely used in economic analysis.

6.1.1 Cattle production function

The cattle production function is specified as a Cobb-Douglas production function of the following general form:

$$Q = a\left[\prod_{k=1}^{n} Z_k^{\beta_k}\right] \tag{6.1}$$

Where:

Q is the total aggregated value of cattle output as defined in section 3.3.2. (Equation 3.5). Z_k is a vector of production inputs, a and β_k are parameters to be estimated.

The fact that production functions facilitate the imposition of the concavity property (Chambers, 1988) and enables coefficient estimates to be interpreted directly as elasticities makes them a useful tool in production analyses. In neo-classic production theory it is generally assumed that output is non-decreasing in each individual input (Varian, 1996). This property is generally illustrated by the downward sloping isoquant showing the substitution possibilities between two inputs while other inputs and output remain constant. Inputs that have non-negative marginal products are generally referred to as freely disposable inputs (Färe *et al.*, 1994). Under certain circumstances, however, output may decrease with some inputs; the presence of such inputs in production function models is equivalent to the presence of negative marginal productivity (Coelli *et al.*, 1998; Färe *et al.*, 1994). An example from agriculture is the use of labour on a given plot of land: agriculture output decreases with a large number of workers on the same field (Zhengfei and Lansink, 2003). Although the Cobb-Douglas production function has some advantages it also presents disadvantages, including the imposition of unitary elasticity of substitution that constrains the elasticity substitution between inputs to be always equal to one. Nevertheless, the Cobb-Douglas functional form may be a good approximation for a production process with inputs that are imperfect substitutes. As noted by Wooldridge (2003), the Cobb-Douglas functional form imposes a strong restriction regarding the marginal effect of explanatory variables on the dependent variable as constant which is not realistic for many economic relationships that exhibit diminishing marginal returns. The standard application of Cobb-Douglas functions involves only continuous inputs. The function can be modified to include binary inputs and the log linear form of the Cobb-Douglas production function is suitable for this. However, care should be taken to appropriately interpret the coefficients of the dummy variables. The traditional interpretation of the dummy variables does not follow in the case of the log of the dependent variable, which is often applied in the Cobb-Douglas functions (van Garderen and Shah, 2002).

6.1.2 Integrating the damage control function

Damage from various biotic and abiotic factors has come to play an increasingly important role in agriculture. The appropriate methodological tool for capturing the effects of damage control inputs like for example, supplementary irrigation, antibiotics, pesticides and trypanocides is the damage abatement function. Previously, agricultural economists have modelled the output of systems involving damage agents (including pest and animal disease) using standard production functions; treating all inputs as if they affect output directly. However, as first introduced by Lichtenberg and Zilberman (1986), damage control inputs are different from conventional inputs because they affect output indirectly by reducing the damage if it occurs (see chapter 3). The difference between direct productive and damage control inputs has some implications for the estimation of production functions. It is thus necessary to segregate conventional inputs from damage control inputs. Hence, a Cobb-Douglas form can be specified with an integrated damage control function, which can be written as follows:

$$Q = a\left[\prod_{k=1}^{n} Z_k^{\beta_k}\right] * G(X_d, X_v)^{\gamma} \qquad (6.2)$$

Where:

Q is cattle output as defined in equation (6.1), Z_k is a vector of productive inputs, X_d is a vector of damage control inputs related to trypanosomosis, X_v is the aggregate of other veterinary inputs and $G(X_{d,} X_v)$ is the damage control function (Lichtenberg and Zilberman, 1986). Other variables are defined as in equation (6.1). The parameter restriction $\gamma = 1$ was imposed to facilitate the estimation. This restriction requires that damage control be proportional to G as is typically assumed in studies of damage control inputs productivity (Babcock *et al.*, 1992; Carrasco-Tauber and Moffit, 1992). Taking into account this restriction, equation (6.2) can be expressed in a logarithmic form as follows:

$$\ln Q_h = \beta_0 + \sum_{k=1}^{n} \beta_k \ln(Z_{kh}) + \sum \beta_m D_{mh} + \ln\left[G(X_{dh}, X_{vh})\right] \qquad (6.3)$$

The notation used in equation 6.3 is defined as follows:

β_0 = ln(a), where ln is the natural logarithm,

h = the *h*th household (h = 1, …, 206),

β = vector of parameters to be estimated,

Z_k = vector of production inputs,

D_m = vector of dummy variables,

X_d and X_v = vector of damage control inputs.

Different functional forms that meet the criteria of a damage control function can be assumed (Fox and Weersink, 1995; Lichtenberg and Zilberman, 1986). However, given that the most appropriate functional form still remains unknown, three exponential specifications were tested. The exponential function is chosen because of its computational tractability and ease of interpretation. The damage control function can include multiple damage control inputs and other explanatory variables such as disease prevalence and drug resistance in the case of trypanocide productivity assessment. Due to the fact that there may be measures that carry disease control effects as a by-product (natural control irrespective of external disease control inputs), a fixed effect term can be introduced in the exponential damage control function. Also, many sources of damage can be assumed (Babcock *et al.* 1992). In this study, it is assumed two sources of damage: trypanosomosis, which is controlled by the use of trypanocide and other diseases that are controlled by the use of other veterinary inputs. In the study area no significant interaction between trypanosomosis and other common diseases has been shown (Grace, 2006), so the two sources of damage are assumed to be independent. Hence, in total four models were estimated as follows:

Base model = Cobb-Douglas only

$$\ln Q_h = \beta_0 + \sum_{k=1}^{n} \beta_k \ln(Z_{kh}) + \sum \beta_m D_{mh} \qquad (6.4)$$

Base model integrating the exponential form of damage control function = **Exponential 1**

$$\ln Q_h = \beta_0 + \sum_{k=1}^{n} \beta_k \ln(Z_{kh}) + \sum \beta_m D_{mh} + \ln\left[1 - \exp(-\beta_d X_{dh} - \beta_v X_{vh})\right] \qquad (6.5)$$

where β are parameters to be estimated.

Base model integrating the simple exponential form of damage control function with a fixed effect term (α) = **Exponential 2**

$$\ln Q_h = \beta_0 + \sum_{k=1}^{n} \beta_k \ln(Z_{kh}) + \sum \beta_m D_{mh} + \ln\left[1 - \exp(-\alpha\ - \beta_d X_{dh} - \beta_v X_{vh})\right] \qquad (6.6)$$

Base model integrating the simple exponential form of damage control function including two sources of damage = **Exponential 3**

$$\ln Q_h = \beta_0 + \sum_{k=1}^{n} \beta_k \ln(Z_{kh}) + \sum \beta_m D_{mh} + \ln\left[(1 - \exp(-\beta_d X_{dh})) * (1 - \exp(-\beta_v X_{vh}))\right] (6.7)$$

Where X_d is a vector of damage control inputs related to trypanosomosis, X_v is the aggregate of other veterinary inputs, β are parameters to be estimated. For simplification, the damage control function assuming two sources of damage in **Exponential 3** is termed $G(X_{d,}\ X_v)$ for the rest of the analysis.

6.2 Description of variables and data used in the production functions

In the section above, the production function models that are used to estimate the parameters of damage control inputs and other production inputs were presented. This section presents the variables and data used in the models. For the production function model, explanatory variables need to be selected according to both production function theory and their relevance. The number and type of variables to be included vary depending on the objectives and hypothesis being tested, and sometimes by the limitations imposed by the data available. Generally the explanatory variables cover input factors, natural conditions, ecological and epidemiological factors, and indicators for the specific farm characteristics. An overview of the variables assumed to have an influence on cattle production in the smallholder livestock production systems is given, their relevance is discussed and the form in which they have been included in the model is indicated. As discussed in section 3.3.2 an exchange ratio is used whereby animals of different average size can be related to a common unit, the Tropical Livestock Unit (TLU), corresponding to a bovine of 250 kg. The production output and inputs are given per TLU.

Output **(Q)**, converted to its logarithmic form is the dependent variable representing the economic value of the total output of cattle production. The total output is composed of liveweight gain, milk, manure, draught animal power, insurance and financial benefits expressed in monetary value [in €] per Tropical Livestock Unit (TLU) and per year (see section 3.3.2). Figure 6.1 shows the share of each component in the formation of cattle output Q. Draught power and manure represent 63% to 78% of output with draught power alone accounting for 57% to 74% of the production depending on the level of disease prevalence and isometamidium resistance. Draught animal power is an important output in the mixed farming systems of the cotton zone of West Africa. Draught power and manure are livestock outputs that serve as inputs into the crop subsystem. However, effective use of draught animals depends on the capability of the animals for work (Pearson and Vall, 1998). Obviously animals that are sick cannot perform as well as animals that are healthy. The International Livestock Research Institute (ILRI, 1997) reported that trypanosomosis reduces significantly the work performance of working animals.

The financing and insurance benefits from cattle production in smallholder crop-livestock system are of special importance in the study area where financial markets function poorly and opportunities for risk management through formal insurance generally absent. The valuation shows that the insurance and financing benefits of keeping cattle range from 12% to 20% of output depending on the epidemiological conditions. This substantial contribution to output may explain why farmers keep unproductive animals in their herd for insurance or financing motives, thereby reducing the biological performance of the herd. Liveweight gain (meat production) accounts only for 7% to 14% of total output, showing that meat production is not the first objective of cattle production in the study zone. The value of the amount of milk extracted for sale and home consumption is low and accounts only for 0.7% to 4%. This is related to the practice of farmers leaving milk preferably for the growth of calves.

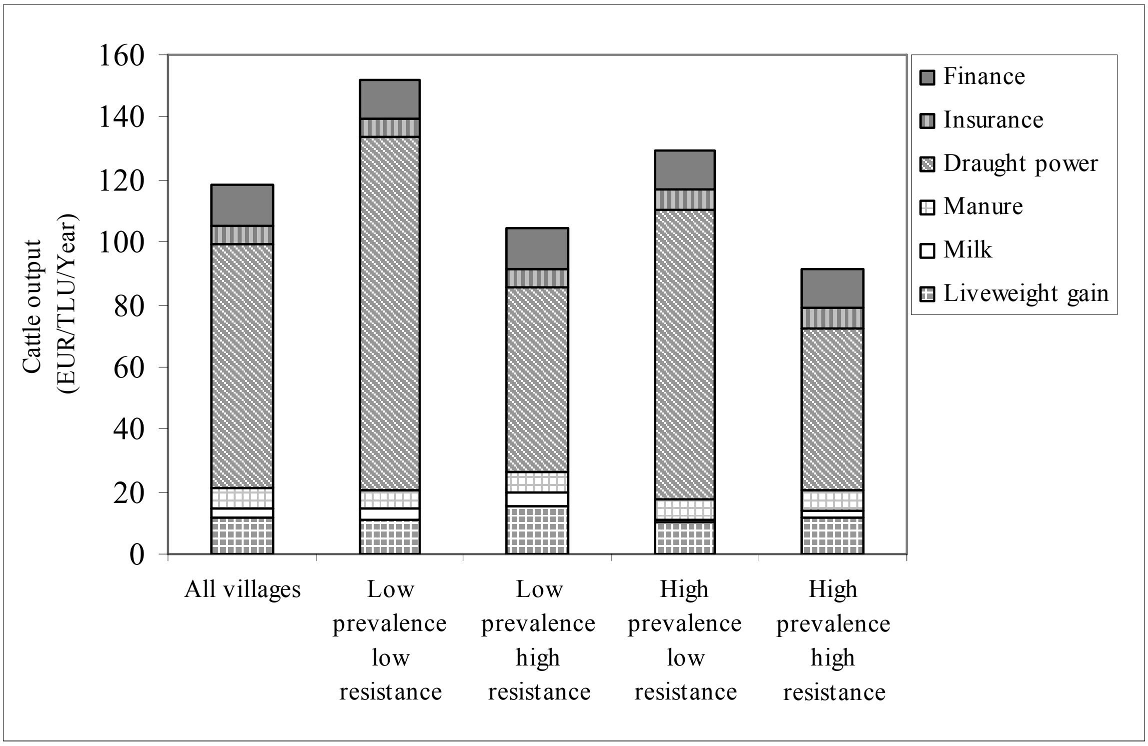

Figure 6.1: Value (€ TLU^{-1} $Year^{-1}$) of cattle output and share of the components under different epidemiological conditions

Source: Own herd-monitoring survey

Herd size is the total TLU under the control of a farmer. The stock of animals expressed in total TLU is a proxy for the stock of capital in cattle production. Evidence from Kenya has shown that wealthier households with larger herds milk their animals less intensively and extract less output from them than average and poor households (ILRI, 1995). In the smallholder livestock production system in the study area, the herd size might have an influence on output and therefore be considered as a factor in the production function.

Preventive trypanocide (ISMM) is the total expenditure in [in €][9] per TLU per year for preventive trypanocides that were used in each herd during the monitoring period (12 months).

Curative trypanocide (DIM) is total the expenditure in [in €] per TLU per year for curative trypanocides that were used in each herd during the monitoring period.

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[9] 1 [€] = 655.9 FCFA (FCFA = The currency of the French-speaking African Financial Community)

Interaction between preventive trypanocide and curative trypanocide: it is assumed that the two types of trypanocide may have a synergistic effect as their modes of action are different. The possibilities of trypanocidal drug synergy have been examined by Williamson *et al.* (1982). The assumption is that, although their modes of action are not similar, they are not independent; the effect of one depends on the level of the other. When ISMM use is high, one additional unit of DIM will only have small impact but when ISMM use is low one additional unit of DIM will have large impact on productivity.

Other veterinary inputs are total collective expenditures [in €] on antibiotics, antihelmintics (treatment against parasitic worms), vaccines, insecticides and acaricides (treatment against ticks) per TLU per household per year. Apart from trypanocide to control trypanosomosis, the use of other veterinary inputs may help to control other diseases, with a positive impact on cattle production output.

Salt and feed are composed of expenditures [in €] for salt and feed purchased per TLU per household during the monitoring period. Trypanosomosis is frequently associated with under-nutrition reducing thus draught work output, milk yield and reproductive capacity (Holmes *et al.*, 2000). Mineral supplementation of grazing livestock is essential for maximizing production. Salt intakes improve livestock growth rate, feed utilisation efficiency and milk yield, leading to a positive effect on livestock output (McDowell *et al.*, 1993).

Interaction[10] between salt and feed purchased and herd size: When the herd size is small, the feed and salt purchased might have different effects on production. Figure 6.2 shows the relation between salt and feed purchased and herd size; the trend is that when the herd size (number of TLU) increases, the salt and feed purchased by cattle farmers decreases. This shows that the most important nutritional inputs feed and salt are more supplied for small herds. As noted in section 5.1.2 (chapter 5), small herds have a high proportion of working animals (oxen); these are more productive and have higher nutritional need than other animals (Mathers and. Otchere, 1993). Supplementation may be on a regular basis in a small herd compared to large herd, with a positive effect on production.

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[10] The base model was used to compare the model that includes the interaction term with the model without interaction term. The result supports the model with the interaction over the model with no interaction.

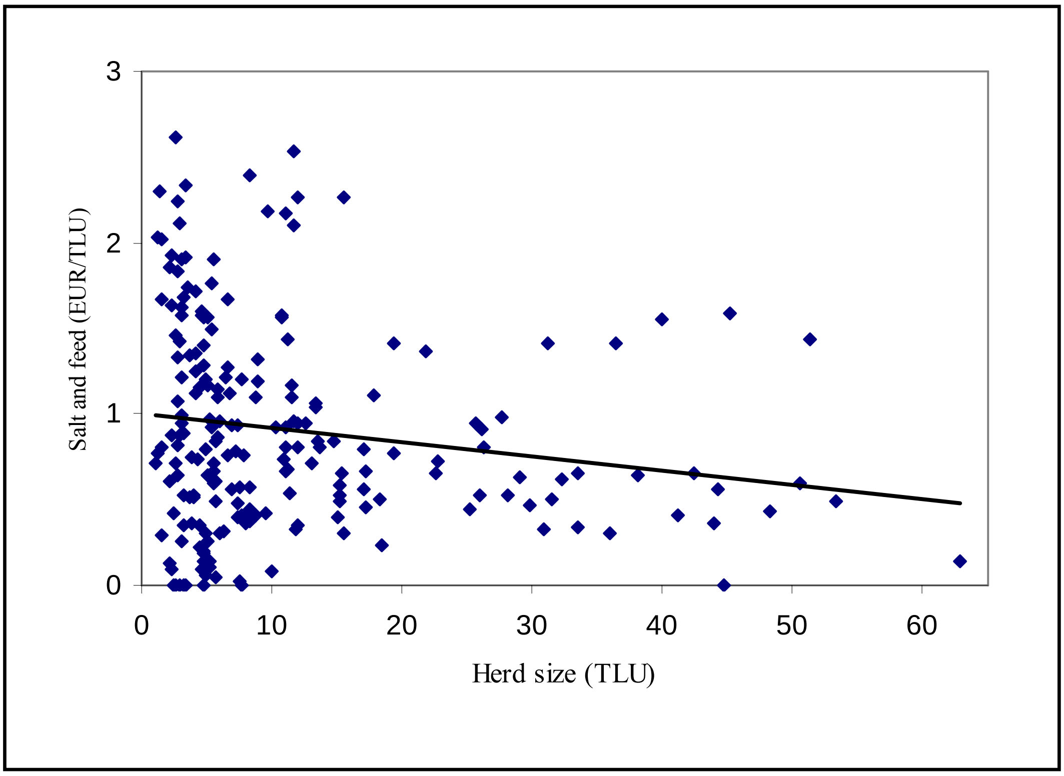

Figure 6.2 Relation between salt and feed purchased and herd size

Source: Own survey

Disease prevalence is a dummy variable representing certain types of villages for the average prevalence of trypanosomosis during the monitoring period (1 for villages of average prevalence above 10% and 0 otherwise, see Table 6.1). Ten percent prevalence of trypanosomal infection is considered high in the study area (McDermott *et al.* 2003; Woitag, 2003).

Drug resistance is a dummy variable representing certain types of villages for treatment failure derived from experimental field-tests for isometamidium resistance (1 for villages of maximum risk reduction superior or equal to 75% using isometamidium and 0 otherwise, see Table 6.1).

Country is a dummy for the country, being 1 when cattle farmers are from Burkina Faso and 0 otherwise. The country dummy represents all of the unmeasured variables associated with the policy environment and access to services that may affect farmers' knowledge and practices. The analysis of household characteristics and asset ownership in chapter 5 shows differences between cattle farmers in the study area of Burkina Faso and Mali. These differences can have an impact on input use and the productivity of cattle. The farming system is Burkina Faso is more intensive with a greater integration in the market economy (Toulmin and Guèye, 2003). It is expected that cattle farmers in Burkina Faso will perform better.

Experience: the most common specification error in studies of production relations involves the omission of a variable related to management (Tokrisna *et al.*, 1985). Generally, the reason for omitting management is the lack of a metric for its direct measurement or as a proxy (Mundlak, 1961). It is thus important to find a management index for cattle farmers who belong to the same group in the population from which the sample was drawn. It is assumed that the number of years the farmer has been keeping cattle will reflect experience and managerial ability in livestock production. Most cattle farmers acquired their knowledge of production through experience and may have become more efficient through trial and error. The effect of introducing better management is to shift the entire production function to the right, thus producing more output from a given amount of resources (Mundlak, 1961). This change will be reflected in an increase in the marginal productivity of each input factor. The number of years the farmer has been keeping cattle as a proxy for livestock keeping experience and management was included in the model as a dummy variable taking the value of 1 if the cattle farmer has been keeping cattle for over 15 years (the average for the whole sample) and 0 otherwise.

Natural conditions such as climate and rainfall can be regarded as homogenous for the whole study area and are not included in the production function models. Also, labour for herding is not included in the models. Almost all livestock keepers use children as herdsmen and in a few cases adults may be used. However, it was difficult to collect data on the herding time and labour inputs. It is assumed that the uniform use of children as herdsmen will not influence the outcomes of the models. Due to the difficulties in allocating the production of grazing cattle to a particular area of land, only the purchased feed are introduced in the models.

Values of the continuous variables included in the models are presented in Table 6.2. The range of the output is 386 [€/TLU/Year], which seems to be large. The standard deviation, which provides an average distance for each herd output from the average output, is also large. However, the distribution of the output is nearly normal (see Figure 6.3). Generally the logarithmic transformation of the Cobb-Douglas production function assumes a nearly normal distribution of errors in the data (Box and Cox, 1964).

The herd size is skewed to the left basically because a lot of cattle farmers have small herds (see Table 6.2). However, the asset ownership analysis in chapter 5 showed that cattle farmers from Mali have large herds compared to their fellows in Burkina Faso.

The average value of trypanocide use is low, with less than one dose of isometamidium on average per TLU per year. However, only a minority (3%) of cattle farmers in the productivity analysis sample did not use any of the two drugs during the monitoring period.

Table 6.2: Mean and standard deviation of continuous variables included in the production function models (N = 206)

Variables	Unit	Mean	SD	Min	Max
Output	[€ $TLU^{-1}Year^{-1}$]	111.68	67.68	39.02	424.68
ISMM	[€ $TLU^{-1}Year^{-1}$]	0.62	0.83	0.00	3.98
DIM	[€ $TLU^{-1}Year^{-1}$]	1.58	1.12	0.00	6.45
Other vet inputs	[€ $TLU^{-1}Year^{-1}$]	2.05	1.78	0.00	13.14
Salt and feed	[€ $TLU^{-1}Year^{-1}$]	2.02	2.29	0.00	12.61
Herd size	[TLU]	11.63	12.07	1.10	62.81

Note: The sample size is reduced to 206 because two cattle farmers with extreme values for inputs used were removed from the sample.

Source: Own survey

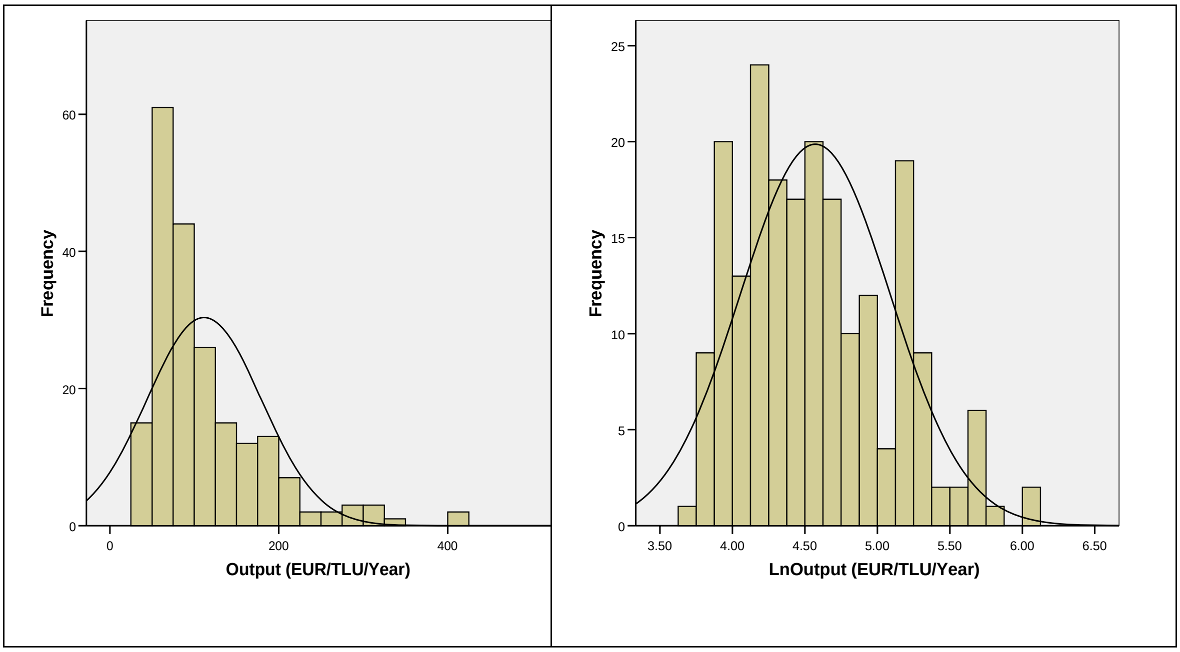

Figure 6.3: Distribution of output [€/TLU/Year] and fitted normal distribution curve

Source: Own survey

An overview of the binary variables included in the models is presented in Table 6.3. The number of herds in high disease prevalence villages is slightly higher (56% of total number of herds). However, almost the same numbers of herds are in low and high resistance villages respectively. One third of the herds are located in Burkina Faso; this is in line with the number of cattle monitored in each country, which is much higher in Mali (see section 4.3 in chapter 4). Only one third of the household heads are considered to be experienced in cattle production. This may be due to the cut-off point of 15 years, which is arbitrary.

Table 6.3: Overview of the binary variables included in the models

Variables	Explanation when the dummy = 1	Nr. of villages	[%] of herds
Disease prevalence	Disease prevalence above 10%	8	55.8
Drug resistance	Maximum risk reduction superior or equal to 75%	10	50.5
Country	Cattle farmers from Burkina Faso	6	31.0
Experience (proxy)	Number of years of keeping cattle above 15	-	34.0

Source: Own survey and data from the epidemiological surveys (Grace *et al*. 2006b) and (McDermott *et al.* 2003)

Table 6.4 shows the comparison of inputs usage. There is no significant difference in diminazene use among cattle farmers in different epidemiological conditions. Also, no significant difference can be found between cattle farmers is situations of low resistance versus high resistance in terms of isometamidium usage. Normally it should be expected that cattle farmers' typical short-term response to the development of resistance to isometamidium is to increase usage levels. However, the use of isometamidium will decrease only when productivity is so low that alternative trypanocides become more efficient.

The results in Table 6.4 show that cattle farmers in low-prevalence-low-resistance areas use significantly more isometamidium than those in high-prevalence-low-resistance conditions. This is not surprising because the prevalence of the disease was measured in a context of trypanocidal drug treatments and isometamidium gives long-lasting protection, hence, a low disease prevalence.

The use of other veterinary inputs shows differences only between cattle farmers in low-prevalence-low-resistance areas versus low-prevalence-high-resistance areas. This can be explained by the fact that when resistance develops, cattle farmers may suspect other diseases and the use of other veterinary inputs may increase. The use of salt and feed also differs in different epidemiological conditions, with farmers in low-prevalence-low-resistance areas using significantly more than those in other epidemiological conditions.

Table 6.4: Comparison of inputs used in different epidemiological conditions

Epidemiological conditions	Means[1] of input use (€ TLU^{-1} $Year^{-1}$)			
	ISMM	DIM	Other veterinary inputs	Salt and feed
Low-prevalence-low-resistance	0.92b	1.40	2.45b	4.66b
	(0.92)	(1.05)	(1.41)	(2.96)
Low-prevalence-high-resistance	0.58ab	1.75	1.61a	1.44a
	(0.81)	(1.21)	(1.10)	(1.44)
High-prevalence-low-resistance	0.32a	1.49	2.11ab	1.00a
	(0.40)	(0.93)	(1.48)	(0.73)
High-prevalence-high-resistance	0.70ab	1.64	2.15ab	1.42a
	(0.92)	(1.22)	(2.59)	(1.66)

Note: ANOVA adjusted for clustering is used for the analysis with the village as the Primary Sample Unit (PSU)

[1] Means in columns followed by different letters are significantly different at 5%. Figures in brackets are standard deviations of the means.

Source: Own computation

6.3 Estimation of the cattle production function

6.3.1 Estimation procedure

In estimating production functions, inputs are generally treated as exogenous. This may cause a simultaneity problem and correlation between inputs and error term may render the estimates inconsistent (Wooldridge, 2003). Although the problem applies to all inputs, it is especially important for pesticides as damage control inputs in crop protection, since they are often applied sequentially, in response to production shocks in the form of pest attacks (Shankar and Thirtle, 2005; Huang *et al.*, 2002). This might also be true for trypanocides as they are used in response to trypanosomosis threat. If the disease prevalence is not incorporated in the models, which is not the case in this study, high levels of disease prevalence may be correlated with lower outputs and it is possible that the covariance of trypanocides and the residuals of the cattle output function is non-zero, a condition that would bias parameter estimates of the impact of trypanocides on output (Huang *et al.*, 2002). Although the disease prevalence is incorporated in the models, the potentially omitted variables and correlations may lead to the endogeneity problem. The prevalence of the disease in the study was measured at village level and not at individual herd level. However, cattle farmers may apply trypanocides in the absence of the disease in their herd; for example the drug may be used because a neighbour has some animals sick with trypanosomosis. Drugs may be applied prophylactically and in the absence of the disease no damage control will occur as the damage agent is not present. Also, many trypanocides are sold and treatments made without a proper diagnosis and in both East and West Africa trypanocides have been reported to be used more frequently than the occurrence of the disease warrants (Machila *et al.*, 2003; Kamuanga *et al.*, 2001). Hence in the study area, trypanocides may be used in the absence of the damaging agent. In these conditions, the expected endogenous variable, trypanocides, can be affected but not the output of cattle production. Then a variable may exist that is correlated with actual trypanocide use but does not affect cattle output except through its impact on trypanocides. Evidence of exogeneity is crucial in assuring that estimates are not biased (Carpentier and Weaver, 1997). When choosing the estimation method, where endogeneity is a problem, consistent estimates can be obtained by suitably instrumenting the relevant variable using the 2SLS estimator. On the other hand, where endogeneity is not a significant problem, the least squares estimator is more efficient than instrumental variables (Wooldridge, 2003). Therefore, it is desirable to have a test for endogeneity of trypanocides that shows whether 2SLS is necessary. However, both OLS and 2SLS are consistent if all variables are exogenous (Wooldridge, 2003). Accordingly, as the entry point of the estimation of cattle production function; the endogeneity of trypanocides was assessed. A Hausman test (Hausman, 1978) was performed under the conventional production function framework. While the assumption is that the conventional model may be mis-specified relative to the damage control model, it is nevertheless considered useful in providing a simplified basis for carrying out the necessary endogeneity tests. The endogeneity test was performed separately for preventive trypanocide, curative trypanocide and for both together at the same time. Veterinary service fees as a proxy for the intensity of veterinary service was used as an instrument and in the test with both trypanocides together, veterinary service fees and the age of the cattle farmer were used.

Table 6.5 shows the results of the endogeneity tests. The Wu-Hausman F-test and the Durbin-Wu-Hausman Chi-sq test show the same results for the preventive and the curative trypanocides considered separately. Also, both tests are insignificant when preventive and curative trypanocides are tested together. Overall, there is no evidence for trypanocide endogeneity and the null hypothesis that trypanocides are exogenous is accepted (see details of each model and the 2SLS[11] estimation results in Appendices D to F). The cattle production function models were then estimated using the linear least squares estimator for the Cobb-Douglas production function and the non-linear ordinary least squares for the production functions integrating a damage control function.

Table 6.5: Tests of endogeneity of trypanocides

Endogenous variable	Wu-Hausman F-test		Durbin- Wu-Hausman Chi-sq test	
	F	P-value	Chi-square	P-value
ISMM	0.1637	0.6863	0.1745	0.6761
DIM	0.1637	0.6863	0.1745	0.6761
ISMM and DIM	0.0816	0.9217	0.1749	0.9163

Note: The endogeneity tests were performed in STATA® 8.0

Source: Own survey

To check for the collinearity problem, a sample estimation of the correlation between the explanatory variables in the models was carried out (see the correlation matrix in Appendix G), showing significant correlation between some of the variables. If the correlation coefficient between any pair of explanatory variables is greater than 0.9 in absolute value, it is argued that it would serve as an indication of a strong linear relationship and cause potential bias to the analysis (Hill *et al*., 2001). None of the correlation coefficients is greater than 0.9. Although, one correlation coefficient at 0.896 was very close to 0.9, the Variance Inflation Factors (VIFs), which attain a maximum value of 8.97 for the variable representing the interaction between herd size and salt and feed, indicates there are no important collinearity problems. There are no formal criteria for determining the magnitude of VIFs that causes poorly estimated coefficients. Myers (1990) suggests that values exceeding 10 may be cause for concern.

Using the Breusch-Pagan test (Breusch and Pagan, 1979), models were tested for heteroskedasticity. Heteroskedasticity exists when the variances of all the observations are not the same, leading to consistent but inefficient parameter estimates. More importantly, the biases in estimated standard errors may lead to invalid inferences (White, 1980).

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[11] The procedure for the endogeneity tests in STATA provides the 2SLS estimation results at the same time. The Wu-Hausman F-test and the Durbin- Wu-Hausman Chi-square test are used to test the H_0 hypothesis that regressors are exogenous. The t-statistic is then computed to test whether the OLS estimates are significantly different from the 2SLS estimates. For isometamidium $|t| = 0.15 < 1.96$ and for diminazene $|t| = 0.11 < 1.96$ indicating that the estimates are not different at 5% level of significance.

Heteroskedasticity was detected when estimating the base model Cobb-Douglas production function only (equation 6.4) and the Cobb-Douglas production functions integrating the exponential damage control functions (exponential 1: equation 6.5) and was corrected using the robust standard error and the non-linear Generalised Methods of Moments (GMM) procedure (Greene, 2003) for equation 6.4 and equation 6.5 respectively. However, the exponential 2 (equation 6.6) and the exponential 3 (equation 6.7) do not present any heteroskedasticity problem, suggesting the variance of the errors is constant across observations (Pindyck and Rubinfeld, 1991).

In a conventional Cobb-Douglas function (base model), the estimated coefficients of the input variables are identical with their production elasticities. However, when the Cobb-Douglas function includes some interaction terms the partial effect or elasticity of the dependent variable with respect to an explanatory variable in the interaction terms depends on the magnitude of the second explanatory variable in the interaction terms. Hence, the estimated coefficients are not directly interpretable. Wooldridge (2003) proposed a mean-centring method that does not change the substantive meaning of the model or the predictions that are made but makes the results more easily interpretable for the variables in the interaction terms. Centring refers to the practice of subtracting a constant from predictors before fitting a regression model. Often the constant is a mean, but can be any value (Wooldridge, 2003). There are two reasons for centring, first if variables are centred the main effects of the interaction terms provide meaningful information. The second reason is that centring reduces the high correlation between the interaction variable and the two main effect variables in the interaction terms. However, the partial effect of the variables in the interaction terms on cattle output can be computed at the mean value of each of them from the non-centred estimates holding all other variables fixed using appropriate derivation.

Also, when dummy variables are used in a model with a log-transformed dependent variable, unlike a continuous variable, the coefficient of the dummy variable, multiplied by 100 is not the usual percentage effect of that variable on the dependent variable (van Garderen and Shah, 2002). Instead it should be calculated as:

$$g = 100 * [\exp(\beta_m - V(\beta_m)/2) - 1] \tag{6.8}$$

where **g** is the percentage change in the level of the dependent variable, β_m is the estimated coefficient of the dummy variable and $V(\beta_m)$ is the estimated variance of β_m.

6.3.2 Results

The results of the parameter estimates of the cattle production function for the base model, the exponential 1, exponential 2, exponential 3 models are presented in Table 6.6, Table 6.7, Table 6.8 and Table 6.9 respectively (see STATA and SAS outputs of models in Appendices H to K). The models have a relatively high explanatory power with an R-squared of 0.659 for the base model and adjusted R-squared ranging from 0.632 to 0.639 for the base model integrating damage control functions (exponential 1, exponential 2, and exponential 3).

Table 6.6: Estimated parameters for the base model (**Cobb-Douglas only**)

Variables	Cobb-Douglas only (Equation 6.4)		
	Coefficient	Standard errors.	t-value
Intercept	5.121	0.179	28.56***
Salt and feed	0.289	0.128	2.26**
Experience	0.068	0.045	1.51
Herd size	-0.304	0.056	-5.43***
Interaction (Herd size*Salt and feed)	-0.166	0.052	-3.20***
Country	0.211	0.059	3.60***
Disease prevalence	-0.196	0.047	-4.13***
Drug (ISMM) resistance	-0.175	0.059	-2.95***
Other veterinary inputs	0.043	0.064	0.67
Isometamidium (ISMM)	0.377	0.115	3.28***
Diminazene (DIM)	0.171	0.073	2.35**
Interaction (ISMM*DIM)	-0.163	0.121	-1.35
F = 41.61***			
R^2 = 0.659			

Note: * = Statistically significant at 10%, ** = Statistically significant at 5%, *** = Statistically significant at 1%.

Source: Own survey

Table 6.7: Results of base model integrating the simple exponential form of damage control function (**Exponential 1**)

Variables	Exponential 1 (Equation 6.5)		
	Coefficient	Standard errors.	t-value
Intercept	5.426	0.172	31.48***
Salt and feed	0.372	0.125	2.98***
Experience	0.086	0.046	1.88*
Herd size	-0.302	0.054	-5.57***
Interaction (Herd size*Salt and feed)	-0.185	0.050	-3.73***
Country	0.181	0.060	3.00***
Damage control function			
Disease prevalence	-0.484	0.253	-1.92*
Drug (ISMM) resistance	-0.438	0.212	-2.07**
Other veterinary inputs	0.029	0.061	0.47
Isometamidium (ISMM)	1.250	0.447	2.80***
Diminazene (DIM)	0.419	0.136	3.08***
Interaction (ISMM*DIM)	-0.244	0.087	-2.79***

F = 33.50***

R^2 = 0.655

Adjusted R^2 = 0.635

Note: * = Statistically significant at 10%, ** = Statistically significant at 5%, *** = Statistically significant at 1%.

Source: Own survey

Table 6.8: Results of base model integrating the simple exponential form of damage control function with a fixed effect term (**Exponential 2**)

Variables	Exponential 2 (Equation 6.6)		
	Coefficient	Standard errors.	t-value
Intercept	5.637	0.357	15.80***
Salt and feed	0.339	0.106	3.18***
Experience	0.079	0.050	1.57
Herd size	-0.299	0.053	-5.66***
Interaction (Herd size*Salt and feed)	-0.176	0.050	-3.54***
Country	0.191	0.057	3.34***
Damage control function			
Fixed effect term (α_d)	0.563	0.357	1.58
Disease prevalence	-0.304	0.261	-1.16
Drug (ISMM) resistance	-0.269	0.220	-1.22
Other veterinary inputs	0.009	0.026	0.35
Isometamidium (ISMM)	0.391	0.382	1.02
Diminazene (DIM)	0.136	0.136	1.00
Interaction (ISMM*DIM)	-0.052	0.082	-0.64

F = 33.81***
R^2 = 0.657
Adjusted R^2 = 0.634

Note: * = Statistically significant at 10%, ** = Statistically significant at 5%, *** = Statistically significant at 1%.

Source: Own survey

Table 6.9: Results of base model integrating the exponential form of damage control function including two sources of damage (**Exponential 3**)

Variables	Exponential 3 (Equation 6.7)		
	Coefficient	Standard errors.	t-value
Intercept	5.428	0.159	34.20***
Salt and feed	0.375	0.103	3.64***
Experience	0.084	0.050	1.70*
Herd size	-0.305	0.052	-5.92***
Interaction (Herd size*Salt and feed)	-0.187	0.049	-3.81***
Country	0.174	0.055	3.19***
Damage control function			
Disease prevalence	-0.512	0.276	-1.86*
Drug (ISMM) resistance	-0.455	0.232	-1.97*
Other veterinary inputs	1.939	0.668	2.90***
Isometamidium (ISMM)	1.377	0.474	2.91***
Diminazene (DIM)	0.456	0.134	3.40***
Interaction (ISMM*DIM)	-0.260	0.105	-2.49**

F = 34.05***
R^2 = 0.659
Adjusted R^2 = 0.639

Note: * = Statistically significant at 10%, ** = Statistically significant at 5%, *** = Statistically significant at 1%.

Source: Own survey

The values of the adjusted R-squared for the three exponential damage control functions are similar, suggesting that none of the specifications can be said to be superior using that criterion. All of the models are regarded as approximating the true but unknown one, and the focus is on obtaining the model that provides the best approximation. In order to find which model among the three exponential specifications would best approximate reality given the data we have recorded, in other words the model that minimises the loss of information, the information theoretic approach was used (Burnham and Anderson, 2002; Carrasco-Tauber and Moffit, 1992). The approach uses Akaike's information criterion (AIC) to compare a series of models, the model with the lowest AIC[12] being the "best" model among all exponential models specified for the data at hand.

The results of the exponential 2 damage control function (Table 6.8) show that the introduction of the fixed term representing the natural control irrespective of external disease control inputs (equation 6.6) did not improve the model. Although the R^2 is nearly the same, the Akaike's information criterion shows that the specification with the fixed term did not fit the data well. Also, none of the coefficients in the damage control function of the model is significant. The exponential 3 damage control function specification including two sources of damage equation (6.7) best fits the data compared to other two damage control function models in terms of the adjusted R^2 and the Akaike's information criterion and was used with the base model (Cobb-Douglas only) in the rest of the analysis.

The signs of the estimated coefficients are as expected for both the Cobb-Douglas only production function and the exponential 3 production function, except the negative sign of the interaction term between isometamidium and diminazene. It was expected that the preventive and the curative trypanocides would have a synergistic effect on trypanosomosis control, with a positive impact on cattle production.

The F-values of the regressions are respectively 41.6 and 34.1 (with 11 and 194 degrees of freedom) for the Cobb-Douglas only production function and the production function integrating the damage control function specification (exponential 3), and are highly significant, indicating that the joint hypothesis of all coefficients being zero is strongly rejected. The intercept coefficients in both models are positive and highly significant. The values are 5.1 and 5.4 for the Cobb-Douglas only production function specification and the production function integrating the damage control function (exponential 3) respectively. Strictly speaking, the values represent the levels of output when the explanatory variables are all zero, which is not realistic because the herd size can never be zero, so the interpretation of the intercept values must be treated with caution. However, it is the estimates of the slopes that are much more important.

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[12] The AIC can be computed for OLS models as follows: $AIC = n * \ln(\sigma^2) + 2k$ where **n** is the sample size, $\boldsymbol{\sigma^2}$ is MSE (mean of sum of squared residuals) and **k** is the number of parameters in the model, including the intercept and the error term. The value of AIC suggests the following ranking exponential 3 (AIC = -455.88), exponential 1 (AIC = -453.55) and exponential 2 (AIC = -451.76).

The estimated production function coefficients effect on cattle production output are only discussed for the Cobb-Douglas function and the Cobb-Douglas part of the exponential 3 production function. This is because the estimated coefficients of damage control function cannot be directly interpretable and can only be used to show the effect of control inputs on cattle production output through the G (X_d, X_v) in equation (6.7), which is the percentage of the attainable output realised. The direct interpretation of those coefficients is not meaningful. However, with adequate derivation techniques, the productivity effect of the damage control inputs can be computed (see next section).

The coefficients of the country dummy in both models are significant and positive. Using equation (6.8), the Cobb-Douglas function shows that cattle farmers in Burkina Faso realise 23% more output compared to their fellows in Mali, but the difference between cattle farmers in Burkina Faso and Mali is only 19% with the production function model integrating damage control function (exponential 3). These results can be explained by the fact that 57% to 74% of the total cattle output per TLU in the study area consist of draught power and the number of day-work of traction animals is significantly higher in Burkina Faso — 55 days per year compared to only 40 days in Mali. In Burkina Faso, draught orientation is stronger, with the mean oxen to adult male cattle ratio significantly higher than Mali (see Table 5.7 in Chapter 5).

The coefficients of experience as proxy for the managerial skill are positive in both models but not significantly different from zero in the Cobb-Douglas only production function. However, the coefficient is significant at 10% in the Cobb-Douglas integrating the damage control function (exponential 3) and suggests that the experience in keeping cattle for over 15 years is associated with 9% increase in cattle production output. Given the difficulties inherent in measuring management skill, the number of years of keeping cattle as proxy may not capture the full magnitude of the managerial skill of a farmer. Also, the cut-off point set at the average number of years of keeping cattle is to some extent arbitrary.

The coefficient of trypanosomosis disease prevalence in the Cobb-Douglas function is negative and highly significant. The interpretation of the coefficient according to equation (6.8) suggests that an annual prevalence of trypanosomosis greater than 10% (regarded as high prevlalence) is associated with 18% decrease in cattle output compare to the situation where the annual disease prevalence is less than 10%. Although the coefficient of disease prevalence is also negative but only significant at 10% in the production function model integrating damage control function, its effect on output cannot be directly interpreted. However, the effect of trypanosomosis disease will be captured in the computation of the marginal effect of trypanocides on cattle production output.

The coefficient of trypanocidal drug (isometamidium) resistance in the Cobb-Douglas only production function is negative and highly significant. The interpretation of the coefficient using equation (6.8) suggests that the presence of high resistance (drug treatment failures over 25% in cattle treated with isometamidium) is associated with 16% decrease in cattle output compared to output of cattle production in low resistance zone. The coefficient for drug resistance obtained in the Cobb-Douglas production function integrating the damage control function (exponential 3) is also negative but only significant at 10%. Although the coefficient is not directly interpretable, it will be used in the computation of the productivity effect of trypanocidal drugs on cattle production.

The coefficients of salt and feed in both Cobb-Douglas only model and the Cobb-Douglas integrating the damage control function (exponential 3) have the expected sign and are significant at 5% and 1% respectively. The Cobb-Douglas only model suggests that for a cattle farmer with the current average expenditure on salt and feed, a 10% increase in total Tropical Livestock Units owned (herd size) is associated with 6.4% decrease in cattle output. The result is similar with the damage control model, which predicts a 6.8% decrease in cattle output with a 10% change in herd size. The results can be explained by the fact that the size and the structure of the herd are very important for cattle production in the study area. Smaller herds are using salt and feed intensively (see Figure 6.2) because they tend to have a higher oxen share (see Table 5.7 in Chapter 5). Also, an increase in salt and feed expenditures spread over more animals in big herds has smaller or no impact on each individual animal and on production.

The coefficients of the preventive trypanocide (isometamidium) in both Cobb-Douglas only model and the Cobb-Douglas integrating the damage control function (exponential 3) are positive and highly significant. The magnitude of the coefficient in the Cobb-Douglas only model suggests that for a cattle farmer with current average expenditure on curative trypanocide (diminazene), a 10% increase in isometamidium is associated with 1.2% increase in cattle output. However, the effect of isometamidium is much more important when no diminazene is used. Results show that for a cattle farmer using zero diminazene, a 10% increase in isometamidium use will be associated with 4% increase in cattle output.

The coefficients of the curative trypanocide (diminazene) in both Cobb-Douglas only model and the Cobb-Douglas integrating the damage control function (exponential 3) are also positive and significant at 5% and 1% respectively. For a cattle farmer with current average expenditure on isometamidium, a 10% increase in diminazene expenditures is associated with 0.7% increase in cattle output. However, when no isometamidium is used, a 10% increase in diminazene expenditures will be associated with 1.7% increase in cattle output.

The coefficient of “other veterinary inputs” is positive but not significantly different from zero in the Cobb-Douglas only model. However, in the production function integrating the damage control function (exponential 3), all the coefficients are at least significant at 10%, including the coefficient of other veterinary inputs — which was not significant in the Cobb-Douglas only model but was highly significant in the exponential 3 production function model. The effect of those coefficients on cattle production will be captured in the computation of the marginal value product of the damage control inputs. In the following section, the marginal productivity of input use in cattle production is assessed.

6.4 Mathematical derivation of the marginal productivity of input use in cattle production

The productivity analysis in this study uses models in which the dependent variable (cattle production output) and the explanatory variables of interest are expressed in terms of monetary value. The approach allows a direct interpretation of the marginal productivity estimates of the various inputs, providing information on the level of monetary returns that are obtained for every unit of money spent on factor inputs. By definition, the marginal productivity is the increase in output arising from a marginal increase of a certain input. It can be computed by taking the first derivative of the production function with respect to that input. In the Cobb-Douglas specification, the coefficient β_k estimates the output elasticity of the productive input Z_k in the equation (6.3) from which the marginal productivity of the inputs is derived.

$$\beta_k = \frac{\partial Q}{Q} * \frac{Z_k}{\partial Z_k} \tag{6.9}$$

The marginal productivity of Z_k using appropriate derivation can be expressed as:

$$\frac{\partial Q}{\partial Z_k} = \beta_k * \frac{Q}{Z_k} \tag{6.10}$$

The derivation of the marginal value product of the damage control inputs X_d is obtained in an indirect manner. It can be expressed as follows:

$$\frac{\partial Q}{\partial X_d} = \frac{\partial Q}{\partial G(X_d, X_v)} * \frac{\partial G(X_d, X_v)}{\partial X_d} \tag{6.11}$$

The marginal value product of $G(X_d, X_v)$ is:

$$\frac{\partial Q}{\partial G(X_d, X_v)} = \gamma * \frac{Q}{G(X_d, X_v)} \tag{6.12}$$

By substituting $\frac{\partial Q}{\partial G(X_d, X_v)}$ with the restriction assumption $\gamma = 1$ (see section 6.1.2), the marginal value product of the damage control X_d can be expressed as follows:

$$\frac{\partial Q}{\partial X_d} = \frac{Q}{G(X_d, X_v)} * \frac{\partial G(X_d, X_v)}{\partial X_d} \tag{6.13}$$

Substituting for $G(X_d, X_v)$ in the functional form of damage control function (exponential 3) equation (6.7), the marginal value product of a specific damage control input X_1, for example, is expressed as follows:

$$\frac{\partial Q}{\partial X_1} = \frac{Q * (\beta_1 + \beta_3 X_2) \exp(-\beta_1 X_1 - \beta_2 X_2 - \beta_3 X_1 X_2 - \beta_4 D_1 - \beta_5 D_2)}{1 - \exp(-\beta_1 X_1 - \beta_2 X_2 - \beta_3 X_1 X_2 - \beta_4 D_1 - \beta_5 D_2)} \tag{6.14}$$

The marginal value product of the other veterinary input X_0 can be derived:

$$\frac{\partial Q}{\partial X_v} = \frac{Q * \beta_v \exp(-\beta_v X_v)}{1 - \exp(-\beta_v X_v)} \tag{6.15}$$

6.4.1 Marginal productivity of damage control inputs

The aggregate cattle production output and production inputs are expressed in terms of monetary value, thus the estimated coefficients for trypanocides and other veterinary inputs can be used to directly compute their marginal value products (MVPs) using the equations (6.10), (6.14) and (6.15) at the mean value of the variables included in the equations. Based on the prevalence of the trypanosomosis disease and the severity of trypanocidal drug (isometamidium) resistance, the marginal value products were computed for four different epidemiological conditions: (i) low-prevalence-low-resistance, (ii) low-prevalence-high-resistance, (iii) high-prevalence-low-resistance, and (iv) high-prevalence-high-resistance as described earlier. Table 6.10 presents the estimated marginal productivity of damage control inputs.

Table 6.10: Estimated marginal value product of damage control inputs in [€]

Epidemiological conditions	Marginal value product in [€]					
	Isometamidium		Diminazene		Other veterinary inputs	
	Cobb-Douglas	Damage Control function	Cobb-Douglas	Damage Control function	Cobb-Douglas	Damage Control function
Low-prevalence-low-resistance	30.40	8.60	8.40	0.40	1.90	1.20
Low-prevalence-high-resistance	25.50	12.50	7.10	0.60	1.60	1.00
High-prevalence-low-resistance	25.00	14.30	6.90	0.70	1.50	1.10
High-prevalence-high-resistance	19.00	22.50	5.30	1.10	1.20	1.00

Note: Computed from production function coefficients in Table 6.6 (equation 6.4: Cobb-Douglas only) and Table 6.9 (equation 6.7: exponential 3)

Source: Own survey

Table 6.10 shows that the Cobb-Douglas only model and the production function model integrating damage control function (exponential 3) generate marginal value products per unit cost of isometamidium greater than unity. The marginal value product for isometamidium in the Cobb-Douglas only model is €30.40 in low-prevalence-low-resistance conditions. This marginal value product decreases to €19.00 in high-prevalence-high-resistance condition. However, for the production function model integrating damage control function (exponential 3) the marginal value product increases from €8.60 in low-prevalence-low-resistance conditions to €22.50 in high-prevalence-high-resistance conditions. The Cobb-Douglas only model generates a marginal value product per unit cost of diminazene greater than unity suggesting that cattle farmers in all epidemiological condition under-use diminazene. However, the production function integrating damage control function specification (exponential 3) shows under-use for diminazene only in high-prevalence-high-resistance conditions (Table 6.10). The results show that the marginal value products of diminazene decrease when disease is common and drug resistance high for the Cobb-Douglas only function whereas the exponential 3 functional form exhibits much higher marginal value product in high-prevalence-high-resistance conditions compared to low-prevalence-low-resistance conditions. For both drugs, the production function model integrating damage control function (exponential 3) shows that there is more than a two-fold increase in the marginal value product from the low-prevalence-low-resistance situation to the high-prevalence-high-resistance one. The high marginal value products of isometamidium in all epidemiological conditions and the marginal value product superior to one exhibited by the production function model integrating damage control function (exponential 3) for diminazene in high-prevalence-high-resistance conditions suggest that farmers could increase the profitability of cattle keeping in those conditions if they increase the amount of trypanocides beyond their current level. This confirms results of other studies comparing drug use to trypanosomosis prevalence, that also suggest current usage of trypanocide is inappropriately low (Grace, 2006).

The Cobb-Douglas only functional form gives a marginal value product more than one for “other veterinary inputs” suggesting that those inputs are underused. However, in the exponential 3 damage control function “other veterinary inputs” were included as damage control inputs. Results show that they are slightly under-used in low-prevalence-low-resistance and high-prevalence-low-resistance conditions, compared to low-prevalence-high-resistance and high-prevalence-high-resistance conditions where marginal value products are equated to one. In the analysis, “other veterinary inputs” are the aggregate of many inputs and are not homogenous. For example, vaccines are typically used to prevent severe losses that occur rarely and assessment based on one year may not capture their impact and benefit. In other cases there is some evidence of overuse. For example, worm medicines are generally not needed by adult animals as they have developed immunity, but are widely given by farmers to animals without distinction of age (Grace, 2006).

Figure 6.4 and Figure 6.5 show respectively for the Cobb-Douglas only and the exponential 3 damage control functions the trend of the marginal value for isometamidium use over the range of expenditures reported in the sample (€0.00 to €4.00 per TLU per year) while holding all other inputs, including diminazene, constant at their average use in different epidemiological conditions.

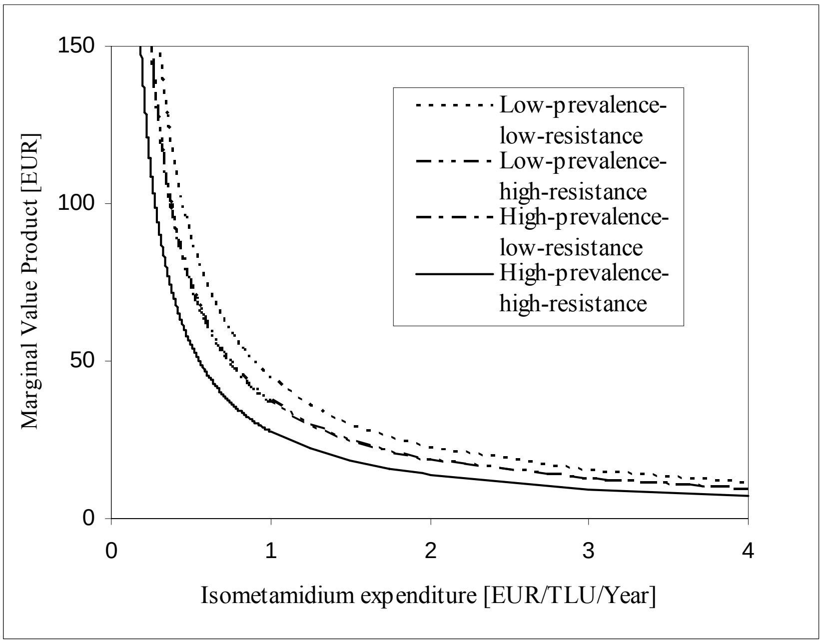

Figure 6.4 Marginal value product of isometamidium in different epidemiological conditions: Cobb-Douglas only

Source: Own survey

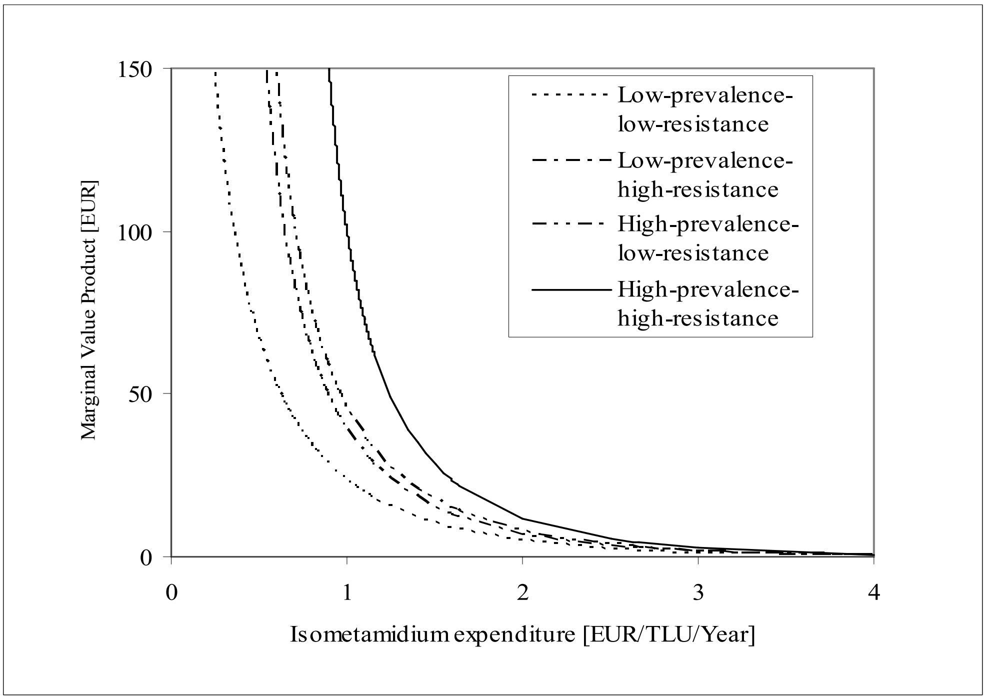

Figure 6.5 Marginal value product of isometamidium in different epidemiological conditions: Exponential 3 damage control function

Source: Own survey

The marginal value products decrease as the levels of isometamidium use increase, showing the diminishing marginal return of the drug. This suggests that increases in the value of an additional output approach zero as isometamidium trypanocide use increases. The decreasing trends of the marginal value products in the low-prevalence-high-resistance and high-prevalence-low-resistance conditions for the Cobb-Douglas only function are close to each other as depicted by the curves of both conditions in Figure 6.4.

The productivity estimates presented in Table 6.10 and Figure 6.5 show that the damage control function provides consistently higher marginal productivity for both trypanocides in the livestock production systems where disease is common and isometamidium resistance is high. However, the conventional production function model (Cobb-Douglas only) shows that the productivity of trypanocidal drug decreases in the situation where trypanosomosis disease prevalence and drug resistance are both high. Based on the theoretical discussion presented in chapter 3 on the damage control framework, high prevalence and high drug resistance increase the potential output loss compared to the situation where the disease prevalence and drug resistance are low. Hence, with the same quantity of disease control input, relatively more output loss will be abated, leading to high productivity of the damage control input

(Lichtenberg and Zilberman, 1986). Similar results have been found for pesticide productivity assessment for cotton production in the case of cotton-rice production systems in Côte d'Ivoire in West Africa (Ajayi, 2000). The results in Table 6.10, Figure 6.4, and Figure 6.5 show that, treating the damage control inputs in cattle production as yield-increasing inputs in the conventional Cobb-Douglas framework may generate misleading results.

6.4.2 Marginal productivity of yield-increasing cattle production inputs

The productivity estimates of other cattle production inputs such as "salt and feed" and the effect of "herd size" as production factor are presented in Table 6.11. The results show a negative influence of herd size using the Cobb-Douglas only functional form and the production function integrating damage control function (exponential 3). This implies that cattle farmers with small herds produce more output per TLU than those with large herds. Such an inverse relationship has also been observed widely in the smallholder crop production. Generally, in the cotton zone of West Africa, small herds contain mainly draught animals that are put to work to support family labour, mainly in land preparation for crop production. While draught animals are used by cattle farmers on their own land, they are also used during the cultivation season for land preparation for other farmers with no draught animals, generating income for the household. Results are consistent with the computation of total cattle output, where the value of draught power represents 57% to 74% of total production. The inverse relationship between herd size and production in this study confirms evidence from Kenya that wealthier households with larger herds extract less output per TLU than average and poor households with small herds (ILRI, 1995).

The marginal value product of salt and feed is greater than one in both the Cobb-Douglas functional form and the damage control specification. The economic interpretation of this result is that cattle farmers in the study zone, regardless of the epidemiological conditions, use less than the optimum quantity of salt and feed. This result was expected because animal feeding is mainly based on free grazing and during the dry season grasses are less available and animals need supplementation. Also, during the dry season, the native grasses and fibrous crop residues alone are unlikely to be sufficient to meet energy requirements for draught animal work (Pearson *et al.*, 1996). Cattle farmers who can afford to buy it provide supplemental feed to animals. Supplementing animals with purchased feed during the dry season leads to an improvement in cattle production. Supplementation in the dry season limits animal weight loss, and mortality, and preserves growth and reproduction potential of the herd, improving fertility and milk production. Given to draught animals before and during ploughing periods, food supplements make it possible to achieve optimal levels of output of the animals (Francis and Ndlovu, 1995). The under-use of salt and feed may be explained by the fact that cattle farmers may lack knowledge on the benefits of supplementation. Also, during the dry season, most cattle farmers lack access to credit and have insufficient cash to buy feed for animals.

Table 6.11: Estimated marginal value product in [€] of salt and feed and the effect of herd size

Epidemiological conditions	Marginal value product in [€]			
	Herd size		Salt and feed	
	Cobb-Douglas	Damage Control function	Cobb-Douglas	Damage Control function
Low-prevalence-low-resistance	-2.84	-2.71	13.85	17.11
Low-prevalence-high-resistance	-2.39	-2.34	11.62	14.81
High-prevalence-low-resistance	-2.35	-2.51	11.38	15.09
High-prevalence-high-resistance	-1.77	-2.23	8.61	14.09

Note: Computed from production function coefficients in Table 6.6 (equation 6.4: Cobb-Douglas only) and Table 6.9 (equation 6.7: exponential 3)

Source: Own survey

6.4.3 Substitution between trypanocides

In this section, the monetary amount by which isometamidium can be reduced by cattle farmers when one extra unit of diminazene is used, so that output remains constant, is explored using the marginal rate of technical substitution. An underlying assumption of substitution is that both output and the epidemiological conditions remain unchanged. The estimation of the marginal product of trypanocides (Table 6.10) shows that they are underused in all epidemiological conditions in the case of isometamidium and when trypanosomosis disease is common and drug resistance high in the case of diminazene, suggesting that cattle farmers can increase their use in those conditions. It is important to note that the biology of drug resistance militates against the exclusive use of one drug. When resistance to isometamidium is present the use of diminazene has beneficial effects for cattle farmers, as trypanosomes are usually not resistant to both diminazene and isometamidium at the same time (Geerts and Holmes, 1998). However, multiple-drug resistant *Trypanosoma congolense* populations were detected in village cattle of Metekel district in north-west Ethiopia (Afewerk *et al.*, 2000). Although multiple-drug resistant may occur in certain circumstances, the use of both drugs to which the different subpopulations of trypanosomes are sensitive may improve the health of cattle. This makes sense biologically; however, the coefficient of the interaction between both trypanocides in the production functions (see Table 66 to Table 69) showed a negative sign suggesting that there is no synergistic effect of both trypanocides on production. The usage of both drugs simultaneously should be done following economic principles (Laxminarayan and Brown, 2001). The marginal rate of substitution can be calculated as the ratio of the marginal value product of the two inputs. Table 6.12 shows the marginal rates of substitution of diminazene for isometamidium in different epidemiological conditions. The results generate a constant marginal rate of substitution of diminazene for isometamidium using both Cobb-Douglas only model and the damage control (exponential 3) specification. The results suggest that expenditure on isometamidium can be reduced by only €0.28 and €0.05 respectively for both models for an additional €1 expenditure on diminazene while keeping cattle production output at the same level in all epidemiological conditions. These marginal rates of substitution of diminazene for isometamidium estimated with both Cobb-Douglas only functional form and the Cobb-Douglas production function integrating damage control function are too small because isometamidium still exhibits high marginal value products in all epidemiological conditions.

Table 6.12: Marginal rates of substitution of diminazene for isometamidium

Epidemiological conditions	Marginal value products [€]				Marginal rates of substitution (absolute value)	
	Cobb-Douglas		Damage control		Cobb-Douglas	Damage control
	ISMM	DIM	ISMM	DIM	DIM for ISMM	DIM for ISMM
Low-prevalence-low-resistance	30.40	8.40	8.60	0.40	0.28	0.05
Low-prevalence-high-resistance	25.50	7.10	12.50	0.60	0.29	0.05
High-prevalence-low-resistance	25.00	6.90	14.30	0.70	0.29	0.05
High-prevalence-high-resistance	19.00	5.30	22.50	1.10	0.28	0.05

Note: Computed from production function coefficients in Table 6.6 (equation 6.4: Cobb-Douglas only) and Table 6.9 (equation 6.7: exponential 3)

Source: Own survey

6.5.1 Damage control and output loss

Using the production function integrating the damage control function specification assuming two sources of damage (exponential 3: equation 6.7), the damage controlled at current trypanocide levels can be computed for different epidemiological conditions, incorporating the estimated coefficients (Table 6.9) and the average values of all the damage control inputs. The resulting factor $G(X_d)$ represents the proportion of the attainable output realised due to the use of damage control inputs X_d. The value of $G(X_d)$ is defined on the [0 , 1] interval; for example a value of 0.95 means that 95% of the attainable output is realised and the attainable output is reduced by 5%. The 5% is the actual output loss that cannot be controlled by the trypanocidal drugs used. Table 6.13 presents the proportion $G(X_d)$[13] of the attainable output realised due to the use of damage control inputs X_d. at the average use of all inputs. The proportion of the attainable output realised is much higher when disease prevalence and resistance are both low, indicating a low level of the actual output loss; whereas in situations where the disease prevalence is high and resistance is also high, much more loss is unabated. The actual output loss in high-prevalence-high-resistance conditions can be two and half times more than in low-prevalence-low-resistance situations (Table 6.13).

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[13] $G(X_d)$ is the proportion of the attainable output realised due to the current use of trypanocidal drugs.

Table 6.13: Damage controlled by trypanocidal drugs at current use level $G(X_d)$ and actual output loss in different epidemiological conditions

Epidemiological conditions	Value of damage control function $G(X_d)$	Actual output loss[a] [%]
Low-prevalence-low-resistance	0.9025	9.75
Low-prevalence-high-resistance	0.8463	15.37
High-prevalence-low-resistance	0.8373	16.27
High-prevalence-high-resistance	0.7435	25.65

Note: Values are computed from the coefficients of the production function integrating the damage control function in Table 6.9.

[a] The actual output loss is part of the avoidable loss (see Figure 3.1 in section 3.2) that is not abated by the current trypanocide use. The avoidable loss is defined as the difference between the attainable output and the simple output (output obtained without isometamidium use).

Source: Own survey

Based on the econometric estimation of the production function integrating the damage control function (exponential 3), the relation between the level of isometamidium use and the actual output losses in different epidemiological conditions can be computed at current average use of other disease control inputs including diminazene. As depicted in Figure 6.6, in the condition of high-prevalence-high-resistance and at current average use of diminazene, the actual output loss can reach 81% if no isometamidium is used. When trypanosomosis and drug resistance are at their low levels, with no isometamidium use, the output loss at current diminazene use may reach 31%. The output loss in high-prevalence-high-resistance when no isometamidium is used represents on average almost €75.00/TLU/Year. This confirms the results of trypanocides productivity (Table 6.10); the productivity of diminazene is more than unity when the prevalence of trypanosomosis disease and isometamidium drug resistance are both high, suggesting that the level of diminazene use in those conditions is low compared to low-prevalence-low resistance conditions where diminazene seems to not be underused (Table 6.10).

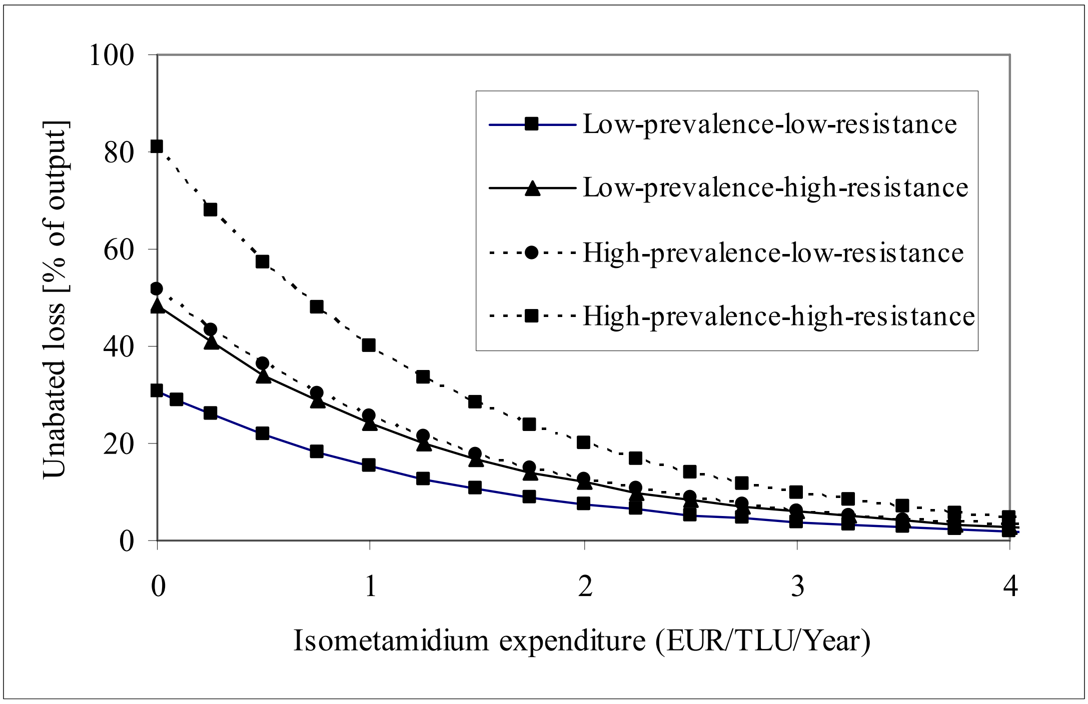

Figure 6.6: Relation between current isometamidium use and output losses (unabated losses) in different epidemiological conditions

Source: Own survey

As depicted in Figure 6.6, the damage agent (trypanosome) has developed resistance to isometamidium so that increasing amounts of the drug have to be used depending on the epidemiological conditions. For example Table 6.14 shows that in order for cattle farmers in high-prevalence-high-resistance conditions to abate 95% of output loss and maintain the output loss at 5% in line with their counterparts in low-prevalence-low-resistance conditions, they have to use 53% more isometamidium per TLU and year (Table 6.14). Parasitological studies have also shown that increasing the dosage or frequency of trypanocides is therapeutically useful, leading to output improvement in the presence of resistance (Silayo *et al.*, 2005; Mdache *et al.*, 1995; Aliu and Chineme, 1980).

Table 6.14: Isometamidium use for the same level of output loss in different epidemiological conditions

Epidemiological conditions	Output loss [% of output]	Isometamidium use [€ TLU^{-1} Year^{-1}]
Low-prevalence-low-resistance	5	2.60
High-prevalence-low-resistance	5	3.30
Low-prevalence-high-resistance	5	3.20
High-prevalence-high-resistance	5	4.00

Note: Values are computed from the coefficients of the production function analysis integrating the damage control function in Table 6.9

Source: Own survey

Table 6.13 and Figure 6.6 show the output loss at the current level of isometamidium use. However, the actual level of use is not optimal because the marginal value product of the drug is more than unity in all epidemiological conditions (see Table 6.11). As the variables are measured in monetary units, the marginal value product represents the increase in output realised from the application of an additional €1.00 of a given input. The economically optimum level of isometamidium use at mean value of all other inputs can then be computed by equating the marginal value product equation (6.14) to one. Using Figure 6.5, the intersection of the marginal value product curves with the horizontal line crossing the Y-axis (marginal value product axis) at one gives the economically optimal use of isometamidium in different epidemiological conditions. Table 6.15 presents the economically optimal use of isometamidium. The optimal use of isometamidium ranges from €4.50 to €5.70 per TLU per year depending on the epidemiological conditions. These values are far bigger than the current use level, which is on average €0.62 per TLU per year. The result confirms the substantial under-use of isometamidium in the study area.

Table 6.15: Economically optimal use of isometamidium in different epidemiological conditions

Epidemiological conditions	Optimal use of isometamidium [€ TLU^{-1} $Year^{-1}$]
Low-prevalence-low-resistance	4.60
High-prevalence-low-resistance	5.20
Low-prevalence-high-resistance	5.00
High-prevalence-high-resistance	5.70

Note: Values are computed from the coefficients of the production function analysis integrating the damage control function in Table 6.9

Source: Own survey

At the economically optimum level of isometamidium use, the output loss compared to the actual output loss is very low in all epidemiological conditions (Table 6.15). The economic output loss can then be computed by subtracting from the actual output loss at the current level of isometamidium use, the output loss at the economically optimum use of the drug (see Figure 3.1 in section 3.2).

Table 6.16: Economic loss of cattle production in different epidemiological conditions

Epidemiological conditions	Actual output loss[a] [% of output]	Output loss at optimum level [% of output]	Economic loss [% of output]
Low-prevalence-low-resistance	9.8	1.3	8.5
High-prevalence-low-resistance	16.3	1.3	15.0
Low-prevalence-high-resistance	15.4	1.4	14.0
High-prevalence-high-resistance	25.7	1.5	24.2

Note: Values are computed from the coefficients of the production function analysis integrating the damage control function in Table 6.9.

[a] The actual output loss is part of the avoidable loss (see Figure 3.1 in section 3.2) that is not abated by the current trypanocide use. The avoidable loss is defined as the difference between the attainable output and the simple output (output obtained without isometamidium use).

Source: Own survey

Table 6.17 summarises values of cattle output and different levels of loss according to the framework presented in Figure 3.1 (see chapter 3). The simple output here is the output obtained without isometamidium use assuming diminazene is used at average level. The difference between the actual output and the simple output which range from €35.00 to €75.00 per TLU per year is the realised profits from additional use of isometamidium starting from the simple output. The actual output realised by cattle farmers in all epidemiological condition is sub-optimal because it is lower than economical output obtained at optimum use of isometamidium. The difference between the economical output and the actual output show that intervention (use of isometamidium) has a cost and can only be an economic option if a corresponding value of the output can be saved to balance the cost of the intervention. The difference between the values of the actual loss and the loss at the optimum use of isometamidium gives the economic loss. However, a sub-optimal situation of too high use of isometamidium above the optimum level is possible and may also lead to economic losses.

Table 6.17: Cattle production output and levels of loss in different epidemiological conditions

Epidemiological conditions	Output and output losses [in €] per TLU per Year					
	Simple output	Actual output	Economical output	Actual loss[a]	Optimum loss[b]	Economic loss
Low-prevalence-low-resistance	77.50	112.30	122.90	11.00	1.50	9.50
High-prevalence-low-resistance	51.00	104.20	122.80	17.00	1.60	15.40
Low-prevalence-high-resistance	49.60	97.30	122.70	15.00	1.80	13.20
High-prevalence-high-resistance	17.60	92.50	122.60	23.70	1.90	21.80

Note: Values are computed from the coefficients of the production function analysis integrating the damage control function in Table 6.9.

[a] The actual output loss is part of the avoidable loss (see Figure 3.1 in section 3.2) that is not abated by the current trypanocide use.

[b] Output loss at optimum level of isometamidium use.

Source: Own survey

6.5.2 Calculation of the total costs of trypanosomosis

It has been estimated using the economic surplus model that animal trypanosomosis costs livestock producers and consumers $1340 million, considering only the loss of meat and milk production (Kristjanson *et al.*, 1999). Preventing or treating the disease with trypanocidal drugs protects about one quarter of cattle living in tsetse-infested areas from the full effects of trypanosomosis. As a control measure, trypanocides are protecting more cattle against the disease than any other method (Budd, 1999). However, it has been shown that whilst controlling trypanosomosis through the use of drugs allows cattle to be kept productively, they do not perform as well as if they were in a completely trypanosomosis-free environment (Trail *et al.*, 1985). In addition, the decreasing effectiveness of the commonly used drugs suggests that the costs of the disease may increase because more drugs have to be used to maintain the productivity of animals, as was shown in Table 6.14. The calculation of the costs of trypanosomosis provides only a partial measure because the effects of the disease are diverse, with direct effects on animal production (including meat, milk, manure and traction) as well as indirect effects on settlement patterns, land use, animal husbandry and farming. Using the methodology developed in the present study, the costs of trypanosomosis for the direct disease effects on cattle production at farm level can be estimated. However, aggregating from the results to national, regional and Africa-wide levels is problematic because of uncertainties about animal numbers, infection rates and the extent of actual, as opposed to potential, tsetse flies infestation (Bourn *et al.*, 2005). The estimation of the costs of the disease was carried out for a standard unit of livestock; the Tropical Livestock Unit (TLU). This number can then be used as a first step in calculating aggregated figures.

The cost (C) of a disease at farm, national or regional level can be defined using two economic components: loss (L), which is the value of output loss due to the disease, and expenditure (E) which is the sum of the costs of veterinary inputs used for the control of the disease; $C = L + E$ (Bennett, 2003; Yalcin *et al.*, 1999; McInerney, 1996). In this study, the expenditure E refers to the sum of the prophylactic veterinary inputs (isometamidium) and the curative veterinary inputs (diminazene) used to mitigate the effects of the disease. The methodology developed allows quantification of the costs of the disease at the actual and optimum levels of isometamidium use keeping other disease control inputs at average levels.

In the previous section, the actual cattle output losses and the losses at the optimal use of isometamidium at farm level were estimated using an econometric model. The production losses range from 9.8% to 25.7% and 1.3% to 1.5% of cattle output for the actual and optimum use of isometamidium respectively, depending on the epidemiological conditions (see Table 6.16). If the actual use and the optimum use of disease control inputs in different epidemiological conditions are considered, the costs of the disease at farm level can be computed. It is estimated that trypanosomosis causes substantial costs per TLU per year at farm level, both in terms of output loss and costs of drug used to mitigate the effects of the disease. Costs depend on the prevalence of the disease and the levels of drug resistance. Where the disease is not highly prevalent and drug resistance is low, the direct costs are also relatively low. The actual costs of the disease can be up to two times higher when the prevalence of the disease is high and isometamidium resistance is also high (Table 6.18). However, at the optimum levels of isometamidium use, the costs of the disease in high-prevalence-high-resistance situations are only 16% more than the costs of the disease in low-prevalence-low-resistance situations. The actual costs of the disease represent on average 12% to 28% of the revenue derived from cattle production in the study area, whereas at the optimum use of isometamidium the costs may represent only 7% to 8% of the revenue, depending on the epidemiological conditions.

Table 6.18: Costs [€ TLU^{-1} $Year^{-1}$] of trypanosomosis at actual and optimal levels of isometamidium use at farm level in the study area

Epidemiological conditions	Value of Output loss		Prevention and treatment costs[a]		Costs[b] of trypanosomosis	
	Actual	Optimum	Actual	Optimum	Actual	Optimum
Low-prevalence-low-resistance	11.00	1.50	2.30	7.10	13.30	8.60
High-prevalence-low-resistance	17.00	1.70	1.80	7.80	18.80	9.50
Low-prevalence-high-resistance	15.00	1.80	2.30	7.60	17.30	9.40
High-prevalence-high-resistance	23.70	1.90	2.30	8.20	26.00	10.10

Note: Values are computed from the coefficients of the production function integrating the damage control function in Table 6.9, the actual average inputs use in Table 6.4, and the optimum use of isometamidium in Table 6.15.

[a] The veterinary service costs are not included because it was not possible to identify the veterinary service exclusively for trypanosomosis control.

[b] The costs include the value of the output loss and the costs of disease control.

Source: Own survey

6.6 Summary

This chapter presented the analysis of the productivity of trypanocides using econometric methods. For the estimation of the production function a Cobb-Douglas production function (base model) and a modified Cobb-Douglas function integrating a damage control function were used. Dummy variables were used for disease prevalence and drug resistance that allowed the analysis to be performed under different epidemiological conditions. Three different specifications of the exponential damage control function were tested. The models have a relatively high explanatory power with an R-squared of 0.659 for the base model and adjusted R-squared ranging from 0.632 to 0.639 for the base model integrating damage control functions. All the variables included in the production functions have the expected sign except for the negative sign of the interaction term between isometamidium and diminazene. It was expected that the preventive and the curative trypanocides would have a synergistic effect, with positive impact on cattle production. The exponential damage control function specification that assumes two sources of damage best fits the data and was used a long with the Cobb-Douglas base model in the analysis.

Both models generate marginal value products per unit cost of isometamidium greater than unity under different epidemiological conditions. Economically, this suggests that livestock keepers are under-using isometamidium and that increasing the level of use would increase profits. The base model generates a marginal value product per unit cost of diminazene greater than unity suggesting that cattle farmers in all epidemiological condition under-use diminazene. However, the production function integrating damage control function specification shows under-use for diminazene only in high-prevalence-high-resistance condition. The high marginal value products of isometamidium in all epidemiological conditions and the marginal value product superior to one exhibited by the production function model integrating damage control function for diminazene in high-prevalence-high-resistance conditions suggest that farmers could increase the profitability of cattle keeping in those conditions if they increase the amount of trypanocides beyond their current level. However, the analysis conducted here is static and does not take into account the negative externality of trypanocide resistance in the future. Resistance to trypanocide is a function of the quantity of trypanocide used (Geerts and Holmes, 1998) and if cattle farmers increase current use of trypanocide they will also increase the likelihood of experiencing future losses from trypanocide resistance (because increased use of trypanocide results in higher levels of resistance which in turn results in greater losses); the economically optimal level of trypanocide use must take this into consideration.

The productivity estimates of trypanocides in this study show that the damage control function provides consistently higher marginal productivity for both trypanocides in the livestock production systems where disease is common and isometamidium resistance is high. However, the conventional production function model (base model) shows that the productivity of trypanocidal drug decreases in the situation where trypanosomosis disease prevalence and drug resistance are both high.

The marginal rate of technical substitution between the two trypanocides suggests that expenditure on isometamidium can be reduced by €0.05 only for an additional €1.00 expenditure on diminazene while keeping cattle production output and the epidemiological conditions constant. The marginal value product of isometamidium is so high compared to diminazene that the marginal rate of technical substitution of diminazene to isometamidium is trivially small suggesting that cattle farmers may be better off only using isometamidium. However, this does not take into account the biological basis of resistance. According to the theory of treatment heterogeneity (Laxminarayan and Brown, 2001), using different trypanocides in different subjects should slow the development of resistance and this strategy is to be preferred even, when one trypanocide shows higher productivity than the other.

Trypanosomosis causes substantial costs per TLU per year at farm level both in terms of output loss and costs of drug used to mitigate the effects of the disease. Following the output loss definitions presented in section 3.2 (see Figure 3.1), at the actual level of isometamidium usage, output losses range from 9.8% to 22.7% depending on disease prevalence and drug resistance levels. It was estimated that output losses may reach only 1.3% to 1.5% of cattle output when isometamidium is used at optimal level depending on the epidemiological conditions. At current use of trypanocidal drugs, the economical losses due to trypanosomosis range from €9.50 to €22.00 per TLU per year. For cattle farmers to maintain the same level of output loss when resistance is increasing, the analysis suggests that they have to use more isometamidium.

Although the valuation of the costs of trypanosomosis is difficult, it was estimated, taking into account the direct effects at farm level, that the disease causes substantial costs which include the control costs and the remaining loss after control. The actual costs of the disease range from €13.30 to €26.00 per TLU per year which represent, depending on the epidemiological conditions, on average 12% to 28% of the output derived from cattle production in the study area. When the use of isometamidium is at the optimum level, the costs of the disease decrease to €8.60 to €10.10 per TLU per year. These costs represent only 7% to 8% of output of cattle production in the study zone, depending on the disease prevalence and drug resistance levels.

Chapter 7

Summary, conclusions and recommendations

7.1 Summary

This study performs an economic analysis of the role of trypanocides in controlling African Animal Trypanosomosis (AAT), in selected villages in Burkina Faso and Mali where resistance to those drugs has been already observed. Trypanosomosis is transmitted by tsetse flies and is a major threat to livestock production in Burkina Faso and Mali. Three main strategies are used for controlling the disease in cattle production: vector control, use of trypanotolerant cattle, and treatment with prophylactic or curative trypanocidal drugs. Generally, the use of drugs is the most important strategy adopted by cattle farmers. However, the reliance on drugs has led to resistance that threatens the effectiveness of the continued use of trypanocides. When resistance has developed, and in a situation where a new drug will not reach the market in the near future, strategies need to be developed that extend the life span of the currently available drugs. As a first step the benefits from current drug use by farmers must be characterised. Previous studies have shown that trypanocidal drugs are the most cost-effective and most common method of controlling trypanosomosis; however, emerging drug resistance is the major constraint to the long-term use of these drugs making the sustainability of trypanocide use questionable. The objectives of this study were (i) to test a damage control function as a tool for measuring the productivity of animal disease control inputs, (ii) to assess the productivity of trypanocide use at farm level under different epidemiological conditions, and (iii) to quantify the costs of trypanosomosis at farm level. To meet these objectives, the following hypotheses were tested. It was hypothesed that (i) the productivity of trypanocidal drugs in cattle production at the farm level differs according to epidemiological conditions, and that (ii) the development of drug resistance contributes significantly to the higher costs of trypanosomosis in the small-scale cattle production system in West Africa. To achieve the objectives of the study, an analytical framework was developed that takes into consideration the distinctive characteristics of yield increasing and damage control inputs.

The farming system of the study area is described as the type of crop-livestock system in the sub-humid zone of Burkina Faso and Mali. In this system crops are grown in association with livestock keeping, and cattle are kept mainly for their contribution to crop production through animal traction. Livestock production is viewed as a technical transformation process in which resources are used to produce livestock products. Under the conditions of small-scale cattle producers in the study area, there are six types of outputs considered in the valuation of cattle production. These can be divided into direct outputs, i.e. milk, meat, draught power and manure, and indirect outputs consisting of financing and the insurance functions of keeping cattle. Summing up the six types of outputs gives the total value of output of cattle production, which serves as the dependent variable for subsequent modelling.

Household level data and quantitative input and output data, and price information for the cattle production function analysis were collected through knowledge, perception and practices survey, herd monitoring, market survey and focus group discussions. The knowledge, perception and practices data encompass socio-economic household characteristics relevant to the identification of factors contributing to trypanocide treatment failures at farm level.

The majority of cattle farmers in the study area considered trypanosomosis the most important disease. Knowledge of the cause of trypanosomosis in the study zone is relatively high compared to other parts of sub-Saharan Africa. Farmers are aware of many strategies to control the disease. The primary strategy is the use of trypanocidal drugs. The results of a logistic regression developed to explain factors that contribute to failures of trypanocidal drug treatments, as perceived by cattle farmers, show that their high demand for advice is an indication that cattle farmers are experiencing drug treatment failures. Also, there are country differences in the extent of treatment failures. Cattle farmers in Burkina Faso are more likely to experience trypanocidal drug treatment failures than farmers in Mali. The use of veterinary and Community Animal Health Worker (CAHW) services contributes significantly to a reduction in treatment failures. Knowledge, perceptions and practices related to factors such as knowledge of the cause of the disease and the appropriate drugs for control make a significant contribution towards a reduction in treatment failures. Older farmers are less likely to experience trypanocidal drugs treatment failures. The results of the model allow the identification of constraints that can limit the implementation of economically optimal use of production inputs and trypanocidal drugs for the control of the disease at farm level in the study area.

To assess the short-term productivity of trypanocide use, a Cobb-Douglas production function (base model) and a modified Cobb-Douglas function integrating a damage control function were used. Dummy variables were used for disease prevalence and drug resistance, allowing the analysis to be performed under different epidemiological conditions. Three different specifications of the exponential damage control function were tested. The specification that assumes two sources of damage best fits the data and was used along with the Cobb-Douglas base model in the analysis. Both models generate marginal value products per unit cost of isometamidium (a trypanocide) greater than unity under different epidemiological conditions. Also, the production function model integrating damage control function generates a marginal value product greater than unity for diminazene (another trypanocide) in high-prevalence-high-resistance conditions.

This study confirms that trypanosomosis is an important disease in the cotton zone of West Africa. Although there is an increasing development of drug resistance, the trypanocidal drugs are still effective. However, at the current sub-optimal levels of isometamidium use (€0.32 to €0.92 per TLU and year depending on epidemiological conditions), the output losses are much higher when disease is common and drug resistance is high. At the actual level of isometamidium usage, output losses range from 9.8% to 22.7% depending on disease prevalence and drug resistance. When the disease control effort reaches optimum levels (€4.60 to €5.70 per TLU and year of isometamidium depending on epidemiological conditions), the output losses are lower in all epidemiological conditions (1.3% to 1.5% of output). This is associated with output losses of 8.5% to 24.2% of total cattle output per TLU and year. These are equivalent to €9.50 to €22.00 per TLU and year depending on epidemiological conditions.

The costs associated with trypanosomosis at actual levels of disease control efforts are much higher than the costs of the disease when isometamidium use is at optimal levels, in all epidemiological conditions. Depending on epidemiological conditions, the total costs of the disease including cost of control and output loss ranges from €13.30 to €26.00 per TLU and year. If, however, farmers would adopt economically optimal disease control efforts, costs would be reduced to €8.60 to €10.10 per TLU and year. While actual costs of the disease represent on average 12% to 28% of the output derived from cattle production in the study area, those costs would be reduced to only 7% to 8%

of output (depending on the disease prevalence and drug resistance levels) if cattle farmers were to adopt economically optimal level of isometamidium use.

7.2 Conclusions

Improvement of the control of cattle trypanosomosis in villages under risk of trypanocide resistance in the cotton zone of West Africa requires an economic analysis of the current use of the most important strategy to control the disease namely trypanocidal drugs. Such analysis was performed by assessing the productivity effects of farmers drug use. This provided a better understanding of cattle farmers' decision making about the use of trypanocides. Also, costs of the disease were quantified under different epidemiological conditions, showing the magnitude of the economic implication of trypanosomosis at farm level.

A major part of the study is the application of the damage control framework as a methodology for measuring the productivity of animal disease control inputs at farm level. The productivity estimates of trypanocides in this study show that the damage control function provides consistently higher marginal productivity for both trypanocides in cattle production systems where disease is common and isometamidium resistance is high. However, the conventional production function model (Cobb-Douglas) shows that the productivity of trypanocidal drug is lower in the situation where trypanosomosis disease prevalence and drug resistance are both high. The high productivity of damage control inputs in high resistance conditions using the damage abatement framework confirms the results of other studies assessing the productivity of damage control inputs (Ajayi, 2000; Lichtenberg and Zilberman, 1986). These results suggest that treating damage control inputs such as trypanocides in cattle production function as yield-increasing inputs in the conventional framework may generate misleading results.

The results of marginal value products generated by the production function model integrating the damage control function for isometamidium in different epidemiological conditions and the marginal value product generated for diminazene by the damage control function in high-prevalence-high-resistance conditions suggest that economically, cattle farmers could increase the profitability of cattle keeping in those conditions if they increase trypanocide inputs beyond their current levels. However, the static analysis applied in this study does not take into account the negative externalities of trypanocide resistance in the future. If the use of trypanocide increases, cattle farmers may experience future losses from trypanocide resistance. The analysis of current trypanocidal drug use shows no significant difference between cattle farmers in a situation of low resistance versus high resistance in terms of isometamidium use. Microeconomic theory would suggest that cattle farmers' short-term response to the development of resistance would be to increase the use of isometamidium as compensation for the decrease in control effectiveness. This situation was not observed in the study area because the productivity of trypanocide is still good. When drug resistance increases, the marginal productivity at current levels of use is high because of the rising impact of the disease. However, a continuous increase in the use of isometamidium may create a lock-in situation where cattle farmers' become path dependent (Cowan and Gunby, 1996). The combination of trypanocidal drugs and choice of cattle breed are two trypanosomosis control strategies that together can foster path dependency of drug use. In the study area, trypanotolerant breeds are less preferred by cattle farmers because of their small size, and the perception by farmers that they are less productive than other breeds. When Zebu cattle (which are trypanosusceptible) can be raised they almost replace the trypanotolerant breeds (Grace, 2006). The increasing introduction of trypanosusceptible breeds has increased the use of trypanocides, which in turn can increase drug resistance. Replacement of trypanotolerant breeds by susceptible cattle encourages trypanocidal drug use, that eventually can lead into a lock-in situation which can make the shift to alternative strategies of trypanosomosis control very costly (Liebowitz and Margolis, 1995). The use of isometamidium will decrease only when productivity is so low that alternative trypanocides become more productive and are adopted. This situation is not likely to be reached very soon because the expenditure on isometamidium can be reduced by only €0.05 for an additional €1.00 expenditure on diminazene, an alternative trypanocide to which trypanosomes show no evidence of drug resistance in villages included in the study. However, continuous and expanding use of trypanocides will inevitably lead to resitiance. By the time resistance is widespread and drugs are no longer effective, the major alternative method of control which is use of trypanotolerant cattle may no longer be available due to lack of breeding stock. In this case the only option for controlling the disease would be the development of new drugs. However the costs of development is prohibitively high. Another option is the eradication of the tsetse vector of trypanosomosis, which is a strategy that has never been sustainable without considerable external support (Budd, 1999). Maintaining the effectiveness of trypanocides is hence a priority for farming systems in West Africa.

The assessment of the costs of the disease estimated in this study shows that trypanosomosis is an important disease in the cotton zone of West Africa. However, it is unlikely that farmers will adopt control methods other than the use of trypanocides. Even the development of resistance will not discourage them from using drugs. As this analysis has shown from a short-term perspective and ignoring the negative externality in the future of drug resistance, farmers are applying suboptimal levels of trypanocides. Because of the common bad nature of drug resistance its effective management requires community action. This requires the attention of national and local authorities, and demands to raise awareness among cattle farmers.

7.3 Recommendations

The control of trypanosomosis has included control of the vector, farming of trypanotolerant breeds and the use of prophylactic or curative trypanocidal drugs. Tsetse control has been sporadically employed for more than 50 years with little long-term success. Trypanotolerant breeds are less preferred by cattle farmers and when trypanosusceptible cattle (Zebu) can be raised they replace trypanotolerant breeds. The use of modern trypanocidal drugs remains the most important strategy for controlling the disease. Based on the major findings of the economic analysis of trypanocide use in villages under risk of drug resistance in this study, the following recommendations are made:

1) The complexities and inherent difficulties of economic analysis of livestock disease are well recognised (Bennett, 1992; Dijkhuizen *et al*., 1995; McInerney, 1996). Based on the findings of this study it can be stated that a method that treats disease control inputs as directly output increasing inputs may lead to wrong conclusions. The damage control function methodology applied in this study can therefore be recommended as a tool for the quantitative analysis of the impact of animal diseases on livestock production.

2) Reinforcing the existing animal health extension system: the role of extension is to help cattle farmers make efficient, productive and sustainable use of their resources, including expenditures on trypanocidal drugs, through the provision of information,

advice, education and training. However, fewer extension professional workers are available to provide information and training due the lack of financial resources in most African countries. It is then recommended that alternatives be developed that are less costly and to the direct advantage of cattle farmers.

3) Promoting rational drug use: the trypanocidal drugs productivity analyses in this study suggest that cattle farmers could increase the profitability of cattle keeping by increasing levels of drug use. On the other hand, if cattle farmers increase their use of trypanocide they will be faced with an increased trypanocide resistance and additional economic losses in the future. Farmers are hence in a double bind situation: they can only farm by using trypanocidal drugs but the more they use, the more they foster resistance that will eventually make these drugs ineffective. Theoretically, the development of resistance can be slowed and perhaps even prevented by “rational drug use” principles. These have been promoted for many years by national and international medical institutions including the World Health Organisation (WHO, 1987) but have not yet been applied to the veterinary context. However, preliminary work by the project in which the current study takes place suggests that rational drug use may be an effective way of slowing the development of resistance to trypanocides (Grace, 2006). Inappropriate drug use in the community resulting from lack of knowledge, incorrect drug selection and incorrect drug regimen (a plan of drug treatments intended to promote better health) is a major factor in the development of resistance. Specific strategies for “rational drug use” have been developed by WHO (2001b) see Appendix N. The objectives of “rational drug use” are typically to: avoid use of drugs by disease prevention, reduce use of drugs by replacing with alternatives, ensure drugs are given only when clinically needed, give the appropriate drug at the appropriate dose, and ensure correct administration of the drug. The strategy can be implemented by four types of interventions as follows: (i) informational/educational interventions providing information or training to health providers or users, (ii) managerial interventions shifting the way services are delivered into more preferred paths and potentially powerful ways of encouraging rational drug use. An important requirement is that there should be effective management in place, often not the case for public services in developing countries. However, managerial initiatives may be effective in the private sector of developing countries, assuming it is functional and that private businesses have incentives to comply with initiatives, and initiatives do not counter their economic interests. Managerial interventions have even been successful when used in the informal

(illegal) private sector (Ross-Dengan *et al.*, 1996), (iii) regulatory initiatives; however in the absence of effective regulation of human health in developing countries, it may be unrealistic to assume that effective regulation of veterinary drugs is attainable, (iv) economic incentives or market-based instruments that change behaviour by providing financial rewards or imposing financial costs. Although often considered as an alternative to regulation, they require some legislation and regulation for their creation and function. Theoretically more effective and less costly than command and control regulation, they have been little used in the pharmaceutical sector in developing countries. Among market-based instruments, price is the single most important determinant of quantity of drug use, although it appears to have little effect on the quality of drugs used (Stephenson, 1996).

Practically, in the study area, applying “rational drug use” requires some changes in policy. Rational drug use requires optimising both quality and quantity of trypanocidal drug use. To meet these objectives, cattle farmers and informal-sector sellers are the most important target groups. However, up until now, their involvement has been largely unacknowledged, as official policy pursues the ideal that all animal treatments are given by trained and qualified professionals. Cattle farmers in the study area are giving the majority of drug treatments and have incentives to do so correctly and cost-effectively. Targeting information at farmers is a potential strategy. Many studies have found that, given small amounts of training and information, farmers can competently give treatments including injections (Grace, 2006). Training improves animal health knowledge and behaviour and often results in positive impacts on livestock health and production (Grace, 2001). Training community-selected farmers as Community Animal Health Workers (CAHWs), who provide animal health services has been a widely used and largely successful strategy (Martin, 2001). However, the creation of low-level cadres has been very controversial, with strong opposition from private veterinarians. Providing information and/or training to the sellers of trypanocides in the informal-sector will also have a beneficial effect. In most cases, changes are needed to the existing policy framework before strategies can be implemented. It is therefore recommended that policy measures be put in place through a process that promotes ownership and buy-in by empowering different actors, especially cattle farmers, private veterinary pharmaceutical suppliers, informal-sector sellers, Community Animal Health Workers and policy makers.

4) Although rational drug use may be an effective way of slowing the development of resistance to trypanocides, a more in-depth analysis of the long-term economic effect of rational trypanocide use on resistance is recommended as further research.

5) The model presented in this study, and the results, provide a basis for further analysis of the long-term economic impact of the control of trypanosomosis under the risk of drug resistance. Nevertheless, the study has some limitations. The most important limitation, which is common to all modelling exercises, is the simplified representation of a complex cattle production system. Because of data limitations the dummy variable used for the epidemiological information in the model did not allow the incorporation of herd specific epidemiological data in the model. However, the representativity at village level of animals included in the disease prevalence and resistance studies ensures that the model is epidemiologically realistic in its representation of the effects of trypanosomosis disease and drug resistance on cattle production. The model focuses on the direct effects of the disease and drug resistance on cattle production at farm level. Further economic consequences including externalities are not included. It is recommended that further research be carried out, particularly including the combination of epidemiological and economic models in a bio economic framework that combines the effects of trypanosomosis on cattle farmers' livelihoods with the long-term and dynamic effects of drug resistance.

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Appendices

Appendix A: Field assessment of isometamidium and diminazene resistance

1 Introduction

This appendix presents the field assessment of isometamidium (ISMM) and diminazene (DIM) treatment failures. The presence of trypanocide resistance can be identified by laboratory tests, in which trypanosome isolates are grown in vivo or in vitro and then exposed to increasing concentrations of trypanocidal drug (Kaminsky and Zweygarth, 1989b; Clausen *et al*., 1999). However, only recently are methodologies being developed that can allow findings from field cases to be generalised to the population of interest. The first reported field test for trypanocide resistance was based on the analysis of collected longitudinal parasitological data, to distinguish between new and recurrent infections; the latter were considered indicative of resistance (Rowlands *et al.,* 1993; Schuckken *et al.,* 2004). Because of variations in the incubation period of trypanosomosis and the low sensitivity of microscopic diagnosis of trypanosomosis, this method is imprecise. Another field test combines Enzyme-Linked Immunosorbent Assay (ELISA) tests for drug detection with parasitological tests for the presence of trypanosomes; the simultaneous presence of both trypanosomes and a high drug concentration is suggestive of resistance (Eisler *et al.,* 1997). Both these methods are observational and less reliable than experimental trials, which better control the confounding factors. Experimental field tests for trypanocides resistance were conducted by McDermott *et al*. (2003) in West Africa (Burkina Faso) on cattle injected with ISMM, a drug that normally protects cattle from infection for two to three months. Cattle were checked every two weeks for the presence of infections, and treatment failures were considered indicative of resistance. Positive animals were treated with DIM, a curative trypanocide, and if animals were still positive 14 days after treatment, resistance to DIM was suspected. This test has been validated by laboratory studies. The same methodology was followed with a control group that received no isometamidium at the start of the study.

2 Methodology

Drug treatment failure assessments were conducted in collaboration with veterinary epidemiologists in six villages in Kénédougou Burkina Faso and 12 in Kénédougou Mali (see map in Figure 4.2). However, in Burkina Faso, data for diminazene were collected for the six villages while for isometamidium results of the previous studies (McDermott *et al.*, 2003) were used. In Mali, 25 villages were selected at random from the 100 villages of the eastern portion of Sikasso region for a cross-sectional survey. The results of the cross-sectional survey were used to determine the prevalence of trypanosomosis. Veterinary epidemiologists consider a prevalence of 10% to be high (McDermott *et al.*, 2003; Woitag, 2003). Based on this threshold, five villages were selected for further longitudinal studies in order to assess the efficacy of isometamidium. Fifty cattle were selected randomly in each village and were treated with isometamidium at the recommended preventive dose (1mg/kg) and an additional 50 cattle were observed as untreated controls. To increase the number of villages in the study, an additional eight villages out of the total number of villages in eastern Sikasso (Kénédougou Mali) and adjacent to the five high prevalence villages, were selected for additional field assessment of trypanocidal drug resistance. Criteria of selection of the additional villages were based on their proximity to the first five villages of the longitudinal study and their accessibility during the rainy season. To assess the efficacy of isometamidium both curatively and prophylactically, treatment failures at 14, 28, 42 and 56 days after the first day of isometamidium treatment were recorded and used in the analysis (Grace, 2006; McDermott *et al.*, 2003).

During the herd monitoring period for production data collection, epidemiological data were also collected three times (the rainy season, the dry cold season and the dry hot season) from the herds monitored in the study. Blood was sampled for the detection of trypanosomes using the buffy-coat technique (Murray *et al.*, 1977). A random sample of cattle was drawn for each trypanosomes prevalence study (three studies in total) in each village. The sample size was determined using the method described by Thrusfield (1995):

$$N_{adj} = \frac{N * n}{N + n}$$

where N_{adj} is the required sample size, n is the sample size based on an infinite population and $\mathbf{N}$ is the size of the study population. Assuming an expected prevalence of 10%, for a desired absolute precision of 5% and a 95% confidence interval the approximate sample size required was calculated. For example, if prevalence were to be estimated using the assumed values above, according to Thrusfield (1995), the sample size required is 138 animals. But in a small study population, say 200 animals:

$n = 138$

$N = 200$

$N_{adj} = (200*138) / (200+138) = 81.66$ which can be rounded to 82 animals.

All cattle detected to be parasitaemic (cattle with parasites present in the blood) were treated with diminazene aceturate and examined two weeks later to again assess the presence of trypanosome infection and the efficacy of diminazene aceturate.

3 Epidemiological conditions of villages included in the production function study

The main purpose is to classify villages included in the production function study into two different categories in terms of trypanocidal drug resistance, which will allow the productivity analysis to be done in different epidemiological conditions. For malaria, resistance was defined by World Health Organisation (WHO) through drugs treatment failure of 25% (OMS, 2003). The same threshold has been adopted because plasmodium and trypanosoma, agents of malaria and trypanosomosis respectively, have similar transmission patterns. A confidence-interval based method is used for the analysis of the data Grace *et al.* (2006b). For example a value of treatment failure of 15% with a confidence interval of [10%, 20%] indicates a maximum risk reduction of 80%. Assuming a threshold of 25% a maximum risk reduction less than 75% reveals evidence for drug resistance.

Table 1 shows the results of the experimental field survey of isometamidium resistance. Data from previous a study by McDermott *et al.* (2003) has revealed evidence for ISMM resistance for four villages included in the study in Burkina Faso.

In all, for the 18 villages included in this study, 10 villages have shown evidence of ISMM resistance and for the remaining eight villages no evidence of resistance could be shown. However, for the purpose of the study, villages with no evidence of resistance are classified as low resistance and villages with evidence of resistance are grouped in the high resistance category.

Using the confidence-interval based method for DIM resistance analysis, no village has shown evidence for resistance (Table 2). Hence, for the economic analysis of trypanocide use in this study, trypanocidal drug resistance refers only to resistance to ISMM.

Table 1: Evidence of isometamidium resistance in the study villages

Country	Village	Average disease prevalence [%]	Maximum [%] risk reduction	Evidence of resistance
Burkina Faso	Diéri	15.78	57	Yes
	M'Bié	23.85	89	No
	Kotoura	3.91	73	Yes
	Sokoroni	4.60	74	Yes
	Sokouraba	12.72	50	Yes
	Toussian Bandougou	23.85	90	No
Mali	Bamadougou.	5.69	81	No
	Bogotiéré	3.06	NA	No
	Diassadiè	14.66	69	Yes
	Farako	7.51	70	Yes
	Finibougou	8.14	74	Yes
	Finkolo	10.38	82	No
	Kafoziéla	2.71	76	No
	Kapala	11.91	60	Yes
	Niangassoba	7.02	87	No
	Niankorobougou	14.92	72	Yes
	Tiogola	12.41	75	Yes
	Wahibéra	20.74	79	No

Note: NA = no analysis possible because of too few cases.

Source: Own survey in collaboration with veterinary epidemiologists and McDermott *et al.* (2003)

Table 2: Evidence of diminazene resistance in the study villages

Country	Village	Fail proportion [%]	Maximum [%] risk reduction	Evidence of resistance
Burkina Faso	Diéri	0.127	95	No
	M'bié	0.154	92	No
	Kotoura	0.200	99	No
	Sokoroni	0.250	97	No
	Sokouraba	0.222	99	No
	Toussian Bandougou	0.157	93	No
Mali	Bamadougou	0.100	99	No
	Bogotiéré	0.400	94	No
	Diassadiè	0.214	90	No
	Farako	0.160	95	No
	Finibougou	0.091	89	No
	Finkolo	0.125	97	No
	Kafoziéla	0.000	100	No
	Kapala	0.212	91	No
	Nianganssoba	0.250	99	No
	Niankorobougou	0.206	93	No
	Tiogola	0.125	95	No
	Wahibéra	0.128	96	No

Source: Own survey in collaboration with veterinary epidemiologists

Appendix B: Prices [in €] of different cattle outputs

Item	Unit	Mean	Minimum	Maximum
Live weight	kg	0.489	0.16	0.83
Milk	liter	0.266	0.076	0.30
Manure	kg	0.010	0.007	0.024
Animal traction	Day-work	9.91	6.10	11.43

Note: €1 = FCFA655.9 (FCFA is the Franc of the French-speaking African Financial Community)

Source: Own survey

Appendix C: Diagnostic of logistic regression model

```
logistic treatment failure advice selftreatment informalsector vetagentcahw age
trypanosomosis sick signstrypanosomosis causetrypanosomosis trypanocide education
childrenatschool active cattle bikes scooter country, robust

Logistic regression                               Number of obs   =        540
                                                  Wald chi2(17)   =      67.81
                                                  Prob > chi2     =     0.0000
Log pseudo-likelihood =  -273.9531                Pseudo R2       =     0.1716

------------------------------------------------------------------------------
             |               Robust
     failure | Odds Ratio   Std. Err.      z    P>|z|     [95% Conf. Interval]
-------------+----------------------------------------------------------------
      advice |   4.093829   1.887815     3.06   0.002     1.658095    10.10765
selftreatm~t |   .7426142   .1750027    -1.26   0.207     .4679195     1.17857
informalse~r |   1.248312   .3496216     0.79   0.428     .7209787    2.161344
vetagentcahw |   .2406598   .1568561    -2.19   0.029     .0670828    .8633676
         age |   .9824621   .0082087    -2.12   0.034     .9665044    .9986833
trypanosom~s |   1.396235   .4192869     1.11   0.266     .7750757    2.515202
        sick |   1.006748   .0175894     0.38   0.700      .972857     1.04182
signstrypa~s |   1.267639    .101556     2.96   0.003     1.083433    1.483163
causetrypa~s |   .5029648   .1249842    -2.77   0.006     .3090426    .8185719
 trypanocide |   .0867847   .0446415    -4.75   0.000     .0316658    .2378462
   education |   .5887992   .2129139    -1.46   0.143     .2898457      1.1961
childrenat~l |   .9920982   .0366581    -0.21   0.830     .9227897    1.066612
      active |   .9895369   .0190021    -0.55   0.584     .9529857     1.02749
      cattle |    .996377   .0052341    -0.69   0.490      .986171    1.006689
       bikes |   1.079181   .0752566     1.09   0.275     .9413169    1.237237
     scooter |   1.073782   .1192001     0.64   0.521     .8638231    1.334774
     country |   3.065559    1.72911     1.99   0.047     1.014833    9.260291
------------------------------------------------------------------------------
```

fitstat

```
Measures of Fit for logistic of treatment failure

Log-Lik Intercept Only:     -330.710     Log-Lik Full Model:         -273.953
D(522):                      547.906     LR(17):                      113.513
                                         Prob > LR:                     0.000
McFadden's R2:                 0.172     McFadden's Adj R2:             0.117
Maximum Likelihood R2:         0.190     Cragg & Uhler's R2:            0.268
McKelvey and Zavoina's R2:     0.309     Efron's R2:                    0.206
Variance of y*:                4.760     Variance of error:             3.290
Count R2:                      0.759     Adj Count R2:                  0.202
AIC:                           1.081     AIC*n:                       583.906
BIC:                       -2736.293     BIC':                         -6.556
```

linktest

```
Logit estimates                                   Number of obs   =        540
                                                  LR chi2(2)      =     114.48
                                                  Prob > chi2     =     0.0000
Log likelihood = -273.46878                       Pseudo R2       =     0.1731

------------------------------------------------------------------------------
     failure |      Coef.   Std. Err.      z    P>|z|     [95% Conf. Interval]
-------------+----------------------------------------------------------------
        _hat |   .9510797   .1198185     7.94   0.000     .7162397     1.18592
      _hatsq |  -.0615933   .0613197    -1.00   0.315    -.1817776     .058591
       _cons |    .048335   .1455102     0.33   0.740    -.2368598    .3335297
------------------------------------------------------------------------------
```

lfit, group(10)

```
Logistic model for treatment failure, goodness-of-fit test

Number of observations =       540
Number of groups =              10
Hosmer-Lemeshow chi2(8) =     1.97
Prob > chi2 =               0.9820
```

Appendix D: Tests of endogeneity of isometamidium: Instrumental variables (2SLS) regression

Variables	Coefficient	Standard errors.	t-value
Intercept	5.201	0.253	20.57***
Salt and feed	0.291	0.104	2.79**
Experience	0.067	0.051	1.32
Herd size	-0.304	0.054	-5.64***
Interaction (Herd size*Salt and feed)	-0.161	0.051	-3.18***
Country	0.196	0.068	2.88***
Disease prevalence	-0.196	0.050	-3.93***
Drug (ISMM) resistance	-0.180	0.055	-3.27***
Other veterinary inputs	0.050	0.060	0.84
Isometamidium (ISMM)	0.081	0.750	0.11
Diminazene (DIM)	0.090	0.214	0.42
Interaction (ISMM*DIM)	0.110	0.695	0.16

F = 32.63***

R^2 / adj. R^2 = 0.651 / 0.631

Instrumented: Isometamidium

Instruments: Salt and feed, experience, herd size, herd size*salt and feed, country, prevalence, resistance, diminazene, isometamidium*diminazene, treatment fees

Tests of endogeneity of: Isometamidium
Wu-Hausman F-test: F(1, 193) = 0.1637 P-value = 0.6863

Durbin-Wu-Hausman chi-sq test: Chi-squ (1) = 0.1745 P-value = 0.6761

Note: * = Statistically significant at 10%, ** = Statistically significant at 5%, *** = Statistically significant at 1%.

Source: Own survey

Appendix E: Tests of endogeneity of diminazene: Instrumental variables (2SLS) regression

Variables	Coefficient	Standard errors.	t-value
Intercept	5.225	0.301	17.36***
Salt and feed	0.278	0.107	2.59**
Experience	0.064	0.051	1.26
Herd size	-0.306	0.054	-5.68***
Interaction (Herd size*Salt and feed)	-0.161	0.051	-3.16***
Country	0.201	0.062	3.27***
Disease prevalence	-0.187	0.054	-3.44***
Drug (ISMM) resistance	-0.178	0.054	-2.29***
Other veterinary inputs	0.068	0.086	0.80
Isometamidium (ISMM)	0.239	0.370	0.65
Diminazene (DIM)	0.035	0.346	0.10
Interaction (ISMM*DIM)	-0.020	0.383	-0.05

F = 32.96***

R^2 / adj. R^2 = 0.653 / 0.633

Instrumented: Diminazene

Instruments: Salt and feed, experience, herd size, herd size*salt and feed, country, prevalence, resistance, isometamidium, isometamidium*diminazene, treatment fees

Tests of endogeneity of: Diminazene
Wu-Hausman F-test: F(1, 193) = 0.1637 P-value = 0.6863

Durbin-Wu-Hausman chi-sq test: Chi-squ (1) = 0.1745 P-value = 0.6761

Note: * = Statistically significant at 10%, ** = Statistically significant at 5%, *** = Statistically significant at 1%.

Source: Own survey

Appendix F: Tests of endogeneity of isometamidium and diminazene: Instrumental variables (2SLS) regression

Variables	Coefficient	Standard errors.	t-value
Intercept	5.201	0.394	13.20***
Salt and feed	0.292	0.193	1.51
Experience	0.067	0.059	1.14
Herd size	-0.304	0.064	-4.76***
Interaction (Herd size*Salt and feed)	-0.161	0.051	-3.15***
Country	0.196	0.094	2.08**
Disease prevalence	-0.196	0.115	-1.71*
Drug (ISMM) resistance	-0.180	0.059	-3.04***
Other veterinary inputs	0.050	0.234	0.21
Isometamidium (ISMM)	0.077	2.060	0.04
Diminazene (DIM)	0.092	0.725	0.13
Interaction (ISMM*DIM)	0.113	1.720	0.07

F = 32.50***

R^2 / adj. R^2 = 0.651 / 0.631

Instrumented: Isometamidium and diminazene

Instruments: Salt and feed, experience, herd size, herd size*salt and feed, country, prevalence, resistance, isometamidium*diminazene, treatment fees, age

Tests of endogeneity of: Isometamidium diminazene
Wu-Hausman F-test: F(2, 192) = 0.0816, P-value = 0.9217

Durbin-Wu-Hausman chi-sq test: Chi-squ (1) = 0.1749, P-value = 0.9163

Note: * = Statistically significant at 10%, ** = Statistically significant at 5%, *** = Statistically significant at 1%.

Source: Own survey

Appendix G: Correlation of variables used in the estimation of the cattle production function

Variables	Output	ISMM	DIM	Other veterinary inputs	Experience	Herd size	Resistance	ISMM*DIM	Salt and feed	Salt and feed * Herd size	Prevalence	Country
Output	1	.173(*)	.127	.321(**)	-.044	-.720(**)	-.343(**)	.174(*)	.267(**)	-.162(*)	-.092	.166(*)
		.013	.069	.000	.533	.000	.000	.012	.000	.020	.190	.017
ISMM	.173(*)	1	-.007	.192(**)	.019	.011	-.110	.896(**)	.252(**)	.227(**)	-.001	-.160(*)
	.013		.915	.006	.788	.878	.115	.000	.000	.001	.994	.022
DIM	.127	-.007	1	.269(**)	-.081	-.068	-.010	.248(**)	-.016	-.027	.103	.054
	.069	.915		.000	.249	.333	.889	.000	.821	.698	.142	.444
Other veterinary inputs	.321(**)	.192(**)	.269(**)	1	.013	-.201(**)	-.031	.252(**)	.293(**)	.187(**)	-.212(**)	.327(**)
	.000	.006	.000		.855	.004	.660	.000	.000	.007	.002	.000
Experience	-.044	.019	-.081	.013	1	.170(*)	-.109	-.029	.238(**)	.308(**)	-.229(**)	-.203(**)
	.533	.788	.249	.855		.015	.117	.681	.001	.000	.001	.003
Herd size	-.720(**)	.011	-.068	-.201(**)	.170(*)	1	.339(**)	-.017	-.181(**)	.340(**)	-.157(*)	-.104
	.000	.878	.333	.004	.015		.000	.810	.009	.000	.024	.138
Resistance	-.343(**)	-.110	-.010	-.031	-.109	.339(**)	1	-.069	-.352(**)	-.179(*)	-.021	.311(**)
	.000	.115	.889	.660	.117	.000		.321	.000	.010	.768	.000
ISMM*DIM	.174(*)	.896(**)	.248(**)	.252(**)	-.029	-.017	-.069	1	.198(**)	.164(*)	.049	-.101
	.012	.000	.000	.000	.681	.810	.321		.004	.019	.487	.148
Salt and feed	.267(**)	.252(**)	-.016	.293(**)	.238(**)	-.181(**)	-.352(**)	.198(**)	1	.800(**)	-.286(**)	-.033
	.000	.000	.821	.000	.001	.009	.000	.004		.000	.000	.640
Salt and feed * Herd size	-.162(*)	.227(**)	-.027	.187(**)	.308(**)	.340(**)	-.179(*)	.164(*)	.800(**)	1	-.310(**)	-.058
	.020	.001	.698	.007	.000	.000	.010	.019	.000		.000	.408
Prevalence	-.092	-.001	.103	-.212(**)	-.229(**)	-.157(*)	-.021	.049	-.286(**)	-.310(**)	1	.008
	.190	.994	.142	.002	.001	.024	.768	.487	.000	.000		.906
Country	.166(*)	-.160(*)	.054	.327(**)	-.203(**)	-.104	.311(**)	-.101	-.033	-.058	.008	1
	.017	.022	.444	.000	.003	.138	.000	.148	.640	.408	.906	

* Correlation is significant at the 0.05 level (2-tailed).

** Correlation is significant at the 0.01 level (2-tailed).

Appendix H: Results of Cobb-Douglas production function (equation 6.4)

```
regress output other veterinary inputs salt and feed herd size feed herd* salt
and feed prevalence resistance experience ISMM DIM ISMM*DIM country, robust
```

```
Regression with robust standard errors                Number of obs =     206
                                                      F( 11,   194) =   41.61
                                                      Prob > F      =  0.0000
                                                      R-squared     =  0.6591
                                                      Root MSE      =  .31037

------------------------------------------------------------------------------
             |               Robust
      output |      Coef.   Std. Err.      t    P>|t|     [95% Conf. Interval]
-------------+----------------------------------------------------------------
othervetinpu |   .0425727    .063945     0.67   0.506     -.083544    .1686895
salt and feed|   .2890924    .128119     2.26   0.025     .0364076    .5417772
   herd size |  -.3043125   .0560373    -5.43   0.000     -.414833    -.193792
saltfeed*Hsiz|  -.1657147   .0518289    -3.20   0.002    -.2679352   -.0634942
  prevalence |  -.1962259   .0474561    -4.13   0.000    -.2898221   -.1026297
  resistance |  -.1748589   .0593077    -2.95   0.004    -.2918295   -.0578883
  experience |   .0679174   .0448384     1.51   0.131    -.0205159    .1563508
        ISMM |   .3768356   .1149286     3.28   0.001     .1501655    .6035056
         DIM |   .1712211   .0727143     2.35   0.020     .0278091    .3146331
    ISMM*DIM |  -.1633422   .1212688    -1.35   0.180    -.4025167    .0758323
     country |   .2107352   .0585772     3.60   0.000     .0952054     .326265
       _cons |   5.121609   .1792991    28.56   0.000     4.767983    5.475234
------------------------------------------------------------------------------
```

`fitstat`

```
Measures of Fit for regress of output

Log-Lik Intercept Only:     -155.954     Log-Lik Full Model:          -45.101
D(194):                       90.202     LR(11):                      221.706
                                         Prob > LR:                     0.000
R2:                            0.659     Adjusted R2:                   0.640
AIC:                           0.554     AIC*n:                       114.202
BIC:                        -943.406     BIC':                       -163.099
```

Appendix I: Results of exponential 1 production function (equation 6.5)

```
Model Summary
Model Variables          1
Parameters              12
Equations                1
Number of Statements     1

Model Variables  OUTPUT
Parameters  a b1 b2 b3 b4 b5 b6 b7 b8 d1 d2 d3
Equations  OUTPUT
The Equation to Estimate is
OUTPUT =  F(a(1), b1(other vet inputs), b2(salt and feed), b3(herd size), b4(salt
and feed* herd size), b5(prevalence), b6(resistance), b7(Experience),
b8(Country), d1(ISMM), d2(DIM), d3(ISMM*DIM))
Instruments  1 @OUTPUT/@b1 salt and feed herd size salt and feed* herd size
@OUTPUT/@b6 @OUTPUT/@b7 Experience Country @OUTPUT/@d1 @OUTPUT/@d2 @OUTPUT/@d3

NOTE: At GMM Iteration 2 convergence assumed because
OBJECTIVE=9.958138E-16 is almost zero (<1E-12).

Nonlinear GMM Summary of Residual Errors

                  DF      DF                                        Adj
Equation       Model   Error        SSE        MSE   R-Square      R-Sq

OUTPUT            12     194    18.9089     0.0975     0.6551    0.6355

Nonlinear GMM Parameter Estimates

                              Approx                  Approx
Parameter       Estimate     Std Err    t Value     Pr > |t|

a               5.426428      0.1724      31.48       <.0001
b1              0.028626      0.0607       0.47       0.6376
b2              0.371791      0.1250       2.98       0.0033
b3              -0.30194      0.0542      -5.57       <.0001
b4              -0.18481      0.0496      -3.73       0.0003
b5              -0.48401      0.2526      -1.92       0.0568
b6              -0.43781      0.2120      -2.07       0.0402
b7              0.086291      0.0460       1.88       0.0622
b8              0.181115      0.0603       3.00       0.0030
d1              1.250003      0.4465       2.80       0.0056
d2              0.418951      0.1362       3.08       0.0024
d3              -0.24427      0.0874      -2.79       0.0057

Number of Observations     Statistics for System

Used               206    Objective      9.958E-16
Missing              0    Objective*N    2.051E-13
```

Appendix J: Results of exponential 2 production function (equation 6.6)

```
Model Summary
Model Variables         1
Parameters             13
Equations               1
Number of Statements    1

Model Variables  OUTPUT
Parameters(Value)  a b1 b2 b3 b4 b5 b6 b7 d1(-1) d2 d3 b8 α
Equations  OUTPUT

The Equation to Estimate is
OUTPUT =  F(a(1), b1(other vet inputs), b2(salt and feed), b3(herd size), b4(salt
and feed*herd size), b5(prevalence), b6(resistance), b7(Experience), b8(Country),
d1(ISMM), d2(DIM), d3(ISMM*DIM), α)

The MODEL Procedure

Nonlinear OLS Summary of Residual Errors

                  DF      DF                                             Adj
Equation       Model   Error        SSE        MSE   R-Square       R-Sq

OUTPUT            13     193    18.7927     0.0974     0.6572     0.6359

Nonlinear OLS Parameter Estimates
                              Approx                   Approx
Parameter       Estimate     Std Err    t Value     Pr > |t|

a               5.637391      0.3568      15.80       <.0001
b1              0.009336      0.0264       0.35       0.7241
b2              0.338742      0.1065       3.18       0.0017
b3              -0.29891      0.0528      -5.66       <.0001
b4               -0.1758      0.0497      -3.54       0.0005
b5              -0.30386      0.2611      -1.16       0.2460
b6              -0.26856      0.2198      -1.22       0.2232
b7              0.078682      0.0501       1.57       0.1181
d1                0.3907      0.3818       1.02       0.3074
d2                0.1359      0.1359       1.00       0.3186
d3              -0.05213      0.0819      -0.64       0.5254
b8              0.191442      0.0573       3.34       0.0010
α               0.562779      0.3573       1.58       0.1168

Number of Observations     Statistics for System

Used               206    Objective         0.0912
Missing              0    Objective*N      18.7927
Heteroscedasticity Test
Equation       Test             Statistic   DF  Pr > ChiSq  Variables

OUTPUT         White's Test         95.44   84      0.1850  Cross of all vars
               Breusch-Pagan         1.44    1      0.2297  1, OUTPUT
```

Appendix K: Results of exponential 3 production function (equation 6.7)

```
Model Summary
Model Variables          1
Parameters              13
Equations                1
Number of Statements     1
Model Variables  OUTPUT
Parameters(Value)  a b1(-1) b2 b3 b4 b5 b6 b7 b8 d1 d2 d3
Equations  OUTPUT
The Equation to Estimate is
OUTPUT =  F(a(1), b1(other vet inputs), b2(salt and feed), b3(herd size), b4(salt
and feed*herd size), b5(prevalence), b6(resistance), b7(Experience), b8(Country),
d1(ISMM), d2(DIM), d3(ISMM*DIM))

The MODEL Procedure
Nonlinear OLS Summary of Residual Errors

                  DF      DF                                        Adj
Equation       Model   Error        SSE        MSE   R-Square      R-Sq

OUTPUT            12     194    18.7045     0.0964     0.6588    0.6395

Nonlinear OLS Parameter Estimates
                              Approx                  Approx
Parameter       Estimate     Std Err    t Value     Pr > |t|

a               5.427911      0.1587      34.20       <.0001
b1              1.939296      0.6679       2.90       0.0041
b2               0.37495      0.1029       3.64       0.0003
b3              -0.30474      0.0515      -5.92       <.0001
b4              -0.18665      0.0489      -3.81       0.0002
b5              -0.51232      0.2759      -1.86       0.0649
b6              -0.45524      0.2316      -1.97       0.0507
b7              0.084474      0.0496       1.70       0.0900
d1               1.37654      0.4735       2.91       0.0041
d2              0.455574      0.1340       3.40       0.0008
d3              -0.25988      0.1046      -2.49       0.0138
b8              0.173994      0.0546       3.19       0.0017

Number of Observations     Statistics for System
Used                 206   Objective         0.0908
Missing                0   Objective*N      18.7045

Heteroscedasticity Test
Equation      Test             Statistic   DF  Pr > ChiSq  Variables

OUTPUT        White's Test         86.82   74      0.1462  Cross of all vars
              Breusch-Pagan         1.59    1      0.2076  1, OUTPUT
```

Appendix L: Questionnaire Knowledge, Perceptions and Practices

Note introductive

Ce questionnaire est réalisé dans le cadre du projet ILRI/BMZ de « gestion améliorée de la chimiorésistance » afin d'évaluer les stratégies de contrôle utilisées par les éleveurs au niveau des exploitations rurales. L'analyse des résultats permettra de déceler les points faibles et de formuler des stratégies à mettre en œuvre en vue de contrôler avec succès le développement de la chimiorésistance.

Les informations sont collectées dans un but strictement scientifique et leur confidentialité sera strictement respectée.

Identification	
Village:	Date:
Nom du répondant:	Questionnaire No:
Nom de l'enquêteur:	Code de l'Exploitation:

1- Généralités

1.1- Age du chef de l'exploitation: 1.2- Sexe: M F

1.3- Education formelle: Aucune/___/ Primaire /___/ Secondaire /___/

Nombre d'années totales d'éducation formelle: /____/

1.4- Education informelle: Alphabétisé /___/ Coranique /___/

1.5- Groupe Ethnique: Autochtone /___/ Migrant/___/

1.6- Nombre de personnes dans l'exploitation: /____/

Age	Masculin	Féminin	Actif	Non actif
0 à 5 ans				
6 ans à 14 ans				
15 ans à 75 ans				
Plus de 75 ans				

1.7- Combien d'enfants vont à l'école? /____/

1.8- Combien de vélos et de mobylettes/Motos, voiture dispose l'exploitation ?

Vélos	Mobylettes/Motos	Voiture

2- Production Animale

2.1- Composition du troupeau de bovins

Catégories	Nombre
Veaux et velles de 0 à 1 an	
Mâle entier > à 1 an	
Mâle castré > à 1 an	
Génisses	
Vaches	

2.2- Nombre de bœufs de labour: /____/

2.3- Race des bovins (nombre dans le troupeau)

Races	Nombre	Nombre utilisé comme bœufs de labour
Zébu		
N'Dama		
Métis		

2.4- Quelles sont les raisons de choix de la race la plus importante dans le troupeau

1...……………………

2...……………………

3...……………………

2.5 Quel est le rôle des bovins dans l'exploitation? (Ordonner seulement les quatre plus importants)

Rôle		Ordre	Autres rôles	Ordre d'importance
Production de viande				
Production de lait				
Production de fumier				
Epargne				
Pour la vente				
Pour la traction animale				

2.6- Depuis quand élevez-vous des bovins? ....

2.7- Aviez-vous un berger? Oui /___/ Non /___/

2.8- Le berger est-il membre de l'exploitation? Oui /___/ ou Non /___/

2.9- Si non comment est-il payé?

En argent (Combien par mois?) ....……………………..

En nature (Quoi et combien par mois?) ....………………

2.10- Depuis quand le berger travaille pour l'exploitation?

2.11- Quel est l'âge approximatif du berger?

2.12 Quel est l'ethnie du berger?

2.13- Qui a la responsabilité pour:

Décider du lieu de pâturage	
Décider du lieu d'abreuvement	
Décider du traitement d'un animal malade	
L'achat des médicaments	
Administrer les médicaments	

3- Alimentation et abreuvement des animaux

3.1- Utilisez-vous des compléments d'alimentation? Oui /___/ ou Non /___/

Si oui lesquels?

	Réponses	Quand? (saison)	Combien de fois par semaine?
Sels			
Fourrages cultivés			
Feuilles / et autres produits provenant des arbres de la brousse			
Résidus de transformation des produits agricoles			
Les résidus de récolte			
Autres			

3.2- Faites-vous la transhumance? Oui /___/ ou Non /___/ Si Oui,

1- Quand au cours de l'année (saison)?	
2- Durée	
3- Distance	
4- Proportion d'animaux	
5- Qui décide du lieu de transhumance ?	

3.3- Combien de fois par jour les animaux sont amenés à l'abreuvement?

	Nombre de fois par jour	Source principale d'abreuvement
Saison sèche		
Saison pluvieuse		
Saison de récolte		

3.4- Quelle est la source d'eau par importance?

	Ordonner par importance	Pendant quelle saison	Distance moyenne aux points d'eau pendant la saison sèche?	Distance moyenne aux points d'eau pendant la saison pluvieuse?
Barrage				
Puits / forage				
Marre/Puisard				
Cours d'eau				
Autres				

4- Connaissance de la trypanosomose animale

4.1- Au cours de l'année passée et de cette année aviez-vous eu des bovins malades?

Oui /___/ ou Non /___/

4.2- Quel genre de problème aviez-vous eu sur les bovins (ordonner seulement les quatre plus importants)?

	Problèmes	Importance	Autres problèmes	Importance
Diarrhée				
Toux / poumons				
Faiblesse				
Peau				
Vers intestinaux				
Tiques				
Trypanosomose				
Avortement				
Fièvre aphteuse				

4.3- S'il y avait des bovins malades de trypanosomose l'année passée?

Combien étaient malades?	
Combien étaient morts?	

4.4- Quels sont les signes de cette maladie? Donnez tous les signes

1	6
2	7
3	8
4	9
5	10

4.5- Comment un animal peut tomber malade de la trypanosomose?

	Causes	Importance	Autres causes	Importance
Mouches tsé-tsé				
Autres mouches				
Tiques				
A partir de l'eau				
Insuffisance alimentation				
Sortilège				
A partir d'autres animaux malades				

4.6- Connaissez-vous la mouche tsé-tsé?
Si Oui, décrivez-la:
……………………………………………………………………………………………………
……………………………………………………………………………………………………

4.7- Supposons qu'un animal est atteint de la trypanosomose

L'animal peut être guéri	Oui	Non
Si Oui comment?		
Quelle est la meilleure façon de guérir l'animal?		
Est-ce que l'animal peut à nouveau attraper la maladie?	Oui	Non
Si oui après combien de temps (en moyenne)		

4.8- Si vous aviez de l'argent pour traiter des animaux malades, aviez-vous de préférence pour une catégorie d'animaux à traiter Oui ou Non
Si Oui, citez les catégories d'animaux par importance

Catégories d'animaux	Importance
Veaux et velles < à 1 an	
Jeunes mâles & femelles	
Vaches	
Vaches en lactation	
Bœufs de labour	

4.9- Qu'est-ce que vous aviez fait la dernière fois lorsqu'un animal est tombé malade de la trypanosomose?

	Réponse	Importance	Autres (nommées)	Importance
Demander des conseils				
Traiter soi-même				
Rien fait				
Tuer l'animal				
Vendre l'animal				

S'il a demandé conseils, spécifier la personne chez qui il a demandé conseils:

4. 10- Est-ce que l'animal a été traité avec un médicament? Si oui lequel?

4.11- Connaissez-vous autres médicaments (moderne ou traditionnel) pour guérir cette maladie?
Oui ou Non Si Oui citez-les

1..………………………
2..………………………
3..………………………

4.12- Parmi ces médicaments lesquels aviez-vous déjà utilisé? (Marquer la réponse par une croix dans la question 4.11)

Si le répondant a cité le Berenil ou le Trypamidium, demander l'efficacité de chaque médicament

Berenil		Trypamidium	
Efficace tout le temps		Efficace tout le temps	
Presque tout le temps		Presque tout le temps	
Plus que la moitié de temps		Plus que la moitié de temps	
Moins de la moitié de temps		Moins de la moitié de temps	
Rarement / Jamais		Rarement / Jamais	

4.13- Quelles peuvent être les raisons pour lesquelles cette maladie n'obéisse pas aux traitements? citez les par importance

1...
2...
3...

4.14- Que faites-vous lorsque la maladie n'obéit pas aux traitements?

	Réponse	Importance	Autres (nommées)	Importance
Augmenter la dose				
Changer de médicament				
Demander conseils				
Répéter le même traitement				
Se séparer de l'animal				

4.15- A votre avis comment peut-on **éviter / prévenir** cette maladie

Méthodes	Réponse	Ordre	Utilisée
Ecran / piège			
Pulvérisation/Pour-on			
Trypamidium			
Berenil			
N'Dama/trypano tolérant			
Eviter les mauvais endroits			
Traditionnelle –herbes, sel, brûlure			
Traditionnelle – prière, surnaturelle			
Autres			

4.16- Si le Trypamidium est utilisé comme médicament de prévention, combien d'animaux en bonne santé sont traités l'année passée

Type d'animaux	Nombre traité	Nombre de traitements réguliers par animal au cours de l'année passée
Bœufs de traction		
Vaches		
Veaux et velles < à 1 an		
Jeunes mâles & femelles		

4.17- Veuillez me montrer les médicaments que vous utilisez contre les maladies

Nom	Date d'expiration	Etat	Utilisé pour	Source/Provenance

4.18- Quelles sont les sources des médicaments que vous utilisez pour traiter vos bovins?
(Ordonner les quatre importantes sources)

	Cocher les sources, (donner le lieu)	Importance
Marché		
Pharmacie vétérinaire		
Vétérinaire privée		
Vendeur ambulant		
Autre éleveur		
Marchand de bétail		
Agent d'élevage		
Autres		

4.19- Pourquoi pensez-vous que ces sources sont importantes?
1..………………………
2..………………………
3..………………………
4..………………………

Remercier sincèrement l'éleveur

Appendix M: Questionnaire for herd monitoring

Fiche 1: Recensement des Animaux (Nombre de Bovins et Structure du Troupeau)

Date	
Village	
Nom du paysan	
Nom de l'enquêteur	
Code de l'exploitation	

Effectif Total du Troupeau	

Catégorie	Nombre	Observations
Veaux et velles de 0 à 1 an		
Mâle entier > à 1 an		
Mâle castré > à 1 an		
Génisses		
Vaches		
Total		

Nombre de bœufs de labour		Observation:

Fiche 2: Prise de Poids des Veaux et Velles

Numéros	Poids (kg)	Numéros	Poids (kg)	Numéros	Poids (kg)	Numéros	Poids (kg)

Fiche 3: Mesure de Tour de Poitrine des Vaches

Numéros	Tour de Poitrine (cm)	Numéros	Tour de Poitrine (cm)	Numéros	Tour de Poitrine (cm)	Numéros	Tour de Poitrine (cm)

Observations:

Fiche 4: Mesure de Tour de Poitrine des Génisses, Taurillons et Taureaux et Bœufs de labour

Génisses		Taurillons et Taureaux		Bœufs de labour	
Numéros	Tour de Poitrine (cm)	Numéros	Tour de Poitrine (cm)	Numéros	Tour de Poitrine (cm)

Observation:

Fiche 5: Quantité de lait prélevée (Observation une fois par mois)

No de la Vache	Quantité Prélevée (litre)		No de la Vache	Quantité Prélevée (litre)		Combien de fois la vache est traite par mois
	Matin	Soir		Matin	Soir	

Observations:

Fiche 6: Variation du Stock d’Animaux de l’Exploitation (Sorties et Entrées)

Catégorie	Sorties								
	Ventes			Mortalité				Donnés	
	Nombre	Valeur	Raison	Tryps	Autres	Abattage	Vols/Pertes	A tiers	En confiage
Veaux et velles de 0 à 1 an									
Male entier > à 1 an									
Male castré > à 1 an									
Génisses									
Vaches									

Catégorie	Entrées				
	Achats			Reçu	
	Nombre	Valeur	Naissances	De tiers	Confiage
Veaux et velles de 0 à 1 an					
Male entier > à 1 an					
Male castré > à 1 an					
Génisses					
Vaches					

Remarques:

Fiche 7: Morbidité, Mortalité (Fiche MM)

Identification de l’animal:

Malade en ce moment, **G**uéri, **M**ort

Symptômes (**P**rimaire, **S**econdaire)

Diarrhée		Membranes muqueuses Pale	
Salivation		Constipation	
Ecoulement Nasal		Dépression	
Ecoulement Vaginal		Emaciation	
Toux		Anorexie	
Difficulté Respiratoire			
Fièvre			
Lésions de la peau			
Aspect du Pelage			
Abcès			

Diagnostics de l’éleveur:

Traitements donnés	Oui	Non

Si traitement

	Traitement a	Traitement b	Traitement c
Quel médicament?			
Quantité donnée (dose & concentration)			
Date du premier traitement			
Combien de fois la dose a été répétée ?			
Qui a donné le traitement (rôle)			
Réponse			
Lieu d’obtention du médicament			
Coût (total & par unité)			

Conseil du spécialiste / traitement

Résultats du Test

Trypanosomosis	
Haemoparasites	
PCV	
Coprologie	
brucellose	
Autres	

Fiche 8: Intrants				
Catégorie	Quantité	Prix Unitaire (FCFA)	Total (FCFA)	Observations
Trypanocides Préventifs				
Trypanocides Curatifs				
Vaccins				
Antibiotiques				
Vermifuges				
Acaricides/Insecticides				
Sels				
Autres intrants achetés				

Combien de charretées de résidus de récolte aviez-vous transporté ce mois?	
Combien de bottes de niébé aviez-vous transporté ce mois?	

Fiche 9: Traction Animale			
Numéro du bœuf	Nombre de jours de travail par mois	Nombre d'heures de travail par jour	Surface cultivée (ha)

Observations:

Appendix N: Specific strategies for improving rational drug use

Training and information	**Regulatory**
• Mass media (radio, television, newspaper) • Provision of printed material, • Continued professional development • Counselling, training of groups or individuals • Academic detailing • Decision-support to change prescription behaviour	• Restriction of antimicrobials to prescription only • Licensing manufacture, importation, distribution and sale of drugs • Registration and inspection of drug sellers • Standards-based marketing authorisation and registration of drugs • Quality control of products and services • Professional bodies to regulate conduct and quality of health service providers and education • Restrictions on drug sales promotion and advertising
Managerial	**Economic/policy**
• Lists of essential drugs and formularies • Evidence-based standard treatment guidelines (non-statutory standards) • Drugs/therapeutics/ethics committees • Peer review and learning structures • Audit and feedback of prescribing practice • Performance targets • Price and quality information (score cards, ranking, quality marks) • Course of therapy packaging • Dispensing and prescribing controls	• Subsidies/taxes on pharmaceutical products to influence price and hence purchasing behaviour • Competition in the provision of health services and products to decrease price and drive up quality • Pharmacy cross-subsidies to encourage service provision in under-served areas • Tax breaks for compliance with regulations, research, relocation to rural areas • Orphan drug provisions to incentivise new products for neglected diseases • Increasing patent length, height and breadth to encourage drugs with new modes of action rather than ‘copy-cat’ products • Removing/placing tariff and non-tariff barriers on pharmaceutical trade • Stimulating research and development by surrogate markets or tournaments/prizes • Tradable permits for resistance

Source: WHO (2001b)