Modelling of economic losses due to CBPP at herd level in Ethiopia

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INTRODUCTION

Contagious bovine pleuropneumonia (CBPP) is a major respiratory cattle disease widespread in several African countries, and remaining a threat to cattle health in Europe; it also occurs in parts of Asia (India and Bangladesh) and in the Middle East (Kuwait) (Masiga et al., 1996; Regalla et al., 1996). Thanks to the efforts of the PARC (Panafrican Rinderpest Campaign) project, rinderpest, once considered the major contagious cattle disease in Africa, has almost been eradicated from the continent, making CBPP currently the primary infectious animal disease targeted in the region. Until the beginning of the 1990s, CBPP vaccination campaigns, combined with rinderpest, had succeeded in controlling the disease. Nowadays however, the incidence of the disease is increasing in several African countries (Masiga et al., 1996); the increase is mainly related to general socio-economic deterioration in Africa, the operational and financial inefficiency of veterinary services, and the increasing movement of cattle due to the intensification of trade, and human migration during wars and droughts.
CBPP is caused by *Mycoplasma mycoides* subsp. *mycoides* biotype small colony (MmmSC); the disease is of great importance in the history of medicine, biology and veterinary medicine. It is an hyperacute, acute, subacute or chronic cattle disease, characterised by pneumonia and extensive lesions of serofibrinous pleurisy (Provost, 1987).
An evaluation of economic losses due to the disease, and a cost benefit analysis of its control strategies in Africa, are indispensable and urgently needed in order to provide policy-makers with sufficient knowledge to select appropriate programmes of control or eradication (OIE, 1994; Masiga et al., 1996).
Very little literature exists about CBPP economic analysis in Africa. Oluokun (1980) carried out a cost-benefit analysis of CBPP control strategies in Nigeria, as did Zessin and Carpenter (1985) in Sudan. Windsor and Wood (1998) discussed the cost of control of CBPP in Central and Southern Africa. Laval (2000) proposed a conceptual framework of the economic impact of CBPP in a zone of Ethiopia, West Wollega.
The objective of this study is to model the economic impact of CBPP at herd level, taking into consideration the specific case of cattle herds in West Wollega, western Ethiopia. Three different herd management strategies (hypothetical stable herd, dairy herd, feedlot herd) will be tested using the deterministic epidemiological model developed by Chalvet-Monfay et al. (2001).

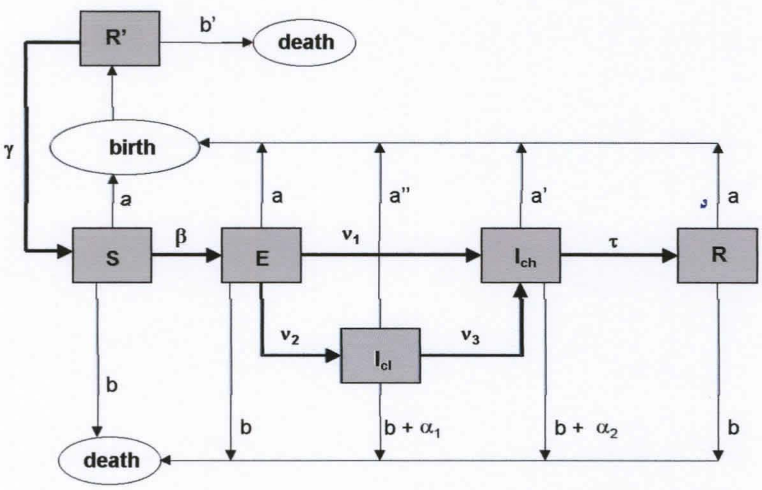
MATERIALS AND METHODS

The comparison of herd gross margins between herds recently affected by CBPP and herds free from CBPP will allow us to calculate the economic losses caused by CBPP for 3 different herd management strategies over a period of four years. This study will not compare strategies of control of CBPP. Only one reference strategy will be studied which is the one observed in the field in West Wollega, Ethiopia, i.e. treatment of CBPP clinical cases with antibiotics (by farmers or at the government clinic), and no vaccination. Revenues from animal products and production costs, including costs of treatment, will be evaluated to calculate the herd gross margin. A deterministic epidemiological model will be used to build an epidemio-economic model of the impact of CBPP at herd level.

The epidemiological model

The epidemiological model is described by Chalvet-Monfay et al. (2001). It is a deterministic, state-transition, differential calculus simulation model representing the spread of CBPP within herds. It follows the SIR scheme: the population is divided into compartments S (Susceptible), I (Infected) and R (Recovered or immune) as first described by Anderson and May (1979). The specificity of the SIR model developed in our study is that compartment I is divided into two groups: clinical and chronic cases (Icl and Ich). The model and the definitions of state variables and parameters are shown in Figure 1.

FIGURE 1: SEIR model of CBPP spread



State variables (compartments) :

- **R'** : Number of juvenile resistant animals (animals assumed to be resistant to the disease until the age of 1 year)
- **S** : Number of susceptible (i.e. naive) animals exposed to CBPP (they can also be resistant)
- **E** : Number of infected animals during incubation period (including animals in incubation period before going to Icl or to Ich directly)
- **I_{cl}** : Number of clinical CBPP infected animals (acute cases) for the first time
- **I_{ch}** : Number of chronic, subacute or symptomless CBPP infected animals (i.e. CBPP seropositive but without acute symptoms) , thereafter called "chronic cases"
- **R** : Number of recovered animals (they do not excrete the pathogen)

Parameters :

- a : Net birth rate of S females .
- a' : Net birth rate of I_{ch} females.
- a" : Net birth rate of I_{cl} females.
- b : Natural death mortality rate of adults (not caused by CBPP).
- b' : Natural death mortality rate of juveniles.
- α_1 : Additional mortality rate of clinical CBPP infected animals I_{cl}.
- α_2 : Additional mortality rate of chronic CBPP infected animals I_{ch}.
- β : disease transmission coefficient (transmission of the disease from S to E) ; used to calculate contact rate

- $S\beta$, number of susceptible animals that are infected by an infected animal per unit time
- ν_1 : Rate of passage of infected animals (E) directly to chronic compartment I_{ch}.
- ν_2 : Rate of passage of infected animals (E) directly to clinical compartment I_{cl} .
- ν_3 : Rate of passage from clinical compartment I_{cl} to chronic compartment I_{ch}.
- τ : Recovery rate of chronic CBPP infected animals I_{ch} (Rate of passage from I_{ch} to R)

Definition of epidemiological and production categories of animals

Epidemiological categories of animals

In order to produce the economic sub-model four epidemiological categories of animal are distinguished:

- R': calves below 1 year, believed to be resistant to CBPP
- N: normal adults: adults which did not show any clinical acute symptoms of CBPP during the year (S, part of E, part of Ich)
- S: sick adults: adults which have suffered from acute clinical CBPP (i.e. Icl) during the year
- D: dead adults: adults which have died during the year

The number of animals present yearly in each category is calculated running the epidemiological model.

Production categories of animals

Three categories of animals are distinguished, which is a simplification of the reality. Each category corresponds to an age/sex group and is related to specific types of animal production.

- "Calves": their age is from zero to one year and they include both sexes. They are considered non-productive. As mentioned by Provost et al. (1987) unweaned animals have low susceptibility to CBPP, and young cattle aged up to 12-18 months are only moderately susceptible to CBPP. In our study we will consider calves under one year old as resistant for the purpose of simplification. Therefore they correspond to the animals present in compartment R' in the epidemiological model.

- "Adult females": this category includes all female animals above 1 year, even if not mature. Two sub-categories can be distinguished: heifers from 1 to 3 years (roughly 1/4 of the "adult females" in the herd) and productive cows above 4 years (roughly 3/4 of the "adult females" in the herd). Production consists of milk from the cows as well as offtake benefit from old cows when culled.

- "Adult males": this category includes all male animals above 1 year, even if not mature. They may be castrated or not. Two sub-categories can be distinguished: bulls ageed 1 to 3 years (1/4 of the "adult males" in the herd) and oxen, castrated and above four years (3/4 of the "adult males" in the herd). Oxen produce animal work (ploughing) and skin and meat when slaughtered (or sold).

Traditional livestock farming in Ethiopia also involves production of manure, which is used as natural fertiliser or fuel. This form of production will not be included in this analysis.

Epidemio-production categories of animals

The combination of epidemiological categories and production categories produces the epidemio-production categories of animals as shown in Table I:

Table I: Epidemio-production categories of animals (in brackets number n_{ij} of animals present in each category)

		Production categories i		
		Calves	Females	Males
Epidemiological categories j	R'	R' (n_{11})		
	N		NF (n_{22})	NM (n_{23})
	S		SF (n_{32})	SM (n_{33})
	D		DF (n_{42})	DM (n_{43})

The use of the epidemiological simulation model and the knowledge of the initial composition of the herd in terms of production categories will allow us to determine the number of individuals $n_{ij}(t)$ present in each epidemio-production category at time t (i.e. every year after t0). This will be one input in the economic sub-model.

The economic sub-model

The economic sub-model is shown in figure 2. Economic indicators used in the model must first be defined.

Gross margin is defined as the enterprise/activity output (hereafter called revenues) less the variable production costs attributable to the activity; fixed costs are ignored.

Gross margin = output – variable costs

In this paper, the gross margin will be calculated for the "cattle rearing" activity in a traditional farm in Ethiopia and will be called "herd gross margin" (HGM). To enable us to calculate HGM, the individual gross margin will be used; this is defined as the gross margin per animal unit.

Annual individual gross margin (IGM)

The annual individual gross margin IGM will allow us to make the transition between the epidemiological model and the economic sub-model.

$IGM_{ij}(t)$ is the difference between annual revenues $R_{ij}(t)$ and annual variable production costs $C_{ij}(t)$ in year t, for an individual animal from the epidemio-production category ij.

$$IGM_{ij}(t) = R_{ij}(t) - C_{ij}(t)$$

In the case of the traditional livestock farming system in the Ethiopian highlands, the formula for $R_{ij}(t)$ is:

$$R_{ij}(t) = T_{ij}(t) + M_{ij}(t) + F_{ij}(t) + O_{ij}(t)$$

$T_{ij}(t)$ = annual revenues from animal work (draught power) in year t for an individual animal from epidemio-production category ij
$M_{ij}(t)$ = annual revenues from milk production in year t for an individual animal from epidemio-production category ij
$F_{ij}(t)$ = annual revenues from manure production in year t for an individual animal from epidemio-production category ij
$O_{ij}(t)$ = annual revenues from offtake (i.e. animal culled: sold or slaughtered at farm) in year t for an individual animal from epidemio-production category ij

In this paper only $M_{ij}(t)$, $T_{ij}(t)$ and $O_{ij}(t)$ will be considered. Since the costs of grazing on pasture lands and consumption of crop-residues by cattle are not taken into account in our study as variable production costs, and since manure is an input to pastures and fields (for crop production), the revenue from manure $F_{ij}(t)$ are not taken into account. We consider that the value of manure produced by each individual is equal to the value of grazing lands and crop residues consumed by this animal.

The formula for $C_{ij}(t)$ (variable production costs) is:

$$C_{ij}(t) = Tr_{ij}(t) + Fe_{ij}(t) + La_{ij}(t)$$

$Tr_{ij}(t)$ = Annual costs of medical treatments (antibiotics, vaccination, other…) in year t for an individual animal from epidemio-production category ij

$Fe_{ij}(t)$ = Annual costs of feeding (supplementation only, not grazing) in year t for an individual animal from epidemio-production category ij

$La_{ij}(t)$ = Annual costs of human labour in year t for an individual animal from epidemio-production category ij

In this paper only $Tr_{ij}(t)$ and $Fe_{ij}(t)$ will be considered. In the traditional farming system in Ethiopia manpower comes from family members and is therefore free. High population density is characteristic of the Ethiopian highlands, and labour availability is therefore higher than the demand at farm level, due to large family sizes and limited farming areas. Therefore, $La_{ij}(t)$ will not be taken into account nor calculated in this analysis.

Herd Gross Margin (HGM) and $\Delta(t)$

The annual herd gross margin in year t HGM(t) is the sum of the $IGM_{ij}(t)$ of each individual animal $n_{ij}(t)$ present in the herd in year t.

$$HGM(t) = \Sigma\Sigma\ [n_{ij}(t) \times IGM_{ij}(t)]$$

We will distinguish $HGM_1(t)$, the annual herd gross margin in year t, with CBPP present (i.e. introduction of a CBPP acute clinical case in the herd at t=0) and $HGM_2(t)$, the annual herd gross margin in year t for the same herd but without CBPP.

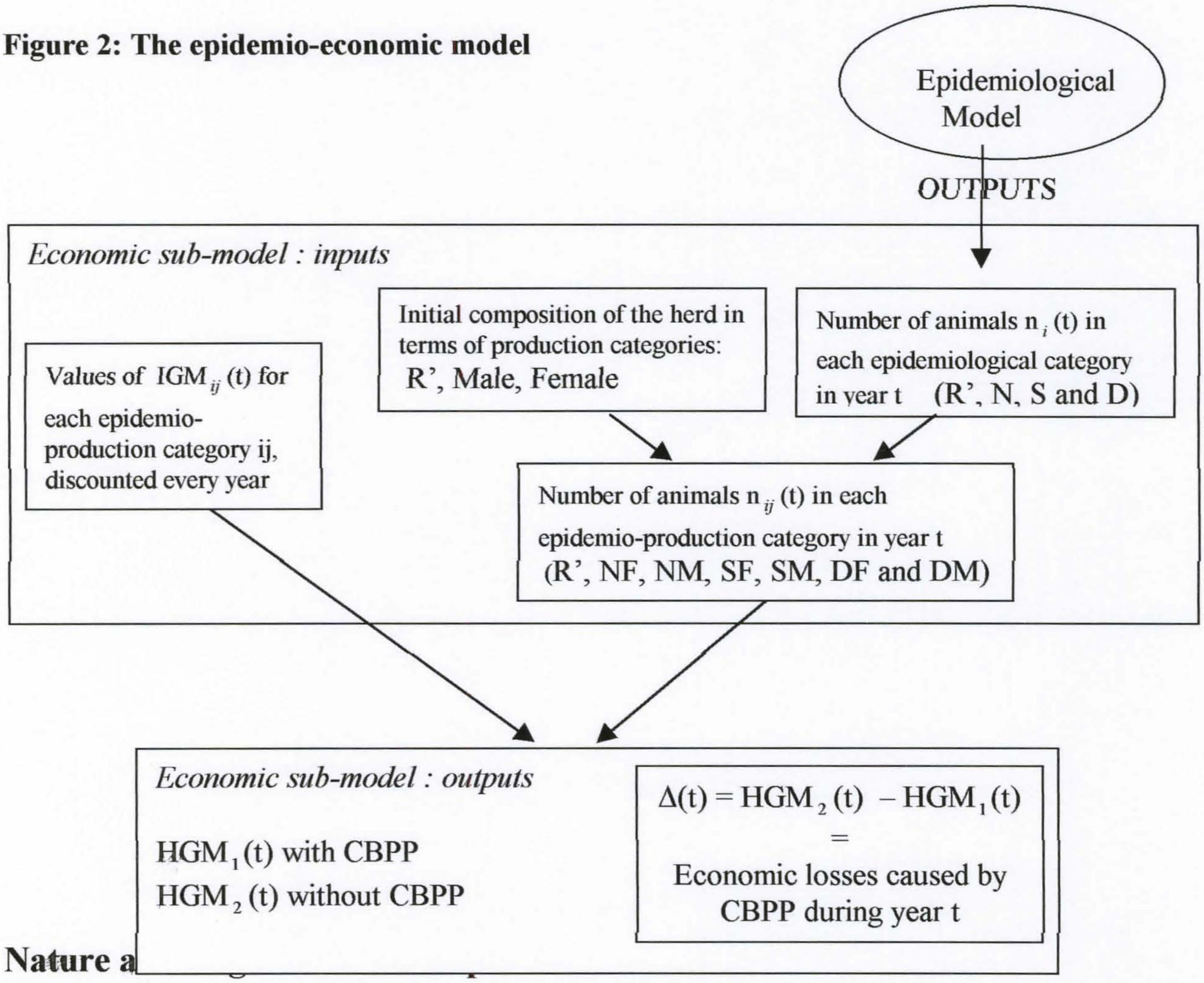
Thus we can define $\Delta(t)$ as the economic loss caused by CBPP at herd level during year t:

$$\Delta(t) = HGM_2(t) - HGM_1(t)$$

Time horizon

The model will be run for a period of four years starting from the introduction of a sick animal (i.e. introduction of one CBPP acute clinical case) into a herd of 20 animals. Therefore, costs in the economic model will need to be discounted yearly using an appropriate discount rate.

Figure 2: The epidemio-economic model



Nature a

Epidemiological parameters: Herd follow up in West Wollega (Ethiopia)

The epidemiological parameters used in the epidemiological model are calculated from the preliminary results of a one year herd follow-up implemented in western Ethiopia (West Wollega Zone, Bodji Woreda). The location of the area within Ethiopia is shown in Figure 3. The area is located at 9.36° Latitude North and 35.59° Longitude East. The production system is a sedentary mixed crop-livestock farming system, as encountered in the Ethiopian highlands in *Wäynä Däga* agro-ecological zones (highlands located between 1500 and 2000 meters above sea level) (Faye, 1994). The climate is tropical humid. Cattle rearing is one of the major activities in this area, which is famous in Ethiopia for its butter production. The main crops cultivated in West Wollega are cereals (maize, sorghum, millet and teff (*Eragrostis abyssinica*)) and coffee as well as some legumes and tubers.

Figure 3: Map of Ethiopia with location of some places of interest for the study

To be completed

CBPP penetrated West Wollega administrative Zone in 1994 from Sudan, and spread within the Zone from West to East. The infectious disease is enzootic in the western Districts of the Zone and epizootic in the most recently affected Districts such as Bodji District.

A herd follow-up designed by a CIRAD-ILRI joint research project was set up in June 2000 in Bodji District. Its aim is to collect epidemiological data concerning the spread of CBPP within herds, as well as demographic and animal production data, in order to better understand the livestock farming system in the area.

A total of 450 animals in 25 herds have been followed for one year in Daro Sombo Peasant Association in Bodji District. Out of the 25 herds, 5 herds with an average number of 20 heads of cattle were affected by CBPP a few weeks before the beginning of the survey, as has been serologically confirmed by CFT and cELISA tests. Three sera samples were collected from each animal and analysed at approximately three-month intervals. The serological results are shown in table II.

Table II: CBPP survey results in West Wollega

Farmer's codes														
BEDE			EJAK			SOTA			WAAY			YENE		
Sampling rank			Sampling rank			Sampling rank			Sampling rank			Sampling rank		
1	2	3	1	2	3	1	2	3	1	2	3	1	2	3

Time elapsed since onset of the disease (months)	2	6	9	2	-	9	3	7	10	2	6	9	-	6	9
Number of animals sampled (from initial individuals)	22	16	14	22	-	17	14	7	6	27	23	20	-	38	30
Number of new positives among samples (CFT or cELISA)	7	2	0	4	-	0	5	0	1	3	2	1	-	8	6
Number of CBPP clinical cases (Icl)	3	1	0	0	-	0	2	0	1	0	2	0	-	0	2
Death from acute CBPP confirmed by serology	1	0	0	0	-	0	0	0	0	0	0	0	-	0	0

If adjusted for a herd of 20 animals, the average number of CBPP positive samples (by CFT or cELISA) is 4.5, 6.2 and 8 out of 20 animals at first, second and third sampling respectively (on average 2.25, 6.25 and 9.25 months after the onset of the disease respectively).
Figure 4 shows the epidemic curve of CBPP in a herd of 20 animals using the state-transition model described above and the epidemiological parameters' values calculated from the field follow-up data in West Wollega as shown in Table III.

Figure 4: Epidemic curve of CBPP in a herd of 20 animals

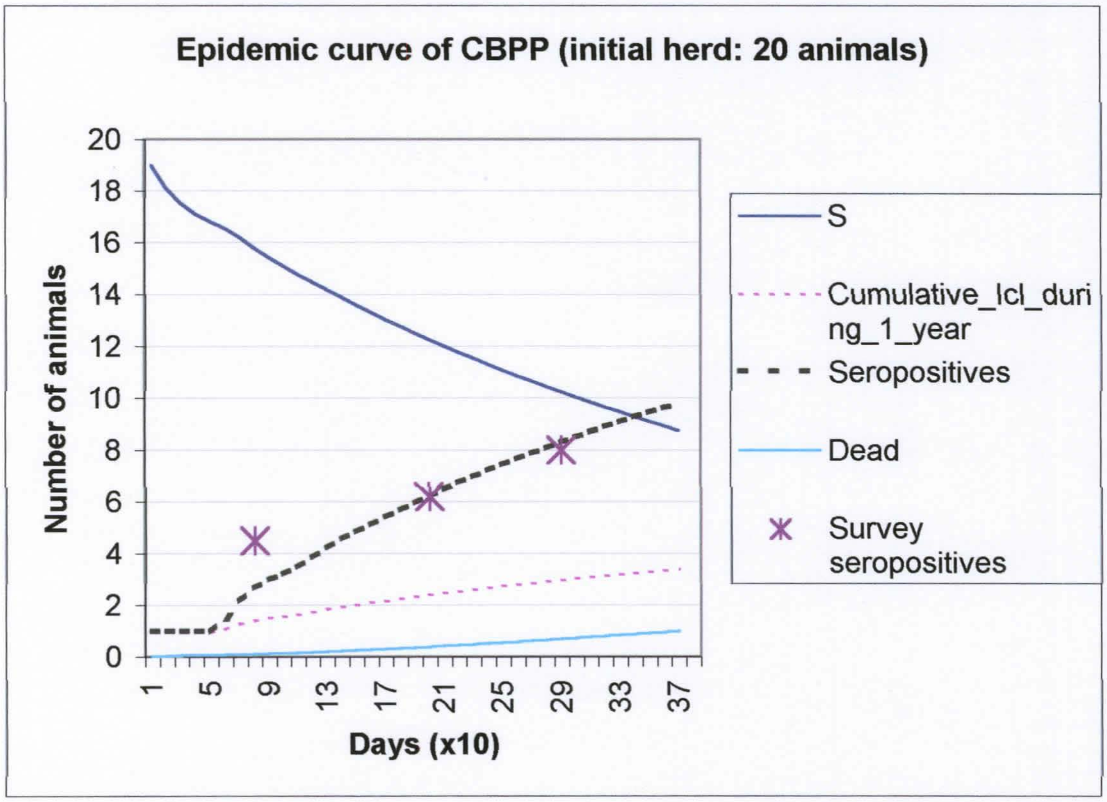


Table III: Epidemiological parameters and reproduction performances

SEIR model Parameter	Origin	Reference	Value
▪ a : Net birth rate of S females .	Calculated	Kiwuwa et al.,	0.83 for mature cows

	from literature	1983	(above 3 yeras)
▪ a' : Net birth rate of I_{ch} females.	hypothesis	No	0.5 x a
▪ a" : Net birth rate of I_{cl} females.	hypothesis	No	0.5 x a
▪ b : Natural death mortality rate of adults (not caused by CBPP).	Follow-up	West Wollega	1/7800
▪ b' : Natural death mortality rate of juveniles.	Follow-up	West Wollega	1/3500
▪ α_1 : Additional mortality rate of clinical CBPP infected animals I_{cl}.	Follow-up	West Wollega	1/360
▪ α_2 : Additional mortality rate of chronic CBPP infected animals I_{ch}.	hypothesis	No	1/2000
▪ β : disease transmission coefficient ; used to calculate contact rate	Follow-up	West Wollega	5.5×10^{-3}
▪ ν_1 : Rate of passage directly to chronic compartment I_{ch} of infected animals (E).	Follow-up	West Wollega	70%
▪ ν_2 : Rate of passage directly to clinical compartment I_{cl} of infected animals (E).	Follow-up	West Wollega	30%
▪ ν_3 : Rate of passage from clinical compartment I_{cl} to chronic compartment I_{ch}.	Follow-up	West Wollega	1/30
▪ τ : Recovery rate of chronic CBPP infected animals I_{ch} (Rate of passage from I_{ch} to R)	hypothesis	No	1/730

The disease transmission coefficient is calculated to be 5.5×10^{-3} for acute cases (Icl), which corresponds to a contact rate of $20 \times 5.5 \times 10^{-3} = 0.11$ susceptible animals that are infected by an infected animal per day in a herd of 20 susceptible animals. Icl animals are assumed to remain in that state during 30 days before passing to the Ich state, and it is believed that they excrete the pathogen profusely during that period. The "basic reproductive rate" for Icl can therefore be calculated as follows: $R_0(I_{cl}) = 0.11 \times 30 = 3.3$, which means 3.3 secondary cases are caused by one infectious Icl animal during its entire infectious period (Diekmann et al., 1990). Among the 3.3 animals 1 will become an acute case (30% of the cases) and 2.3 will directly become chronic cases.
The contact rate for Ich (chronic cases) is assumed to be 50 times lower than those of Icl but the excretion period is assumed to be two years (730 days). The basic reproductive rate for Ich is therefore (0,11/50) x 730 = 1.6 (0.5 Icl and 1.1 Ich).

Some of the parameters could not be calculated and are presently only hypotheses. An additional 1000 head of cattle have now been included in the follow-up in order to clarify the parameters (especially transmission coefficient), but results are not yet available. The parameters shown in Table III are therefore preliminary results, which have to be confirmed by further results.

Animal production and production factors

➢ *Animal production data*

Animal production data are collected from literature.

Reproductive performances and milk production performances are drawn from ILCA data from the Asela research Centre (Kiwuwa et al., 1983). Performances from Arsi breed, which is a small format breed of Ethiopian zebu similar to that found in Wollega, are shown in table IV. The authors mention that the results of their study showed production levels in the station to be similar to those on smallholder farms.

Table IV: Production performances of Arsi breed in Asela station (Ethiopia) (Source: ILCA)

Parameter	Value
Calving interval	439 days
Age at first calving	34.4 months
Average annual milk production	689 kg/year
Butyric rate of milk	5.5 %

The average annual milk yield of the Arsi breed given by Kiwuwa et al. (1983) is very close to the predicted lactation yield of the Horro breed, estimated to 653.4 kg/lactation by Gebreegziabher (2001) in Bako Research Centre. Horro breed is the zebu breed found in West Wollega.

Draught production figures are drawn from Goe (1987) and Gryseels and Goe (1984). Oxen are used approximately 50 days/year for ploughing activities in Ethiopian highlands.

➢ *Production factors data*

- Treatments :

The quantity and the nature of treatments used to cure the cattle and their costs are drawn from the preliminary results of the herd follow-up in West Wollega.

- Animal feeding:

Milking cows are occasionally given supplementary food at the beginning of lactation period and during drought periods. Oxen are systematically given supplements, during working days only. Fattening males in feedlots are supposed to be given daily supplements for 50 days prior to being sold.

Supplementation comprises cereals (maize, sorghum or others) and salt. The average amount of supplementation is decided as follows (assumptions based on preliminary results of animal production follow-up in West Wollega, except for fattening):

Milking cows: 100 kg per year

Working oxen: 1 kg per working day

Fattening males: 2 kg per fattening day

Additionally, calves (R') are estimated to suckle 250 litres of milk in their first year if kept in the herd (preliminary results from animal production follow up in West Wollega). This explains why their IGM is negative in table VII.

➢ *Effect of CBPP on animal production and production factors*

The qualitative effect of CBPP on animal production and production factors was described by Laval (2000) at herd level in West Wollega. The quantitative effect proposed for clinical cases (SF and SM) is hypothetical and based on field experience in West Wollega.
It is assumed that for female acute CBPP cases (SF) annual milk production is decreased by 20% on average, as is supplementary feeding during the same year, because of decreased appetite and feed consumption.
Concerning working animals, it is also assumed that for acute CBPP cases (SM) annual working output is decreased by 20%, as is feeding expenditure.
If sold during the year following a CBPP clinical event, an animal is expected to gain only half the normal amount of body weight gained if being fattened (case of herd 3, see below), therefore animals SMsold have half the gained value of NMsold. They also require only half the normal feeding expenditure for fattening.

Dead animals (DF and DM) are assumed to have been producing normally for half of the year (within that 12 months they live, on average, for only 6 months). It is also assumed that they have died quickly (1 to 2 weeks) and that the impact on production during the average 6 productive months is negligible.

Economic data

Except treatment costs, economic data are also collected from literature.

Table V shows the prices of some agricultural products of interest during 1999, drawn from CSA (1999).

Table V: Annual average price of some agricultural products and livestock in West Wollega from September 1998 to August 1999 (CSA, 1999).

Item	Price in Birr (Ethiopian currency)	Price in US$ (1Birr = 0.125 US$)
Maize (kg)	0.85	0.11
Sorghum (kg)	0.75	0.09
Wheat (kg)	1.32	0.17
Butter (kg)	16.91	2.11
Heifer	287.14	35.9
Cow	470.27	58.8
Bull	325.31	40.7
Ox	550.87	68.9

Butter is the only milk product marketed in West Wollega. Only the price of butter is available, and it is therefore used to calculate the price of milk. For this purpose it is first necessary to evaluate the original amount of milk needed to produce 1 kg of butter using coefficients of conversion (Meyer and Duteurtre, 1998). The butyric rate being 5.5 % (Kuwiwa et al., 1983), using the calculation method proposed by O'Mahony and Peters (1987), for a butter with 82% of fat content, the coefficient of conversion is 15.7 kg of milk to produce one kg of butter. Considering other milk sub-products as economically negligible, the price of one kg of milk is therefore 16.91 / 15.7 = 1.08 Birr (= 0.135 US$).

Oxen can be rented on a cash basis, at US$ 1.50/day/pair without manpower, which brings the cost of one day of work for one ox to 0.75 US$ (Gryseels and Goe, 1984).

Fattened oxen are expected to raise 225 Birr if sold ; their value is assumed to increase from bulls' cost to oxen's cost.

Treatment costs are drawn from the herd follow-up in West Wollega (Bodji District). The average cost of treatment for a CBPP clinical case (one or two antibiotic injections) is 10 Birr/animal, the same as for other potentially fatal diseases. The average expenditure for cattle health in West Wollega (excluding CBPP treatments) is calculated to be 0.4 Birr per animal per year.

The cost of supplementation is estimated to be 1 Birr per kg since it is composed of maize, sorghum or other more expensive cereals, mixed with salt.

The discount rate chosen is 5%, which is very near to the interest rate at the Commercial Bank of Ethiopia (Addis-Ababa) in 2001.

Herd structure and management

The model will be applied to three different herd management strategies.

1. *An hypothetical stable herd* **(Herd 1)** composed of 20 animals (10 males and 10 females) without demographic movement (except death from CBPP) as considered in Chalvet-Monfay et al. (2001). The herd is considered demographically stable; it is an assumed that there is no addition of calves and no culling. Only milk and draught production are taken into account.

2. *A dairy herd* **(Herd 2)** composed of 20 females and 5 (female) calves at the beginning. The birth-rate is 0.83 calves per cow per year, and the removal of animals from the herd is shared between natural mortality and culling of old cows. Heifers represent 25% of the "adult females". Only cows are fertile and we consider that a calf will be removed if it is a male and will stay in the herd if it is a female; the entry of new females into the herd will therefore be considered as 0.75 x 0.83 x 0.5 = 0.31 per cow per year. Culling of old cows occurs at the age of nine. Therefore the life of each individual is divided into 3 periods: calf (0-1 year), heifer (2-3 years) and cow (4-9 years).

3. *A feedlot herd* **(Herd 3)** composed of 20 males with a turnover period of one year (i.e. 20 entry and 20 culled during one year). They are used for work if oxen and sold after 50 days of fattening. It is assumed that 25% are bulls (and therefore do not work) and 75% are oxen.

RESULTS

Epidemiological modelling

Table VI shows the herd composition in terms of epidemio-production categories for herds 1, 2 and 3 for each year during a 4 year period. The composition of the herds without CBPP is shown in italics.

Table VI: Epidemio-production categories of animals in different herds after simulation using SEIR epidemiological model with CBPP challenge (introduction of a clinical case at t0) (bold) and without CBPP (*italic*).

HERD 1	Epidemio-production categories													
	Calves		Females						Males					
	R'		NF		SF		DF		NM		SM		DM	
Year 0	**0**	*0*	**9,5**	*10*	**0,5**	*0*	**0**	*0*	**9,5**	*10*	**0,5**	*0*	**0**	*0*
Year 1	**0**	*0*	**7,9**	*10*	**1,7**	*0*	**0,4**	*0*	**7,9**	*10*	**1,7**	*0*	**0,4**	*0*
Year 2	**0**	*0*	**8,3**	*10*	**0,7**	*0*	**0,6**	*0*	**8,3**	*10*	**0,7**	*0*	**0,6**	*0*
Year 3	**0**	*0*	**8,2**	*10*	**0,3**	*0*	**0,6**	*0*	**8,2**	*10*	**0,3**	*0*	**0,6**	*0*
Year 4	**0**	*0*	**7,9**	*10*	**0,1**	*0*	**0,4**	*0*	**7,9**	*10*	**0,1**	*0*	**0,4**	*0*

HERD 2	Epidemio-production categories									
	Calves		Females						Offtake	
	R'		NF		SF		DF		NF sold	
Year 0	**5**	*5*	**19**	*20*	**1**	*0*	**0**	*0*	**0**	*0*
Year 1	**5,6**	*6,4*	**17,6**	*21,4*	**3,7**	*0*	**1,6**	*1*	**2,1**	*2,6*
Year 2	**5,4**	*7*	**20,4**	*24*	**2**	*0*	**2,2**	*1,1*	**2,3**	*2,8*
Year 3	**5,8**	*7,8*	**21,7**	*26,6*	**1,4**	*0*	**2,2**	*1,2*	**2,6**	*3,2*
Year 4	**6,3**	*8,7*	**23**	*29,6*	**1,1**	*0*	**2**	*1,3*	**2,7**	*3,5*

HERD 3	Epidemio-production categories											
	Males						Offtake					
	NM		SM (stayed in herd)		DM		NM sold		SM sold		Total sold	
Year 0	**19**	*20*	**1**	*0*	**0**	*0*	**0**	*0*	**0**	*0*	**0**	*0*
Year 1	**17,8**	*19,4*	**1,8**	*0*	**1,7**	*0,9*	**17,5**	*19,7*	**1,3**	*0*	**18,8**	*19,7*
Year 2	**19**	*19,2*	**0,3**	*0*	**1,6**	*0,9*	**17,6**	*19,3*	**1,1**	*0*	**18,7**	*19,3*
Year 3	**18,8**	*19,1*	**0,3**	*0*	**1,5**	*0,9*	**17,8**	*19,2*	**0,8**	*0*	**18,6**	*19,2*
Year 4	**18,8**	*19,1*	**0,3**	*0*	**1,4**	*0,9*	**17,9**	*19,1*	**0,7**	*0*	**18,6**	*19,1*

Calculation of IGM (t=0)

Herd 1:

NF: IGM = R – C = M – (Fe + Tr) = (0.75 x 689 x 1.08) – (0.75 x 100 + 0.4) = 482.6

SF: IGM = R – C = M – (Fe + Tr) = (0.75 x 0.8 x 689 x 1.08) – (0.75 x 100 x 0.8 + 10 + 0.4) = 446.5 – 70.4 = 376.1

DF: IGM = ½ (0.75 x 689 x 1.08) – (1/2 x 0.75 x 100 + 10 + 0.2) = 279 – 47.5 = 231.3
NM: IGM = R – C = (0.75 x 50 x 6) – (0.75 x 50 + 0.4) = 225 – 37.9 = 187.1
SM: IGM = R – C = (0.75 x 0.8 x 50 x 6) – (0.8 x 0.75 x 50 + 10 + 0.4) = 180 – 40.4 = 139.6
DM : IGM = ½ (0.75 x 50 x 6) – (1/2 x 0.75 x 50 + 10 + 0.2) = 112.5 – 29 = 83.5

Herd 2:
R': IGM = R – C = 0 – (Fe + Tr) = - (250 x 1.08 + 0.4) = - 270.4
NFsold: IGM = (½ x 689 x 1.08 + 470.3) – 1/2 x (100 + 0.4) = 842.3 – 50.2 = 792.1

Herd 3:
NMsold : IGM = (1/2 x 0.75 x 50 x 6 + 550.9) – [(1/2 x 0.75 x 50 + 100) + 325.3 + 0.2]
= 219.1
SMsold : IGM = [½ (0.75 x 0.8 x 50 x 6) + 438] – [½ (0.8 x 0.75 x 50) + 100/2 + 10 + 0.2 + 325.3] = 127.5

Table VII: Individual gross margin of various epidemio-production categories of animals

Item	Normal animals			Sick animals		Dead animals		Offtake animals		
	R'	NF	NM	SF	SM	DF	DM	NFsold	NMsold*	SMsold*
Revenues										
Milk	-	558	-	446.5	-	279	-	372	-	-
Traction	-	-	225	-	180	-	112.5	-	112.5	90
Offtake (sale price)	-	-	-	-	-	-	-	470.3	550.9 (0)	438 (0)
Total revenue	0	558	225	446.5	180	279	112.5	842.3	663.4 (112.5)	528 (90)
Variable costs										
Feeding	270	75	37.5	60	30	37.5	18.8	50	118.8 (18.8)	65 (15)
CBPP treatments	-	-	-	10	10	10	10	-	-	10
Other treatments	0.4	0.4	0.4	0.4	0.4	0.2	0.2	0.2	0.2	0.2
Purchase	-	-	-	-	-	-	-	-	325.3 (0)	325.3 (0)
Total variable costs	270.4	75.4	37.9	70.4	40.4	47.7	29	50.2	444.3 (19)	400.5 (25.2)
Ind gross margin	**-270.4**	**482.6**	**187.1**	**376.1**	**139.6**	**231.3**	**83.5**	**792.1**	**219.1 (93.5)**	**127.5 (64.8)**

* If animals are not fattened (only borrowed for one year without payment) then consider the values in brackets (and see below the results for herd 3b)

Note that the revenue from milking cows (NF) is dramatically decreased if the calf is kept in the farm and suckles (IGM of R' is negative), which is always the case under the traditional farming system in the Ethiopian highlands.
The high difference between the IGM of NFsold and NMsold is explained by the fact that IGM of NMsold is calculated taking into account the cost of purchasing the animal (feedlot herd for fattening with a turnover of one year) whereas NF has no purchasing cost since the animal is assumed to be born on the farm.

Discounted values of IGM(t)

Table VIII: Discounted values of Individual Gross Margins IGM(t) for each epidemio-production categories of animals (discount rate = 5%)

	Epidemio-production categories of animals									
	R'	NF	SF	DF	NM	SM	DM	NFsold	NMsold	SMsold
Year 0	-270,4	482,6	376,1	231,3	187,1	136,9	83,5	792,1	219,1	127,5
Year 1	-257,5	459,6	358,2	220,3	178,2	130,4	79,5	754,4	208,7	121,4
Year 2	-245,3	437,7	341,1	209,8	169,7	124,2	75,7	718,5	198,7	115,6
Year 3	-233,6	416,9	324,9	199,8	161,6	118,3	72,1	684,2	189,3	110,1
Year 4	-222,5	397,0	309,4	190,3	153,9	112,6	68,7	651,7	180,3	104,9

Calculation of HGM and Δ(t)

General results

Table IX: Annual Herd Gross margin with (HGM_1) and without (HGM_2) CBPP and HGM losses Δ(t) caused by CBPP in 3 herds of 20 animals with different management strategies

	Herd 1			Herd 2			Herd 3		
	$HGM_1(t)$	$HGM_2(t)$	Δ(t)	$HGM_1(t)$	$HGM_2(t)$	Δ(t)	$HGM_1(t)$	$HGM_2(t)$	Δ(t)
Year 1	5989	6378	389	9909	10369	460	7356	7639	283
Year 2	5539	6074	536	10402	11031	630	7008	7162	154
Year 3	5040	5785	745	10365	11697	1331	6640	6786	146
Year 4	4498	5510	1011	10211	12345	2134	6324	6445	120
Total 1 to 4	**21066**	**23747**	**2681**	**40887**	**45442**	**4556**	**27329**	**28032**	**703**

Considering the herd gross margin only, the economic losses caused by CBPP within 4 years of the appearance of the disease in the herd are 11.3%, 10% and 2.5% of the herd gross margin for herds 1, 2 and 3 respectively.

Results for herd 3 changing IGM of outgoing animals: turnover without payment

We run the model for herd 3 with the same management strategy (with a turnover of 20 males every year) but with a different value of the IGM for outgoing animals (NMsold and Smsold) since it is assumed, as observed in West Wollega, that there is no fattening, i.e. no revenue from sale, no initial purchase and no extra feeding for fattening (as shown in Table VII). Males are only used for work and this is the only revenue taken into consideration.

NMsold : IGM(0) = 112.5 – (18.8 + 0.2) = 93.5 (instead of 219.1)
SMsold : IGM(0) = 90 – (15 + 10 + 0.2) = 64.8 (instead of 127.5)

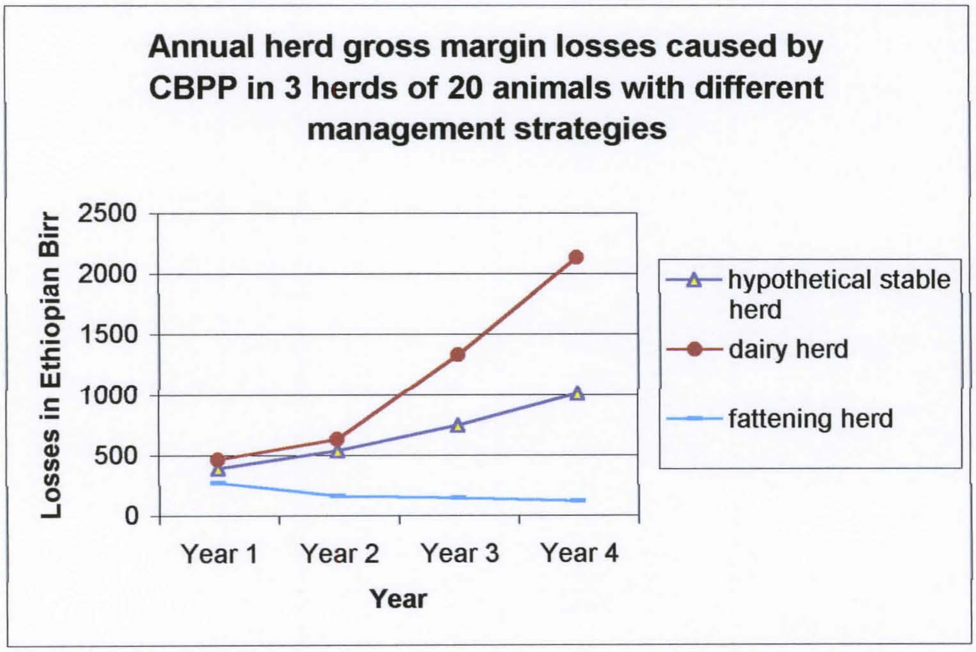
Table X: Herd Gross Margin for herd 3 changing the value of IGM

	Herd 3a (fattening)			Herd 3b (turnover only, no fattening)		
	$HGM_1(t)$	$HGM_2(t)$	Δ(t)	$HGM_1(t)$	$HGM_2(t)$	Δ(t)

Year 1	7356	7639	283	5185	5283	98
Year 2	7008	7162	154	4941	4963	22
Year 3	6640	6786	146	4665	4703	37
Year 4	6324	6445	120	4439	4471	32
Total 1 to 4	**27329**	**28032**	**703**	**19230**	**19420**	**190**

Considering the herd gross margin only, the economic losses caused by CBPP within 4 years of the appearance of the disease in herd 3 are 2.5% of herd gross margin for IGM calculated with fattening and 1,0% if calculated without fattening.

Figure 5: Annual herd gross margin losses caused by CBPP in 3 herds of 20 animals with different management strategies



Sensitivity analysis

A sensitivity analysis was performed by changing the values of uncertain parameters and restarting the simulation. Economic parameters (discount rate) and epidemiological parameters (additional mortality rates α_1 and α_2, rates of passage ν_1 and ν_2, disease transmission coefficient β) are tested hereafter.

Discount rate

Table XI: Herd Gross Margin for herd 1 changing the values of discount rate

	Discount rate: 5%			Discount rate: 10%			Discount rate: 20%		
HERD 1	$HGM_1(t)$	$HGM_2(t)$	$\Delta(t)$	$HGM_1(t)$	$HGM_2(t)$	$\Delta(t)$	$HGM_1(t)$	$HGM_2(t)$	$\Delta(t)$
Year 1	5989	6378	389	5717	6088	371	5241	5581	340

Year 2	5539	6074	536	5047	5535	488	4241	4651	410
Year 3	5040	5785	745	4383	5032	648	3376	3876	499
Year 4	4498	5510	1011	3735	4574	840	2637	3230	593
Total 1 to 4	**21066**	**23747**	**2681**	**18882**	**21229**	**2347**	**15494**	**17337**	**1842**

Considering the herd gross margin only, the economic losses caused by CBPP within 4 years of the appearance of the disease in herd 1 are 11.3%, 11.1% and 10.6% of herd gross margin for discount rate values of 5%, 10% and 20% respectively.

Epidemiological parameters: additional mortality caused by CBPP

The additional mortality rate caused by CBPP for acute cases, calculated from the preliminary results of the follow-up in West Wollega, is very inaccurate since only one death was known to be caused by CBPP within our sample. The Icl additional mortality rate α_1 given in Table II' is 1/360 death per unit unit time (=day), which means, considering that the average duration of the acute clinical state is 30 days, a case mortality rate (i.e. mortality rate in the acute form) equal to 30 x 1/360 = 8,3%.
In the literature, case mortality rates approaching 50% are recorded (Lindley, 1971 ; Masiga et al., 1996) whilst other authors mention a case mortality rate ranging from 15 to 30% (Dedieu et al., 1996).
The ratio of acute cases/infected calculated from Turner (1954) or CIRAD-EMVT (1992) is approximately 40% whereas it is 30% according to the results of our survey in West Wollega.

Four sensitivity analyses were performed for herd 1, modifying the epidemiological parameters' values, as shown in Table XII.

Modifications in parameters' values are as follows:

- a case mortality rate equal to 25%, therefore α_1 = 1/120
- a case mortality rate equal to 50%, therefore α_1 = 1/60
- v_1 and v_2 shifted respectively from 70% and 30% to 60% and 40%
- α_2 divided by 2, therefore α_2 = 1/4000

Table XII: Modified values of epidemiological parameters for sensitivity analyses

Parameter	Initial value (main analysis)	Sensitivity analysis Epi1	Sensitivity analysis Epi2	Sensitivity analysis Epi3	Sensitivity analysis Epi4
▪ α_1 : Additional mortality rate of clinical CBPP infected animals I_{cl}.	1/360	1/120	1/360	1/60	1/360
▪ α_2 : Additional mortality rate of chronic CBPP infected animals I_{ch}.	1/2000	1/2000	1/2000	1/2000	1/4000
▪ v_1 : Rate of passage directly to chronic	70%	70%	60%	60%	70%

compartment I_{ch} of infected animals (E).					
▪ v_2 : Rate of passage directly to clinical compartment I_{cl} of infected animals (E).	30%	30%	40%	40%	30%

Table XIII: Results of sensitivity analyses modifying some epidemiological parameters: values of Δ(t) (annual HGM losses caused by CBPP) in Ethiopian Birr

	Initial value (main analysis)	Sensitivity analysis Epi1	Sensitivity analysis Epi2	Sensitivity analysis Epi3	Sensitivity analysis Epi4
Year 1	389	382	534	480	352
Year 2	536	597	621	818	371
Year 3	745	865	888	1112	498
Year 4	*1011*	*1058*	*1106*	*1308*	*609*
Total 1 to 4	**2681**	**2902**	**3149**	**3718**	**1830**

Considering the herd gross margin only, the economic losses caused by CBPP within 4 years of the appearance of the disease in herd 1 are 11.3%, 12.2%, 13.3%, 15.7% and 7.7% of herd gross margin with modified values of epidemiological parameters as described above in analyses "initial", Epi1, Epi2, Epi3 and Epi4 respectively.

Transmission coefficient (associated with additional mortality)

Higher values of transmission rate combined or not with higher values of additional mortality rate (as shown in Table XIV) are tested; the results are shown in Table XV.

Table XIV: Modified values of disease transmission coefficient and additional mortality rate for sensitivity analyses

Parameter	Initial value (main analysis)	Sensitivity analysis Tra1	Sensitivity analysis Tra2	Sensitivity analysis Tra3	Sensitivity analysis Tra4	Sensitivity analysis Tra5
▪ β : disease transmission coefficient; (*Icl to Icl basic reproduction rate in italic*)	5.5×10^{-3} *(1)*	11×10^{-3} *(2)*	22×10^{-3} *(4)*	11×10^{-3} *(2)*	11×10^{-3} *(2)*	22×10^{-3} *(4)*
▪ α_1 : Additional mortality rate of clinical CBPP infected animals I_{cl}. (*case mortality rate in italic*)	1/360 *(8.3%)*	1/360 *(8.3%)*	1/360 *(8.3%)*	1/120 *(25%)*	1/60 *(50%)*	1/60 *(50%)*

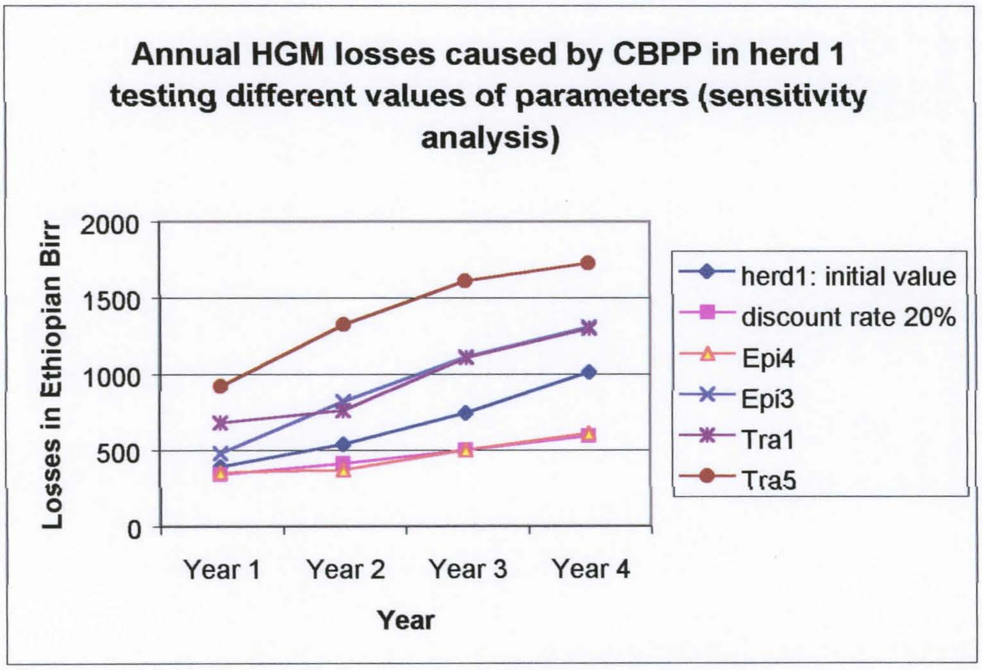
Table XV: Results of sensitivity analyses modifying disease transmission coefficient and additional mortality rate: values of Δ(t) (annual HGM losses caused by CBPP) in Ethiopian Birr

	Initial value (main analysis)	Sensitivity analysis Tra1	Sensitivity analysis Tra2	Sensitivity analysis Tra3	Sensitivity analysis Tra4	Sensitivity analysis Tra5
Year 1	389	680	779	714	724	922
Year 2	536	760	850	951	1125	1322
Year 3	745	1111	1201	1285	1450	1611

Year 4	1011	1298	1360	1459	1610	1728
Total 1 to 4	**2681**	**3848**	**4190**	**4410**	**4909**	**5584**

Considering the herd gross margin only, the economic losses caused by CBPP within 4 years of the appearance of the disease in herd 1 are 11.3%, 16.2%, 17.6%, 18.6%, 20.7% and 23.5% of herd gross margin with modified values of epidemiological parameters as described above in analyses "initial", Tra1, Tra2, Tra3, Tra4 and Tra5 respectively.

Figure 6: Annual HGM losses caused by CBPP in herd 1 testing different values of parameters (sensitivity analysis)



DISCUSSION AND CONCLUSION

Discussion of the methodology: The use of simulation models and Gross margin in animal health economics

Use of simulation models

This paper shows how an epidemiological simulation model can be linked with an economic model; it shows the inter-relationship and complementarity between the epidemiological and economic scientific disciplines in the field of animal health economics, as noted by Mlangwa and Samui (1996).

Simulation models use mathematical expressions to represent aspects of the real world. Simulation models are quantitative models widely used in animal health economics, as has been reported by many authors (Bennett, 1992 ; Dijkhuizen, 1988 ; Mlangwa and Samui, 1996 ; Ngategize and Kaneene, 1985).

Assumptions contained within quantitative models, including the values of the parameters (e.g. epidemiological parameters) will determine the results of the model; their specification is therefore most important (Bennett, 1992). Bennett (1992) also mentions that even with relatively poor data on the distribution of possible values of parameters, simulation models can be used, although simulation is not a replacement for reliable information about diseases and their effects on livestock production.

Sensitivity analysis can be used to counteract potentially inaccurate assumptions; this method has been used in this study and is discussed hereafter.

The epidemiological model developed in our study is a deterministic state-transition model. It has been used in animal epidemiology by Trewhella and Anderson (1983) to investigate the dynamics of bovine tuberculosis in badgers and more recently by Durand and Mahul (2000) to generate FMD outbreak scenarios in France and to define how the FMD epidemic is likely to behave.

Use of Gross margin in animal health economics

Gross margins are useful for enterprise comparisons and for assessing enterprise productivity, but can also be applied to animal disease impact assessment (Rushton et al., 1999); indeed, gross margin data can provide the baseline productivity information for a system that enables much further analysis.

Examples of use of gross margin in animal health economics are available in the literature. Rushton et al. (1999) demonstrate how gross margin can be used to compare the impacts of disease on an extensive cattle system after an outbreak of FMD, under different control strategies. Chamboko et al. (1999) used the gross margin to analyse the impact of heartwater and tick control on the profitability of large scale commercial and smallholder beef farms in Zimbabwe.

Although gross margin should be based on actual data the use of models for simulation purposes is acceptable where time is limited for the collection of necessary information (Rushton et al., 1999).

Use of the model for decision making

The model can provide a useful means for decision making in animal health economics, by carrying out cost benefit analysis. It can be used to explore how the herd economy behaves, including the effects of disease control strategies. Van der Kamp et al. (1990) describe a simulation model for exploring strategies of leptospirosis control in the Netherlands, incorporating cost-benefit analysis. Juste and Casal (1993) used a stochastic simulation model to compare different strategies for the control of paratuberculosis in a flock of sheep.

Discussion of the results and sensitivity analyses

General results

Results from epidemiological modelling show an highest epidemiological impact (mortality and morbidity) the first year after the onset of CBPP in every herd management strategy, except in herd 2 (dairy herd) where mortality is slightly lower in year 1. Nevertheless the epidemiological impact of CBPP is low as compared to high figures mentioned in the literature (Lindley, 1971 ; Dedieu et al., 1996 ; Masiga et al., 1996).

Results from economic modelling show that the herd gross margin is always positive, which shows the viability of cattle rearing in the situations proposed in this study, even if CBPP is present in a herd.

The economic impact of CBPP is low in the study conditions: the total HGM losses caused by CBPP in four years are less than 12% for every herd management strategies.

The results suggest that different herd management strategies tend to influence the impact of CBPP at herd level. Especially, the low total HGM losses of 2.5% and 1% in four years calculated for herd 3 and herd 3b respectively (Table X), suggest that a high turnover of individual cattle in a herd hides the consequences of CBPP. It can be explained by the low rate of transmission of the disease, consequently its slow spread, and the permanent arrival of animals assumed to be healthy, both minimising the visible impact of CBPP if renewal of animals is high.
The economic impact of CBPP is higher in the case of a dairy herd (herd 2) since CBPP interferes on birth rates and the long duration of presence of animals in the herd allows to see the consequences of CBPP in the long term (especially mortality of chronic cases).

Sensitivity analysis

Sensitivity analyses were performed changing values of economic and epidemiological parameters.
Discount rate's change has a little impact on the results and for herd 1, even with a discount rate of 20%, the total HGM losses are 10.6%, which is similar with the total HGM losses of 11.3% with a discount rate of 5%.

Epidemiological parameters can have a great impact on the results. According to our analyses the total HGM losses in herd 1 vary from 7.7% to 15.7% if additional mortality rates and acute cases/infected ratio are modified. However it is worth to notice that even with a very high increase of additional mortality rate (from 8.3% to 50%) the impact on economic losses is not in proportion that much (from 11.3% to 15.7%). Indeed dead animals do not anymore participate to the propagation of the disease whereas a low case mortality rate allows surviving highly excretory animals to disseminate the pathogen. In some extend high case mortality rate is not that much harmful.
The parameter which seems to have the greatest impact on the results is the disease transmission coefficient, especially if combined with higher values of additional mortality rates. Economic losses can be increased by more than two times in herd 1 (from 11.3% to 23.5%) if transmission coefficient and additional mortality rates are heightened.

Recommendations and conclusion

Although, as discussed above, a high turnover of animals in a herd can hide the consequences of CBPP, such a practice is particularly dangerous and should be proscribed if animals are sent to other herds, free from the disease, where they can transmit the infection. In West Wollega turnover of animals is very frequent: farmers exchange their animals, especially during the dry season, because of the availability of grazing lands, and during the farm working period through contracts for ploughing on neighbours' land. Farmers practising high renewal of animals may not see the impact of CBPP when keeping the animals of other farmers for middle term periods (6 months).

As seen in the sensitivity analysis the results of the epidemio-economic model are mainly dependant on the epidemiological parameters. The epidemiological parameters calculated from the follow-up in west Wollega show a low transmission rate of the disease and a very low case mortality rate (8.3%) as compared to values given in the literature (15 to 90%). Further investigations are necessary with a larger sample (in process on the field in West Wollega) in order to clarify the values of those parameters.
Animal production and economic data used in the analysis are drawn from experimental stations, literature and statistics; the results would be more accurate if data were drawn from the reality and further investigations are also necessary and on process on the field in West Wollega in order to fill this gap.

The low values of transmission and mortality rates found in West Wollega are likely to be related to the characteristics of the studied system in a specific area. They could from now on partly be explained by the systematic use of treatments by farmers in West Wollega in order to tackle the infection. Although not recommended since it is blamed for perpetuating the infection (Provost, 1996) the use of antibiotics may reduce the economic impact of CBPP at farm level. For the purpose of eradicating CBPP from a region the use of antibiotics should be proscribed since treatments allow the survival of symptomless chronic carriers which can transmit the infection within a herd, and also to CBPP free herds, perpetuating the disease. However, the reality is different: the availability of and easy access to antibiotics through private vendors, and in some areas through smugglers, combined with the operational and financial inefficiency of official veterinary services, especially concerning eradication programs, gives farmers the option to follow a different strategy. Farmers tend to use antibiotics as much as they feel the positive impact of them and in fact, the results from the survey in West Wollega reveal that treatments seem to be successful at individual farm level.

Rather than eradication, a more realistic animal health policy objective would be CBPP economic impact alleviation at farm level. Such an objective would seek to optimise the adequate use of treatments in adequate situations. Nevertheless, although likely to influence it, there is no proven evidence of the effect of treatment on CBPP transmission rate and further research should be undertaken seriously on that issue. Other factors may explain the low transmission rate observed in West Wollega; they include a lowly pathogen strain of Mycoplasma, a particular resistance to the disease of local cattle breeds or local herd management practises which tend to minimise the effect of the disease. As noted by Laval (2000) there are several external (i.e. explained by farm external environment) and internal (i.e. explained by on-farm management) factors which can have an impact on the spread of CBPP within the herd. Internal factors include the use of treatments but also management behaviours such as isolation of sick animals. Thus the benefit of the use of treatments could even be amplified if accompanied by additional education for farmers on disease management at herd level (for instance slaughter for meat consumption of affected and treated animals).

Further research should be carried out in this direction, since no research results are currently available on such a specific, thus far non-recommended strategy.

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