Economic analysis of animal disease control inputs at farm level: the case of trypanocide use in villages under risk of drug resistance in West Africa

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Abstract

This paper presents an economic analysis of the use of drugs (isometamidium and diminazene) in controlling African Animal Trypanosomosis (AAT), a serious disease of cattle and small ruminants in villages that exhibit resistance to isometamidium in Burkina Faso and Mali in West Africa. The study applies a production function framework integrating a damage control function to assess the short term productivity effect of trypanocide use under different epidemiological conditions.

We found that the marginal value products of isometamidium in all epidemiological conditions, and the marginal value product of diminazene in high-prevalence-high-resistance conditions are positive and greater than one revealing an underuse of trypanocidal drugs in those conditions. The economical optimum level of isometamidium is far larger than the current use level. In a strict economic interpretation, this implies that in the short term cattle farmers could increase the profitability if they increase trypanocide input beyond current levels. On the other hand, if the use of trypanocide increases, cattle farmers will also be more likely to experience future losses from trypanocide resistance.

In this paper we demonstrated the feasibility of applying the damage control framework for measuring the productivity of veterinary therapeutic drugs at farm level in poor African countries.

Key words: Burkina Faso, damage control, Mali, productivity, trypanosomosis

Introduction

Improvements to input productivity and returns gained from agriculture defined as both crop and livestock have been identified as a key means of reaching poverty reduction targets and at the same time protect the biological resources available (Fafchamps et al 2001, Wood et al 2000, Pimentel et al 1997). However, many factors, including livestock diseases such as African Animal Trypanosomosis (AAT), jeopardize the ability of agriculture to achieve this important goal. AAT is probably the most important cattle disease in Sub-Saharan Africa and the recommended strategy for controlling the disease is an integrated approach combining vector suppression in epidemiological hot spots and disease management at the herd level through the strategic use of trypanocides and/or genetic improvement of local trypanotolerant breeds (Hendrickx et al 2004). In West Africa the most important strategy remains the use of trypanocidal drugs and many treatments of sick animals are made by farmers (Grace 2005); other strategies are much less commonly employed (McDermott and Coleman 2001). Farmers' high reliance on drugs for the control of the disease makes them very vulnerable to the emergence of drug resistance (Grace 2005). There is concern in sub-Saharan Africa that livestock keepers overuse trypanocidal drugs. Studies in East and West Africa have shown that trypanocidal drugs are used more frequently than trypanosomosis occurs and there is a persistent tendency to use drugs despite the knowledge among livestock keepers of low trypanosomosis prevalence (Machila et al 2003, Kamuanga et al 2001). However, there is little if not no information about the productivity effect of trypanocide use in order to support economically whether cattle keepers overuse or not trypanocides. The study reported here is the first published study assessing the productivity of veterinary therapeutic drugs at farm level in poor African countries. The study provides an opportunity to apply to animal disease control the damage control model (Shankar and Thirtle 2005, Qaim and Zilberman 2003, Huang et al 2002, Carpentier and Weaver 1997, Lichtenberg and Zilberman 1986) that has been widely applied to crop protection inputs' productivity analysis.

Model specification

Output definition

The measurement of input productivity in a cattle production system using the production function approach requires the identification of an appropriate single indicator that can describe the different outputs of the system. A variety of indicators have been used and the difference in indicators is due to differences in the purpose of the analysis. The majority of indicators have specified output (often confined to meat and/or milk) in terms of value, mass or energy (James and Carles 1996). Under the conditions of small-scale cattle producers in West Africa there are six types of outputs considered in this study for the valuation of the total output of cattle production. These can be divided into direct outputs milk, meat, draught power, plus manure, and indirect outputs including financing and insurance benefits of keeping cattle (Moll 2005).

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 such as 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 liveweight 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 in this study 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 number of months spent in the herd.

To define the output of the system, herds were selected for monitoring from 18 villages for which, levels of AAT prevalence and trypanocidal drug resistance are known (6 in Burkina Faso and 12 in Mali). The six villages of Burkina Faso were selected from previous drug resistance study where 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 in south east of Sikasso. Of these, five with high AAT prevalence were selected along with eight which were adjacent to these high prevalence villages. The 18 villages included in the present study had been subject to new epidemiology studies from June 2003 to May 2004 (Grace 2005). A total of 208 herds selected comprising 3565 animals (Table 1) were monitored from June 2003 to May 2004 the end of the monitoring period. Apart from blood sampling and month-to-month recording of veterinary inputs and events in the herds, all management decisions were made by the herd owners, without external interference. Additional price data were collected in local markets and abattoirs, and through focus group discussions.

Table 1. Epidemiological information and number of herds and animals monitored per village

Countries	Villages	Annual disease prevalence, %	Presence of drug resistance	Number of herds involved	Number of animals
Burkina Faso	Diéri	15.8	Yes	11	141
	M'Biè	23.8	No	9	45
	Kotoura	3.91	Yes	16	180
	Sokoroni	4.60	Yes	11	208
	Sokouraba	4.60	Yes	9	74
	Toussian Bandougou	23.8	No	8	48
Mali	Bamadougou	5.69	No	17	144
	Bogotiéré	3.06	No	8	211
	Diassadiè	14.7	Yes	9	132
	Farako	7.51	Yes	12	537
	Finibougou	8.14	Yes	8	330
	Finkolo	10.4	No	21	252
	Kafoziéla	2.71	No	13	193
	Kapala	11.9	Yes	11	212
	Niangassoba	7.02	No	6	115
	Niankorobougou	14.9	Yes	5	175
	Tiogola	12.4	Yes	13	419
	Waibéra	20.7	No	21	149
Total				208	3565

Source: Own survey, Grace 2005 and McDermott et al 2003

To formalize the 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 changes in body weight and number of animals per herd. The value of the recurrent production Q_r during the monitoring period is defined as:

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

Where:

q_{ji} is the quantity of recurrent production **j** produced by animal i and

p_j the price for the recurrent output j (three recurrent products are considered: milk, draught power, and manure),
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 period. 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.

$$Q_e = \sum_{i=1}^{n} (p_{i_{(t+1)}} - p_{i_t}) \quad (2)$$

The benefit from financing can be estimated based on the concept proposed by Bosman et al (1997) stating 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). The factor 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 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 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 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.

$$B^f = \sum_{i=1}^{n} b^f p_i \quad (3)$$

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 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 0.08 of the average value of the stock. Moll (2005) stated that if alternative options are not present, 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 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.

$$B^s = \sum_{i=1}^{n} b^s * \left[p_{i_{(t+1)}} + p_{i_t} \right] / 2 \qquad (4)$$

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:

$$Q = Q_r + Q_e + B^f + B^s \qquad (5)$$

This value Q of the cattle production output as defined in this study is used as dependent value in the production function modeling.

Econometric model

We assume a Cobb-Douglas production function with an integrated damage control function. The total cattle production output **Q** can be expressed as follows:

$$Q = a\left[\prod_{k=1}^{n} Z_k^{\beta_k}\right] * G(X_d, X_v)^{\gamma} \qquad (6)$$

Where:

Z_k is a vector of productive inputs,

X_d and X_v are vectors of damage control inputs and

$G(X_d, X_v)$ is the damage control function.

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, Lichtenberg and Zilberman 1986). Taken into account this restriction and assuming that cattle production output is also function of other variables such as managerial skill, equation (2) can be expressed in the logarithmic form as follows:

$$\ln Q_h = \beta_0 + \sum_{k=1}^{n} \beta_k \ln(Z_{kh}) + \sum \beta_m D_m + \ln\left[G(X_{dh}, X_{vh})\right] \qquad (7)$$

Different functional forms that meet the criteria of damage control function can be assumed, however, given that the most appropriate function still remains unknown (Fox and Weersink 1995, Lichtenberg and Zilberman 1986), we used the exponential damage control function. The exponential function was chosen because of its computational tractability and ease of interpretation. We also estimated the logistic damage control function and found that the exponential best fits the data. Many sources of damage can be included in the production function integrating a damage control function. In this paper, we included in the model two sources of damage, trypanosomosis which is controlled by the use of trypanocides and other diseases which are controlled by the use of other veterinary inputs. In the study area no significant interaction between AAT and other common diseases has been shown (Grace 2005), therefore it was assumed that the two sources of damage are independent, and the damage control function can be written in equation (7) as follows:

$$\ln Q_h = \beta_0 + \sum_{k=1}^{n} \beta_k \ln(Z_{kh}) + \sum \beta_m D_m + \ln\left[(1-\exp(-\beta_d X_{dh} - \beta_m D_m)) * (1-\exp(-\beta_v X_{vh}))\right] \qquad (8)$$

The notation used in equations (7) and (8) are defined as follows:

β_o = 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.
X_d is a vector of damage control inputs related to AAT,
X_v is the aggregate of other veterinary inputs

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 is 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.

Output **(Q)**, converted to its logarithmic form is the dependent variable representing the monetary value of the output of cattle production. The output is composed of liveweight gain, milk, manure, draught animal power, insurance and financial benefits expressed in monetary value [in Euro (€)] per Tropical Livestock Unit (TLU) and year. Draught power and manure represent 63% to 78% of output with draught power alone accounting for 57% to 74% of the production. The cattle keeping valuation showed that the insurance and financing benefits of keeping cattle range from 12% to 20% of output. 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 accounts only for 7% to 14% of total output. The value of the amount of milk extracted for sale and home consumption is low and accounts only for 0.7% to 4% of the output (Affognon 2007).

Preventive trypanocide (ISMM) (X_1) is the total expenditure in [in €] per TLU per year for preventive trypanocides that were used in each herd during the monitoring period (12 months).

Curative trypanocide (DIM) (X_2) is the total expenditure in [in €] per TLU per year for curative trypanocides that were used in each herd during the monitoring period.

Interaction between preventive trypanocide and curative trypanocide (X_1X_2): 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 (X_3) 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 AAT, the use of other veterinary inputs may help to control other diseases, with a positive impact on cattle production output.

Salt and feed (Z_1) 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.

Herd size (Z_2) 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 variable in the production function.

Interaction between salt and feed purchased and herd size (Z_1Z_2)*:* When the herd size is small, the feed and salt purchased might have different effects on production. In the study area, small herds have a high proportion of working animals (oxen); these are more productive and have higher nutritional need than other animals. Supplementation may be on a regular basis in a small herd compared to large herd, with a positive effect on production.

Disease prevalence (D_1) 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 1). Ten percent prevalence of trypanosomal infection is considered high in the study area (McDermott et al 2003).

Drug resistance (D_2) is a dummy variable representing certain types of villages for treatment failure derived from experimental field-tests for isometamidium resistance (1 for villages of the maximum risk reduction superior or equal to 75% using isometamidium and 0 otherwise). No village has exhibited evidence for resistance to diminazene using the threshold of the maximum risk reduction superior or equal to 75%. Hence, for the economic analysis of trypanocide use in this paper, trypanocidal drug resistance refers only to resistance to isometamidium.

Country (D_3) 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 of cattle farming. The farming system in 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 (D_4)*:* the most common specification error in studies of production relations involves the omission of a variable related to management. 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 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 model. Almost all livestock keepers use children as herdsmen and in a very 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 model. 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. Table 1 gives the mean values and standard deviations of variables used in the model.

Table 2. Descriptive statistics of the variables included in the model

Variable	Minimum	Maximum	Mean	S.D	Unit
Output	45.3	431	118	67.7	€ per TLU
Salt and feed	0.00	12.6	2.02	2.29	€ per TLU
Experience	1.00	50.0	15.0	10.7	Years
Herd size	1.00	63.0	11.6	12.1	TLU
Other veterinary inputs	0.00	13.1	2.05	1.78	€ per TLU
Isometamidium (ISMM)	0.00	3.98	0.62	0.83	€ per TLU
Diminazene (DIM)	0.00	6.45	1.58	1.12	€ per TLU
Disease prevalence	0.00	1.00	0.56	0.50	Dummy
Drug resistance	0.00	1.00	0.50	0.50	Dummy
Country	0.00	1.00	0.30	0.46	Dummy

Source: Own survey, S.D = Standard Deviation

Estimation and results

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 AAT threat. If the disease prevalence is not incorporated in the models, which is not the case in this paper, 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. Although the disease prevalence is incorporated in the models, the potentially omitted variables and correlations may lead to the endogeneity problem. We then performed 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).

The prevalence of the disease in the study was measured at village level and not at individual herd level. Cattle farmers may use 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 AAT. Drugs may be used 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). 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. The instrumental variable (IV) method was used to test for the endogeneity of trypanocides. Veterinary service fees as proxy for the intensity of veterinary service and the age of livestock keeper were used as instruments. The Wu-Hausman F-test and the Durbin-Wu-Hausman Chi-square test show that there is no evidence for trypanocide endogeneity and the null hypothesis that trypanocides are exogenous was accepted. The Cobb-Douglas production function with an integrated damage control function (equation 8) with the dependent variable, total cattle production output **Q** was estimated using non-linear Proc model in SAS.

When analyzing cross sectional data using econometric methods, it is important to address some of the problems that may occur. These include heteroskedasticity and multicollinearity. A sample estimation of the correlation between the explanatory variables in the models shows significant correlation between some of the variables. However, 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 (Z_1Z_2), indicates there are no important collinearity problems. There are no formal criteria for determining the magnitude of VIFs that causes poorly estimated coefficients. Values exceeding 10 may be cause for concern (Myers 1990).

Estimation results

The results of parameter estimates are presented in Table 3. The signs of the estimated coefficients are as expected, 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 AAT control, with a positive impact on cattle production. The coefficient of the country dummy is significant and positive. Using the dummy interpretation approach described by van Garderen and Shah (2002) cattle farmers in Burkina Faso realise 19% more output compared to their fellows in Mali. 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 (55 days per year) in Burkina Faso 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. The coefficient of experience as proxy for the managerial skill is positive and only significant at 10%. This 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 results suggest that for a cattle farmer with the current average expenditure on salt and feed, a 10% increase in total TLU owned (herd size) is associated with 6.8% decrease in cattle output. 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 because they tend to have a higher oxen share for animal traction. Also, an increase in salt and feed expenditures spread over more animals in large herds has smaller or no impact on each individual animal and on production.

Table 3. Results of the estimated model

Variables	**Production function (Equation 8)**		
	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**

*N = 206 ; F = 34.05*** ; Adjusted R^2 = 0.64*
** Significant at the 10% level ; ** Significant at the 5% level ; *** Significant at the 1% level*

Marginal productivity of trypanocides

The aggregate cattle production output and production inputs are expressed in terms of monetary value, thus the estimated coefficients for trypanocides can be used to directly compute their marginal value products at the mean value of the variables included in the model. We compute the marginal value products for four different epidemiological conditions using the following equation (example of isometamidium X_1):

$$\frac{\partial Q}{\partial X_1} = \frac{Q^*(\beta_1 + \beta_3 X_2)\exp(-\beta_1 X_1 - \beta_2 X_2 - \beta_3 X_1 X_2 - \beta_4 D_1 - \beta_5 D_2)}{1 - \exp(-\beta_1 X_1 - \beta_2 X_2 - \beta_3 X_1 X_2 - \beta_4 D_1 - \beta_5 D_2)} \quad (9)$$

Table 4 presents the estimated marginal productivity of trypanocidal drugs. The marginal value product of isometamidium and diminazene increases when disease is common and drug resistance high. However, the marginal value product for diminazene is only greater than one in high-prevalence-high-resistance conditions.

Table 4. Estimated marginal value product of trypanocides [in €]

Epidemiological conditions	Isometamidium	Diminazene
Low-prevalence-low-resistance	8.60	0.40
Low-prevalence-high-resistance	12.50	0.60
High-prevalence-low-resistance	14.30	0.70
High-prevalence-high-resistance	22.50	1.10

Note: Computed from production function coefficients in Table 3
Source: Own survey

The high marginal value products greater than one of isometamidium in all epidemiological conditions and the marginal value product superior to one exhibited for diminazene in high-prevalence-high-resistance conditions suggest that cattle farmers in the study zone underuse trypanocidal drugs in those conditions. This confirms results of other epidemiology studies comparing drug use to AAT prevalence, that also suggest current usage of trypanocide in the study zone is inappropriately low (Grace 2005). In a strict economic interpretation, this implies that in the short term cattle farmers could increase the profitability if they increase trypanocide input beyond current levels. On the other hand, if the use of trypanocide increases, cattle farmers will also be more likely to experience future losses from trypanocide resistance.

As trypanocide use and output 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 is computed by equating the marginal value product equation (9) to one.

Table 5 presents the economically optimal use of isometamidium under different epidemiological conditions. The values are far larger than the current use level, which is on average €0.62 per TLU per year confirming the substantial under-use of isometamidium in the study area.

Table 5. Estimated 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: Computed from production function coefficients in Table 3

Conclusions

This paper investigated the short-term productivity effect of drugs in controlling AAT, the most important cattle disease in West Africa. We seek to provide insight into the assessment of the productivity of trypanocidal drugs use in a context of increasing drug resistance. The damage control framework was applied to animal disease control. These results demonstrate the feasibility of damage control framework for measuring the productivity of animal disease control inputs at farm level in poor African countries. By casting the production economics analysis of cattle keepers in a damage control framework, we have been able to explore the productivity effect of trypanocides. Results reveal that cattle keepers to be currently under using isometamidium in all epidemiological conditions and diminazene when disease is common and the isometamidium resistance is high. Because trypanocidal drugs act as damage control agents, the occurrence of damage determines their productivity. As damage increases, damage control inputs become more important, and this is reflected in their marginal productivity. The model presented in this paper, and the results, provide a basis for further analysis of the long-term economic and dynamic 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 modeling 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.

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