Cost-benefit analysis of contagious bovine pleuropneumonia control strategies at herd level in Boji district, West Wellega (Ethiopia)

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Abstract

CBPP (Contagious bovine pleuropneumonia), a respiratory disease of cattle, is one of the major threats to livestock health and productivity in Africa in general and in Ethiopia in particular. Its control is an important issue to African veterinary services. Results from economic analysis are necessary to justify implementation of appropriate control programs. This study provides the results of a cost-benefit analysis (CBA) of CBPP control strategies at herd level under traditional management in the highlands district of Boji (West Wellega, Ethiopia). Data necessary for CBA were collected from on-farm longitudinal surveys in 72 herds. A CBPP incidence study was carried out. The surveys revealed that in Boji district, public animal health services delivery was low and farmers resort for private sector service delivery or own personal management of CBPP cases. Four strategies were compared in the CBA: the first is antibiotic treatment and isolation of sick animals as locally practiced and the others were various vaccination protocols. An epidemio-economics model was employed to conduct the CBA. Results showed that, according to farmer's view, individual management strategies such as medical treatments were the most cost-effective on a short-term basis. A community-based participatory approach and private management of CBPP aiming at reducing herd-level economic impact were indicated as alternative options to that suggested by official national and international regulations.

KEY-WORDS : CBPP (Contagious bovine pleuropneumonia), Cost benefit analysis, herd monitoring, incidence study, epidemio-economics modelling, Ethiopia

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Background

This working paper presents the methods and results of a cost-benefit analysis of CBPP control strategies carried out as part of a PhD Thesis under Lyon I University (France) and a research project (ATP: Action Thématique Programmée) funded by CIRAD-EMVT (France). Sera samples were analysed (cELISA test) in the laboratory of the Animal Health Programme of CIRAD-EMVT (FAO World reference laboratory for CBPP) and in the National Animal Health Research Centre (NAHRC) of Sebata (Ethiopia).

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The Animal health Teams of the Ethiopian Ministry of Agriculture (Addis Ababa) and of West Wellega Zonal Agricultural Office (Ghimbi), and the Boji woreda Agricultural Office (Bila), including the staff of Bila veterinary clinic, are acknowledged for their support and advises in the implementation of the herd monitoring. The authors would like to express their warm consideration and thanks to the farmers of Boji District for their continuous cooperation in providing data and willing to exchange information. The quality and accuracy of the data collected is due to the active contribution of the enumerators, who are dully acknowledged.

1 Introduction

Contagious Bovine Pleuropneumonia (CBPP) is one of the major threats to cattle health and production in Africa, where it was reported from 18 countries in 2000 (OIE, 2002). It is a highly contagious disease of cattle caused by *Mycoplasma mycoides* subspecies *mycoides* small colony (*Mmm*SC) (Cottew and Yeats, 1978; Nicholas and Bashiruddin, 1995) and characterised clinically in its acute form by respiratory signs (polypnea, coughing), a typical posture with extended neck and arched back, and general signs (Provost et al., 1987 ; FAO EMPRES, 1997). A marbled pneumonia and fibrinotic pleurisy are the most obvious lesions.
Transmission occurs from direct, close and repeated contacts between diseased and healthy animals. Disease incubation is 6 weeks in average. The involvement of chronic carriers in the perpetuation of the disease has been suggested by several authors (Mahoney, 1954; Martel et al., 1985; Provost et al., 1987; Egwu et al., 1996; Masiga et al., 1996). CBPP is therefore characterised by its insidious nature. Favouring factors of CBPP spread include husbandry practices involving compact grouping of herds during the day and confinement at night (Provost et al., 1987). In Africa between-herds CBPP contagion is essentially related to uncontrolled animal movements caused by trade, transhumance or nomadism, and population movement due to civil wars (Roeder and Rweyemamu, 1995a).

During 40 years, its prevention in Africa relied upon internationally-funded rinderpest control programmes. Pan-African mass vaccination campaigns were carried out, during which cattle were immunised against both rinderpest and CBPP. These international efforts almost resulted in the disappearance of the clinical CBPP from Africa. Rinderpest was nearly eradicated from Africa and most countries recently stopped vaccination (and increased rinderpest surveillance) to be officially recognised as free of rinderpest. Additionally the economic recession observed in the 1980s and 1990s throughout the continent has lead to a decline of veterinary services budgets and therefore to relaxation of CBPP control and surveillance measures altogether responsible of the reappearance of the disease in countries where it had been previously eradicated or, at least, kept under control (Masiga et al., 1996; Windsor, 2000). Nowadays CBPP is, along with rinderpest, considered as the major contagious disease of cattle on the continent by African veterinary services, including PACE programme (Pan African programme for the Control of Epizootics).

Because it is unlikely that pan-African CBPP vaccination campaign will be funded in the near future, research should be oriented in identifying alternative control strategies, both at the farm and upper (national or regional) levels. In particular priority should be given to the cost-benefit analysis of CBPP control or eradication strategies in order to formulate appropriate recommendations (OIE, 1994; Masiga and Domenech, 1995). Economic assessments of these strategies is not possible without a good understanding of the underlying biological processes (Rushton et al., 1999). Epidemiological data on disease spread is an important preliminary need for economic analysis; few are available on within-herd spread of CBPP (Bygrave et al., 1968; Lindley, 1971).

In Ethiopian highlands, cattle is the cornerstone of the whole agricultural system: animal power, milk and meat, manure... (Hadera Gebru, 2002). Veterinary services recently reported a resurgence of CBPP in the province of West Wellega. A research programme was set up to estimate the epidemiological parameters of disease spread, build simulation models of CBPP dynamics and use them to compare different strategies for disease control. This paper presents the results of a cost benefit analysis (CBA) of CBPP control strategies at herd level using within-herd CBPP-spread parameters estimated from a herd monitoring in the district of Boji, West Wellega.

2 Context of the study and source of data

The district of Boji was selected for this study because of its location in the highlands of Ethiopia, where more than 70% of the human and animal population live, and because of the emergence of CBPP in the area, as recently reported by the Ministry of Agriculture (Animal Health Team).

2.1 Geographic and climatic characteristics of the Boji district

Boji district is located in West Wellega (Western Ethiopia) at latitude of 9.36° N and longitude 35.59°E (Fig. 1). Its surface area is 966.1 km^2 and its human population 100,300 (CSA, 2001). The area is predominantly classified as "*woynadega*" (middle altitude) zone with an altitude varying from 1200 to 2100 m asl. (Getahun, 1978). The rain is monomodal in pattern and occurs from May to October with a peak in July. The annual rainfalls in district vary between 1300 and 2000 mm (West Wellega Zonal Agricultural Office, 2002, personal communication).

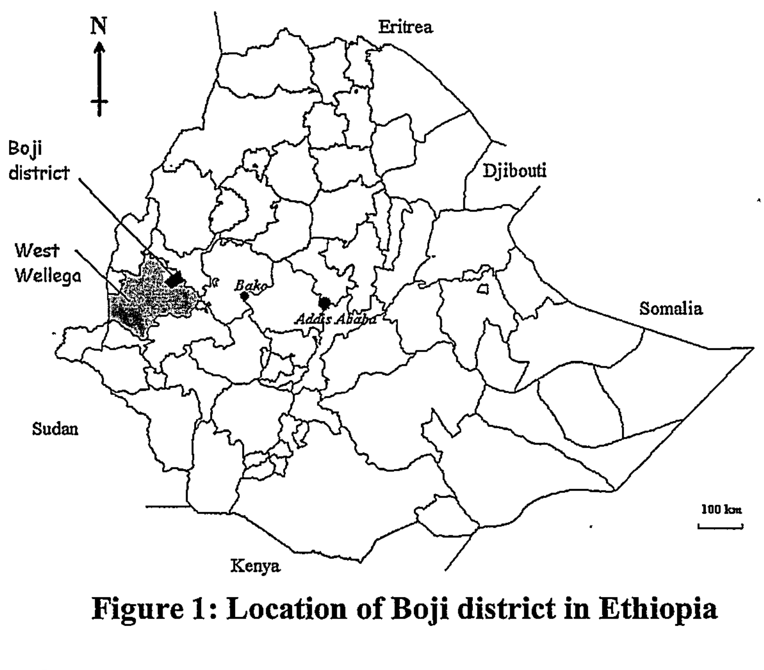


Figure 1: Location of Boji district in Ethiopia

2.2 The production system

The production system in the district of Boji is a mixed system combining closely a mainly cereal-based agriculture and livestock farming with small farm size and a subsistence economy. The first objective of the farmers is to meet the food requirements of the household throughout the year (Laval, 2000). McDermott et al. (1999) underlined the necessity to consider the nature

and specificities of small scale farms when undertaking economic assessments of animal health programmes. Rushton et al. (1999) also recommended a preliminary description of the farming system before applying gross margin methods (see below) for small scale farms under traditional management.
Two cross-sectional surveys were conducted in 2000 and 2001 in the district of Boji (Freguin, 2000 ; Descamps, 2001) in order to describe the production system. Lesnoff et al. (2003a) estimated the demographic parameters of cattle livestock using the results of a herd monitoring (i.e. longitudinal survey) involving 70 herds during one year.
Cattle farming plays a major role in the system. During the study, cattle population in the district of Boji was 55,700 heads of Horro bread (Boji district Agricultural Office, 2002, personal communication), an intermediate Sanga-zebu type (Alberro and Haile-Mariam, 1982). The livestock sub-system is hereafter described through livestock practices, as suggested by Landais and Deffontaines (1989). Through farmers interviews livestock practices are analysed following the classification of Landais (1992) who distinguished grouping, management, renewal, exploitation and processing practices, to which exchange practices are added. Cattle only are considered since rearing of other animals such as sheep and goats is not well developed, unlike in the central and northern highlands of Ethiopia (Gryseels and Anderson, 1983).

2.2.1 Grouping practices: the constitution of cattle herds

In the district of Boji, a cattle herd can be defined as the whole of the animals which are regularly gathered together at night in the same enclosure under the responsibility of the same household; herd management during the day can vary according to the type of function required of the animals (oxen, cows, calves….) and the season to meet the objectives of the household. Mature animals and the young, which have been weaned, are gathered together during the night in a temporary enclosure in the open air, the *della*, built on a plot of land on the farm. This enclosure is moved regularly, every 3 to 5 days, to allow the spreading of dung and urine on the cultivated plots. The young, which have not been weaned, are separated from the main herd and remain in a separate shelter at night. These have no contact with the other animals except during milking. The herds vary in size, from a few animals to about forty, with an average size of 10.5 cattle per *della* (Descamps, 2001). This figure is superior to that of other systems in the Ethiopian highlands. It was 6.3 around Bako in 1986, including 15% of farmers without animals (therefore a raised average of 7.4 heads of cattle for those owning animals) (Legesse Dadi et al., 1992) and 5.0 around Debre Behran in 1980 (Gryseels and Anderson, 1983). For the large herds of more than 15 to 20 heads, several farmers own different animals but the management is carried out jointly. The structure of the herd showed a greater number of females (61%) and low proportion of animals beyond the age of 9 years (Lesnoff et al., 2003a).

2.2.2 Management practices

During the day, the animals of the *della* graze, with a keeper, on common or private pastures or, at the end of the dry season, on crop residues after the harvest. Several herds can mix on common pastures; a single keeper can then undertake the surveillance of all the animals. In the lowlands (*kolla*) only, animals could graze freely without keeper. The mixing of the herds on the pastures is a risk factor for the spread of contagious diseases such as CBPP. The young animals, not yet weaned, can be brought separately to the pastures or remain tied up on the farm. Other foodstuffs, originating from agricultural products, can supplement the animals' rations: residues from the cereal harvest and, for working animals only (oxen during farm work and lactating cows), concentrates in the form of grain (maize, sorghum), salt or other residues such as from the making of *tella* and *arake* (local alcoholic drinks). Bulls are castrated at the age of 4 or 5 years to then be trained for traction work. Docile bulls of good physical constitution can be left whole (i.e. non-castrated), to be used for reproduction. A reproductive male, chosen for his qualities, is often brought for mating to a neighbouring herd and can then spend several nights in the *della*. This also presents a transmission risk factor for contagious diseases between herds. Births occurred mainly at the beginning of the dry season, between November and February and the average age of heifers at first calving was between 5 and 6 years (Lesnoff et al., 2003a). The mating period occurred between February and May, i.e. after the period of intensive farm work (harvesting and threshing, Table I). The mating period in the district of Boji is linked to the work schedule of the animals. The favourable period is when the animals not involved in work are available for reproduction.

Livestock farmers make use of public and private veterinary services for the treatment of sick animals but can also use an informal market for the purchase of medicine (notably injectable antibiotics). Vaccination campaigns are organised by the public services but this remain infrequent. Finally, for certain pathologies such as anthrax a traditional veterinary medicine based on plants is still in use.

Table I: Schedule of the main types of farm work by crop and season, in Boji district, West Wellega, Ethiopia

	SEASON			
	Bona December, January, February	***Arfasaa*** March, April, May	***Gana*** June, July, August	***Birra*** September, October, November
Climatic event	Dry season	End of the dry season, first rains: link period	Height of the rain season	End of the rain season
Type of culture				
Maize and sorghum	fertilisation (manuring)	Ploughing (Apr.-May) sowing (May)	weeding	harvest (Oct.-Nov.)
Teff and millet	harvest (Dec.) threshing (Jan.-Feb.)	fertilisation	ploughing, sowing, trampling	weeding, harvest (Nov.)
Yam	planting		harvest	ploughing
Maize in « *bonné*[a] »	ploughing (Dec.-Jan.), sowing (Jan.)		harvest (June)	
Coffee	harvest		planting	Weeding

[a] *bonné*: lower damp gullies

2.2.3 Exchange practices

The scale of animal exchange practices through loans between farmers is one special feature of the livestock system in the study zone. During the herd monitoring loans appeared to be the most frequent cause of departure of an animal from the herd, well ahead of sales and slaughter and also the most frequent reason for entry into the herd, ahead of purchase; more than 30% of the animals above the age of one year were removed during the year for loans (Lesnoff et al., 2003a). These exchanges become effective through loan contracts. They are commitments of varying length between two farmers wishing to share animal resources (for draught power and manuring mainly) and vegetable resources (pasture, cultivation), to the benefit of each contracting party (Table II). During a loan, the entrusted animals enter the herd of the recipient farmer who then takes over its management. Three types of contract can be singled out (Table II): fattening contracts against manuring (*dereba*), ploughing contracts (*goubo*) and supervision contracts. They include all categories of animals although *derebas* include mostly the young non-productive groups (between 1 and 5 years) and *goubos* only the males used for traction.

Table II: Distribution and length of loan contracts and benefits received by each contracting party in the district of Boji in 2000 (from Fréguin, 2000)

Type of contract	Distribution (proportion)	Length of contract	Benefits for the contracting parties	
			For the lender	For the recipient
Dereba	56%	1 to 12 months	Management and feeding of animals	Manuring
Goubo	21%	from 1 days to several weeks	Part of the recipient's harvest	Draught power, manuring
Supervision	23%	Long period of unspecified duration (> 1 year)	Management and feeding of his animals	Manuring, other productions (traction, milk)

The frequency of departures on loans varies with the types of contract and the seasons (Table III). For instance, departures in *goubo* are more frequent during the end of the dry season (*arfasaa*) and the height of the rain season (*gana*) because it is the ploughing season. Certain types of farmers tend to lend most of their animals, especially in *dereba*. This is the case for farmers with large numbers of animals (more than 10) who do not have enough pasture close by to feed their herd. Others, on the other hand, tend to receive animals. This is the case for farmers with small numbers or for farmers with no animals who need draught power for ploughing and borrow one or two oxen by *goubo* during the ploughing season. The contracts of the *dereba* type are frequent from the farmers from the highlands (*woynadega*), who are the lenders, towards those from the lowlands (*kolla*), the recipients. The exchanges take place during the dry season (*bona*) when the pastures in the highlands (with greater population and livestock density) are not sufficient, whereas they are still plentiful in the pastoral zones of the lowlands.

Table III: Distribution of animal exchange contracts (departure from a herd) by season in the district of Boji (from Fréguin, 2000)

	Bona	*Arfasaa*	*Gana*	*Birra*	Total
Dereba	76%	16%	1%	7%	100%
Goubo	0	60%	23%	7%	100%
Supervision	39%	36%	8%	17%	100%

2.2.4 Renewal practices

Renewal practices are operations which modify the composition of the herd (Landais, 1992), except in the case of exchanges, because these are temporary. Therefore, they include purchases, sales, slaughter and gifts. Sales were of the order of one animal per herd per year (Table IV). Purchases were not so frequent. Slaughter on the farm was very rare and no gift was recorded (Lesnoff et al., 2003a). The main cattle market in the district of Boji takes place in Bila twice a week. There are two other secondary markets in the district. Animal commercial exchanges can also take place directly on the farm. All types of animals were sold but draught power oxen were more concerned than others; they also had the greatest value (Laval and Assegid Workalemahu, 2002). The main reason for sales is the need for cash for the household and more infrequently for the culling of aged animals. Purchases by a farmer are motivated by the need to stock a herd or capitalise in cattle which involve mainly the wealthier farmers with larger herds.

Table IV: Number of animals departures and arrivals during the year by size of the herd in the district of boji in 2001 (source: herd monitoring of 70 herds)

			Departures during the year (number)			Arrivals during the year (number)	
Size of the herd	Number of herds monitored	Average size of the herd	Slaughter	Sale	Loan	Purchase	Loan
< 10	15	8.1	0.20	0.80	2.73	0.20	1.73
10 - 20	37	15.0	0.05	1.32	5.64	0.54	5.0
>20	18	25.2	0.22	1.00	12.0	1.11	8.44

2.2.5 Practices for the exploitation of animals: animal productions

As in most mixed systems seen in the Ethiopian highlands (Astatke and Mohamed-Saleem, 1996), the first objective of cattle rearing in the district of Boji is the production of animal labour, yoke traction particularly. The males, most often castrated and always in pairs, pull a plough, named locally the "*maresha*" (Goe, 1987), for the ploughing of plots intended for cultivation following a well defined schedule (Table I). The most intensive period of traction work is from

May to August and oxen worked for about 101.7 days in year 2001 (Laval and Assegid Workalemahu, 2002). There are two other types of animal work: the trampling of the fields to break up the clods of earth, an indispensable operation especially for the growing of teff (*Eragrostis abyssinica*) and millet, and the threshing of cereals to separate the grain from its hull. Threshing is a very physical activity that takes place principally in January and February. All types of animals can do these two operations and, in particular, the young ones. The other important animal productions are milk and manure. Lactating cows are milked twice a day; the calf is removed at night and during the day from its mother and allowed to suckle before milking, to stimulate the coming of the milk, and after milking, if there is still some available. The mean lactation length was estimated to 314 days and the total milk yield was found to be 587 litres, 37% of which was suckled by the calf (Laval and Assegid Workalemahu, 2002). The manure, used as fertiliser, allows the recycling of organic matter. It is spread on the plots at night mainly through the shifting of the *dellas* or when the animals wander in the fields after the harvest. Manure can also be used for the making of floors in houses and in harvest threshing areas. It is not used in dried form as household fuel, contrary to other systems in the highlands where wood is lacking (Lupwayi et al., 2000). Finally, meat and skins are utilised when animals are slaughtered. Animals to be culled are preferably sold for meat in the town centres where meat is mostly sold and consumed.

2.2.6 Processing and marketing practices

Milk is processed and commercialised (Duteurtre, 1998). After a few days of fermentation, milk is manually churned in a clay pot or a round gourd to obtain butter. The buttermilk remaining is used to produce a cottage-type-cheese, called *badou* in Boji. This traditional process is widely spread in the Ethiopian highlands (O'Connor, 1994). In Boji the family consumes some of the butter, but a significant amount is sold on the local market from where it can be exported to bigger urban markets such as Addis Ababa. *Badou* is not sold and the household consumes it.

2.3 *Data necessary for the CBA*

The type of data necessary to conduct the CBA of CBPP control strategies in Boji district are presented in Figure 2. They are of 5 types. Modelling methods mentioned in Figure 2 will be described in Chapter 4 (materials and methods of CBA).

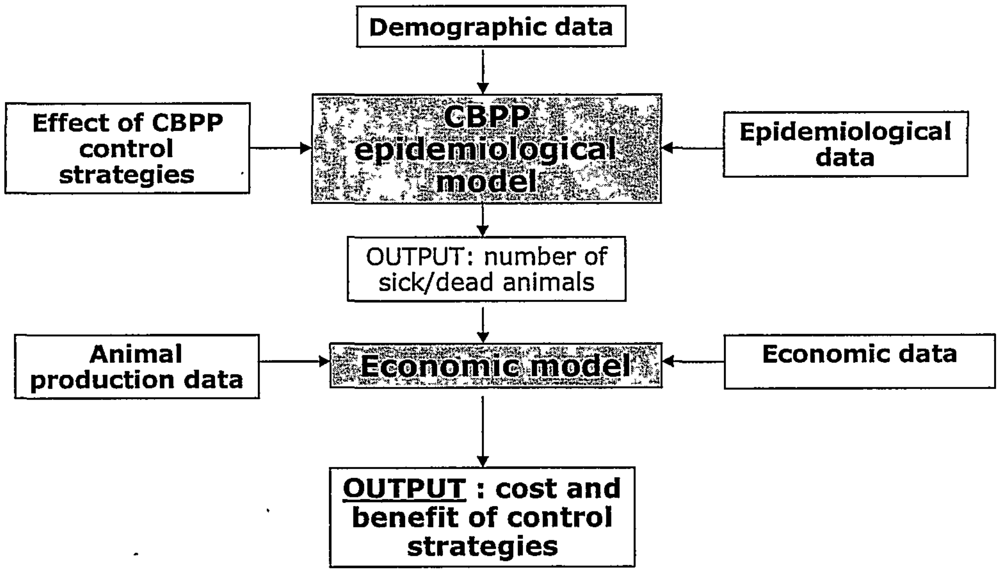


Figure 2: Data necessary to conduct a cost benefit analysis of CBPP control strategies at herd level using epidemio-economics modelling methods

2.3.1 Source of data: herd monitoring

The herd monitoring method as described and recommended by Faugère and Faugère (1986; 1993) and ILCA (1990) was applied to record accurate necessary data. It included 4 components: demographic, animal production, economics and health. Seventy two herds were monitored for 12 to 18 months, between June 2000 and February 2002. Herds were selected in rural highlands. To be selected they should contain a relatively high number of non borrowed animals (i.e. >5 owned animals) at the start, to ensure continuity of the survey. The mean herd size during the monitoring was 15.9 heads of cattle (min : 4.3; max : 32.8), which was higher than the average herd size in the district. Animals above 1 year represented on average 84% of the herds. In order to study within-herd spread of CBPP, newly contaminated herds were actively searched using slide agglutination tests (Turner and Etheridge, 1963) and farmers interviews (questioned on respiratory diseases occurrence). Each animal was ear-tagged for permanent identification. Trained enumerators visited the herds every two weeks to record demographic events (entry, birth, mortality, offtake), animal production and economic data (inputs, including the type and cost of veterinary care applied, and outputs) and the clinical signs of sick animals.

Most of the data used in the CBA were drawn from the results of this herd monitoring. Demographic data (herd size and composition, offtake, mortality, birth rates...) were estimated by Lesnoff et al. (2003a). Animal production and economic data per categories of animals were estimated by Laval and Assegid Workalemahu (2002); economic data are presented in Table V (from Laval, 2002). Data related to the effect of CBPP control strategies and epidemiological data (CBPP incidence, case fatality...) were estimated from literature and from the results of the health component of the herd monitoring.

Table V: Yearly inputs and outputs of cattle in Boji district, West Wellega (Ethiopia) (Birr per head of cattle, 1 Birr = 0.125 US$). Estimated from a herd monitoring during year 2001. (from Laval, 2002)

Type of data	Categories of animals			
	Heifers (1 to 3 years)	**Bulls (1 to 3 years)**	**Females (≥ 4 years)**	**Males (≥ 4 years)**
Inputs				
Supplementary feeding	0	0	5.80	9.70
Veterinary inputs	0.25	0.25	0.65	0.75
Total (inputs)	0.25	0.25	6.45	10.45
Outputs				
Work	0	0	0	274.60
Milk	0	0	123.00	0
Manure	16.00	16.00	31.90	31.90
Offtake revenues[a]	16.85	-7.25	22.25	51.00
Total (outputs)	32.85	8.75	177.15	357.50
Individual Gross Margin (outputs – inputs)	**32.60**	**8.50**	**170.70**	**347.05**

[a] Offtake = (sale + slaughter) – purchase;
Offtake revenues = sale price of live animal x yearly offtake rate (offtake rate estimated by Lesnoff et al., 2002)

2.3.2 CBPP monitoring and clinical examination

Blood samples were collected continuously every 3 months from all animals to determine individual serological CBPP status, and occasionally from sick animals and new animals entering a herd. In order to sort CBPP clinical cases, symptoms of the respiratory tract (Provost et al., 1987), were monitored: cough, discharges and visible breathing disorders (abdominal, noisy or discontinuous breathing). Respiratory frequency was measured from sick animals (of which 24 CBPP clinical cases above 2 years within the first week of the disease) and also from an additional 185 healthy animals above 2 years for further comparison. Symptoms concerning the general condition (body condition, posture, appetite) and other systems (digestive, nervous, eyes, skin, locomotion and reproduction) were also recorded. In case of death, a diagnosis of the cause was deduced from clinical signs observed prior to death and whenever possible from post-mortem examination. For the latter, lungs and chest cavity were carefully examined to ascertain that the death was caused by CBPP or not.

The onset of CBPP (confirmed serologically) in a herd corresponded to the time of the first clinical case observed either by the farmer him-self (if occurred prior to the start of the monitoring) or by an enumerator. Onset of CBPP in selected herds should not occur more than 2 months prior to the start of the monitoring in order to avoid eroded information.

For each positive herd, a transversal retrospective survey was conducted at the end of the monitoring to investigate individual health management practices applied by farmers for CBPP clinical cases.

3. Analysis of data from health monitoring: CBPP management and incidence

3.1 cELISA testing

Using the method described by Le Goff and Thiaucourt (1998), competitive enzyme-linked immuno-sorbent assay (cELISA) test based on the use of a monoclonal antibody was conducted at CIRAD-EMVT (FAO world reference laboratory for CBPP, Montpellier, France) and at National Animal Health Research Centre (NAHRC, Sebata, Ethiopia) on 6500 sera collected at different times. Individual results were considered negative below 35% of inhibition, doubtful between 35 and 50% and positive above 50%. A herd was interpreted positive if more than one animal was diagnosed positive. The doubtful individuals of a positive herd were subsequently considered as positive. Serologically positive animals were considered "CBPP clinical cases" if at least 2 respiratory symptoms were observed at the same time or one respiratory symptom associated with general signs.

Results of the incidence study presented hereafter are preliminary results. A 35% inhibition threshold was taken (40% and 50% are described in the reference method (Le Goff and Thiaucourt (1998)) for doubtful and positive animals, respectively) when sero-conversion was observed (rise of more than 20% inhibition between two samplings for the same animal) and since many animals between 35 and 50% showed CBPP clinical signs in affected herds.

3.2 Data analysis

All the data sets were entered and validated using LASER, a software developed by CIRAD-EMVT for herd monitoring data management (Juanès and Lancelot, 1999).

Because of the high frequency of between-herd animal movements, one cohort of animals was considered for the incidence study in positive herds : the same individuals, present at the start of the survey, were followed during the monitoring period. New animals entering the herds during the follow-up were discarded for the incidence analysis. Un-weaned animals kept separated from the *della*'s herd were also discarded since they were considered as not involved in CBPP within-herd spread.

Cumulative incidence rate (CI) was calculated per 4 months periods after the onset of the disease in each herd. CI was computed for serological occurrences only and was defined as the proportion of non-diseased (negative) individuals at the beginning of a period that become diseased (positive) during the period (Thrusfield, 1995). CI for each 4 months period t being referred as CI_t, the yearly CI_{year} was computed as :

$$\mathrm{CI}_{year} = 1-(1-\mathrm{CI}_1)(1-\mathrm{CI}_2)(1-\mathrm{CI}_3) \qquad \text{(Equation 0)}$$

Another variable was the proportion of CBPP clinical cases out of positive serological cases (P_C). Logistic regression models were used to test time and strategy effects on CI_t, and time effect on P_C. A quasi-likelihood method was considered in complement of ordinary logistic regression (OLR), to take into account the potential within-herd correlation. This method (VIF-LR) used the variance inflation factor or dispersion parameter ϕ, estimated as the Pearson's Chi-squared (goodness of fit of the ordinary logistic regression model) divided by the residual degrees of freedom (McCullagh & Nelder, 1989). In VIF-LR, variances of models parameters estimates and tests are scaled by ϕ.

3.3 *Results*

3.4.1 CBPP herd level results

Out of 72 herds monitored, 27 showed evidence of CBPP with positive cELISA. Of them, 18 were referred as positive herds and 9 as doubtful. CBPP did not spread in the latter, of which 6 showed only one isolated CBPP case (clinical case serologically confirmed or dead) and 3 one or two positive serological cases without symptoms.

3.4.2 CBPP management strategies

Two types of practices were spontaneously implemented by farmers to manage individual CBPP clinical cases: separation from the rest of the herd to avoid contact with healthy animals, thereafter referred as “isolation”, and treatment with antibiotics, a 10% oxytetracycline suspension, administered intra-muscularly at a dose of 10 to 20 ml per cattle. 56 CBPP clinical cases (confirmed serologically) were observed (62 if adding cases excluded from the cohort), of which 43% were treated. Most of treated animals (80%) had a single injection, the remaining cattle had 2 or 3 injections at 24 hours intervals. Only 7% of the antibiotics (including also antibiotics for other diseases) were provided by the public services, while other were delivered either through private services or informal markets (farmers and smugglers) and administered by the farmers. The average cost of CBPP treatment was 8.60 Birr (1 Birr = 0.125 US$ in 2001) per treated animal. No public CBPP control strategies (vaccination, stamping out) were observed during the period of the survey.

At herd level the combination of CBPP control strategies is presented in Table VI. Isolation was referred as complete when applied day and night to all sick animals during the acute phase (at least one week) and partial if not. Treatment coverage was referred as partial and good if less than 50% and more than 50% of clinical cases were treated, respectively. To sum up, CBPP management at herd level was referred as complete (strategy C) if good treatment coverage or complete isolation, and partial (strategy P/N) if partial treatment coverage and partial or nil isolation (Table VII). Of the 18 positive herds, full information was available from 13 only.

Table VI: Health management strategies implemented by the farmers to control CBPP in 13 herds affected by CBPP in Boji district

Isolation from the herd of CBPP clinical cases	Treatment of CBPP clinical cases (antibiotic)	
	Partial treatment coverage (<50% of clinical cases)	Good treatment coverage (>80% of clinical cases)
No isolation	7[a], 8, 9, 10, 11	4
Partial isolation	6, 12, 13	-
Complete isolation	2, 3	1, 5

[a] Farmer number

3.4.3 CBPP serological incidence

Results of CBPP serological incidence study (C or P/N strategy) are presented in Table VII. Time and strategy effects on CI_t were tested for the first year period. Only two cases, discarded from the tests, were observed after 1 year, in strategy P/N (Table VII).

Figure 3 and Table VIII show time evolutions of empirical cumulative incidence rates CI_t and results of the VIF-LR model, respectively. Variance inflation factor was estimated to $\phi = 1.82$ (P = 0.003) from the most complex model (time + strategy + time x strategy), which confirmed the presence of over-dispersion in the data. Interaction "time x strategy" was not significant. CI_t showed a highly significant decrease in time. The strategy effect was slightly significant (P = 0.062).

Finally, the additive model "time + strategy" was selected to estimate and compare CI_{year} between the 2 strategies. Probability distributions of CI_{year} were estimated using Monte Carlo simulations. The estimated model parameters vector and its VIF-scaled variances-covariances matrix were used to simulate (with a multivariate normal random generator, respecting the asymptotic normality of quasi-likelihood estimators) n = 5,000 new parameters vectors. For each of these vectors, CI_t were calculated for the 2 strategies and CI_{year} was calculated from Equation 0. CI_t estimates and their Monte Carlo confidence intervals are presented in Table IX. CI_{year} estimates (95% confidence interval in brackets) were 43.8% (33.5; 57.0) and 70.6% (60.1; 81.2) for strategy C and strategy P/N, respectively. The critical value 0 was not included in the 95% confidence interval of the difference between strategy C and strategy P/N (-41.3; -10.8).

Table VII: CBPP serological (cELISA) cumulative incidence in 13 herds under different health management in Boji district (West Ethiopia)

Strategy	Farmer number	Period after the onset of CBPP outbreak in the herd				
		1 to 4 m.	>4 to 8 m.	>8 to 12 m.	>12 to 16 m.	>16 to 20 m.
Complete health management (strategy C)	1	8[a] / 22[b]	3 / 11	0 / 7	0 / 7	0 / 7
	2	4 / 18	0 / 14	0 / 13	0 / 11	0 / 10
	3	3 / 14	1 / 9	1 / 8	0 / 6	
	4	11 / 16	0 / 2	0 / 2	0 / 2	
	5	4 / 20	1 / 13	1 / 12	0 / 10	0 / 10
Partial health management (strategy P/N)	6	6 / 14	1 / 7	0 / 5	0 / 5	
	7	7 / 17	8 / 10	0 / 2		
	8	6 / 10	1 / 3	1 / 2		
	9	8 / 16	0 / 7	0 / 6	0 / 6	
	10	12 / 21	0 / 6			
	11	5 / 9	1 / 3	0 / 1		
	12	2 / 10	2 / 7	2 / 4	1 / 2	
	13	10 / 12	0 / 2	1 / 2	0 / 1	1 / 1

[a] Cumulative incidence (positive cELISA)
[b] Number of negative animals from the initial cohort present at the beginning of the period *t*

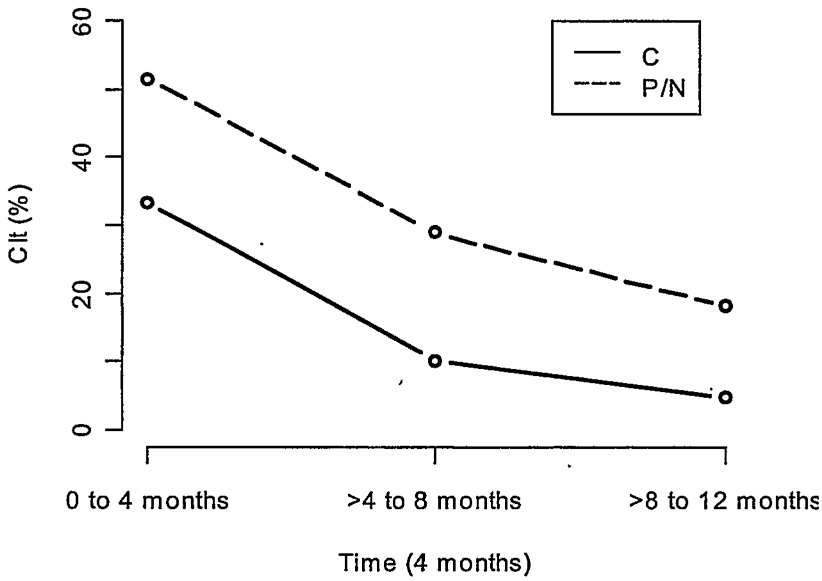


Figure 3: Empirical serological cumulative incidence rate CI_t (%) by 4 months periods for 2 management strategies in monitored herds

(C: complete treatment and/or isolation, P/N: partial or nil treatment and isolation)
Time represented the time after onset of the disease in the herd.

Table VIII : Parameters estimates for the VIF [a] logistic regression models adjusted on the serological cumulative incidence rates CI_t. Model's components were time effect (0 to 4 months, >4 to 8 months, >8 to 12 months), strategy effect (C, P/N) and interaction.

Parameter	Estimate	P-value[b]
Intercept	-0.693 (0.304) [c]	0.023
Time >4 to 8 m. [d]	-1.482 (0.711)	0.037
Time >8 to 12 m.	-2.303 (1.032)	0.026
Strategy P/N[d]	0.748 (0.401)	0.062
Time >4 to 8 m. x Strategy P/N	0.526 (0.880)	0.550
Time >8 to 12 m. x Strategy P/N	0.743 (1.304)	0.569

[a] VIF dispersion parameter was $\phi = 1.852$.
[b] Wald test.
[c] Standard error of the parameter.
[d] The first modality of factors time and strategy was constrained to 0.

3.4.4 CBPP clinical signs

Regression logistic model "time" was used to test time effect on P_C. Cases observed after 4 months were brought together in one single period (Table X). The over-dispersion factor ϕ was non-significant ($P = 0.201$) and only the OLR model was considered. Time effect was slightly significant ($P = 0.051$, Table XI). Global estimated P_C (over all periods) was 47.8% (s.e. = 4.6) (Table XII).

Duration of symptoms expression, defined as the number of weeks that sick animals expressed respiratory symptoms after the onset of the disease, was estimated for 56 CBPP clinical cases (36 un-treated and 20 treated) that survived (50 from the cohort + 6 additional). Distributions of these durations were comparable for un-treated and treated CBPP clinical cases (Kolmogorov-Smirnov test, $P = 0.42$; Khi-square test, $P = 0.30$). The mean duration was 3.5 weeks.

3.4.5 Mortality

All deaths caused by CBPP in herds occurred within the first 4 months period of the outbreak. Six deaths were observed: 3 out of 39 un-treated and 3 out of 23 treated clinical cases. Case fatality rate (defined as proportion of clinical cases that died) difference between un-treated and treated animals was not significant (Fisher's exact test, $P = 0.66$). Overall CBPP case fatality rate was 9.7% (s.e. = 3.8).

Table IX: Estimates (Monte Carlo 95% confidence interval in brackets) of the serological cumulative incidence rates CI_t calculated from the VIF additive logistic regression model time + strategy

Strategy	Time		
	1 to 4 m.	>4 to8 m.	>8 to12 m.
C (%)	31.2 (22.7; 41.4)	12.5 (6.7; 21.9)	6.5 (2.5; 15.9)
P/N (%)	53.1 (43.4; 62.8)	26.3 (16.1; 40.1)	14.8 (6.0; 31.7)

Table X: Number of clinical forms observed within the positive serological cases detected during herd monitoring.

Time	Positive serological cases	Clinical forms
0 to 4 m.	75	41
>4 m.	42	15

Table XI: Parameters estimates for OLR model adjusted on the proportion of CBPP clinical cases out of positive serological cases. Model component was time effect (0 to 4 months, >4 months).

Parameter	OLR	
	Estimate	P-value[a]
Intercept	0.187 (0.232)[b]	0.419
Time >4 m[c]	-0.775 (0.397)	0.051

[a] Wald test.
[b] Standard error of the parameter.
[c] The first modality of factor time was constrained to 0.

Table XII: Estimates of the proportion of CBPP clinical cases out of positive serological cases (P_C) during the herd monitoring.

Time	Value (%)	Standard error
Time 0 to 4 m.[a]	54.7	5.7
Time >4 m.[a]	35.7	7.4
Total[b]	47.8	4.6

[a] Estimates with the OLR model "intercept + time".
[b] Estimates with the OLR model "intercept only".

4 Cost benefit analysis : Materials and Methods

4.1 Technical characteristics of the cost-benefit analysis (CBA)

Some of the technical characteristics of the CBA are first defined: the viewpoint, the level of analysis, the time horizon, livestock practices considerations and CBPP control strategies selected for the analysis.

4.1.1 The viewpoint and the level of analysis

The farmers' viewpoint is retained for the analysis, that of other stakeholders of the animal health system (government, care takers) and of the livestock sector (traders, butchers, consumers) being left out.

As mentioned previously public service's intervention in the control of CBPP is weak in Boji district. Farmers are the principal stakeholders that take part financially and in taking decisions in the management of animal diseases. This essentially individual and private management mostly justifies the retained viewpoint. On the other hand, the cattle livestock trade remains localised in Boji district and even in the West Wellega Zone, where no cattle exporting market exist. Although CBPP is a disease on OIE list A, it is not a constraint to local commercial exchanges and has no effect in the context of Boji on the stakeholders of livestock sector on the local or regional scale.

In this analysis, the farmer is considered as the only one to be affected by the consequences of the disease and to finance its control. For all CBPP control strategies including vaccination the hypothesis of cost recovery (all costs covered by the farmers) is considered. In reality, the government in Ethiopia subsidises vaccination. However, due to the incapacity (financial and logistic) of public services to cover the demand, cost recovery context was assumed in this analysis, in spite of a context of budget constraint. Lack of cash access is in fact the major constraint to farm management in Ethiopia and the institutionalisation of a loan system is often recommended as a necessary preliminary step before introducing technological innovations in small African exploitations (Freeman and al, 1998). Farmers have in fact a limited but real potential of investment for animal health, which was revealed by the private use of antibiotic treatments. It is thus supposed that if a private service of vaccination existed, farmers would have recourse to it besides; this hypothesis was made valid by a short inquiry about vaccination costs covering acceptability.

A context of budget constraint is therefore assumed with the viewpoint retained; this will have an important effect on the interpretation of the CBA results and the classification of strategies.

Economic mechanisms are studied at the individual farm level and more specifically at the breeding activity level of the exploitation. The level of analysis is therefore micro-economics: the herd. Meso-economic and Macro-economic levels are not dealt with.

4.1.2 Choosing the time horizon

The time horizon of the CBA has been limited to one year. This choice is justified by biological (extinction of the disease in a herd) and strategic (duration of the efficiency of control strategies)-reasons

4.1.2.1 Biological reasons

Field observations are, in particular, the reasons for this choice. The herd monitoring has in fact showed that the disease clinically disappears in less than a year among the herds infected by CBPP, which was confirmed serologically. Yet, farmers intervened by treating or isolating the infected animals (strategy 1, defined later). Without intervention (strategy 0), not much information is available on the duration of persistence of CBPP in an infected herd. Nevertheless many authors assume the carriage of the pathogenic agent by cured animals ("lungers") for a long period of time. In particular, and though it was not observed during our survey, a reappearance of CBPP in an apparently cured herd is not excluded. Two explanations can thus be formulated: it could be a new infection of the herd, not related to the previous one, caused by a contact with outer diseased animals. The economic analysis of the PPCB should therefore be resumed at time 0. It could be on the other hand, a reappearance of the disease carried by animals of the herd apparently cured (chronic carriers) and excreting the pathogenic agent, this reappearance being therefore considered as continuity of the disease among the herd. In this case, the analysis should be carried out over a period of time greater than a year. However, as no real consensus on the epidemiological role of chronic carriers exists (Windsor and Masiga, 1977) and as the bacteriological analysis carried out by Sintayehu et al (2002) suggested the disappearance of the pathogenic agent from treated and cured animals in Boji district, a period lesser than a year was retained for the analysis.

4.1.2.2 Strategic reasons

The objective of the proposed strategies is the control of the disease at the herd level, which implies a short-term vision of the effects. If the objective of the strategies were the eradication of the disease from the region, choosing a time horizon greater than one year (several years) would have been necessary, the strategies effect being appreciable in the long run. Due to technical reasons, the proposed strategies are efficient on a short term only. The vaccines available at the present time, T1 sr or T1/44 only confer a partial protection (Yaya et al., 1999, Thiaucourt et al., 2000) and for a period of time lesser than a year (Tulasne et al., 1996). If these are applied individually on herds, the latter can be re-infected in subsequent years by reason of contact with non-vaccinated animals of neighbouring herds.

On the other hand, in mixed systems, the exploitation and incomes are managed on a yearly basis in terms of agricultural productions according to the calendar (annual) of cultivation. The time perception of the operator concerning investments, the availability of capital and the benefits of the exploitation is also a year, which corresponds to the time horizon chosen.

Hence, for biological and strategic reasons, it is assumed that the economic impact of the PPCB and the benefit of control strategies for a period exceeding one year do not depend any more on the disease but on the farmer's choice.

In fact, these can repopulate their herds in the case of mortality caused by CBPP (which has a cost) or keep a diminished livestock (with a subsequent reduction of income implied). In the analysis, it is assumed that the herd is repopulated at the end of the period, and the cost of this is taken into account. Under this hypothesis, the herd having regained its initial size and the disease being extinct, CBPP has no effect beyond a period of one year and an analysis with a time horizon of more than a year is not justified any more.

Choosing a time horizon of one year removes the technical constraint of discounting classically described in the cost-benefit analysis method.

4.1.3 Livestock practices

It is allowed to assume that factors related to the management of the herd, or "livestock practices", might have an influence on within-herd spread of CBPP, on its economic impact and on the economic efficiency of control strategies.

Health management practices (isolation of diseased animals, treatment and vaccination) are analysed in the CBA though comparing control strategies.

On average, a herd's composition is as follows (Lesnoff et al., 2003a):

- Calves (non weaned animals of less than one year): 16%
- Heifers and young males (from 1 to 3 years old): 23%
- Cows (females of 4 years and more): 40%
- Oxen (males used for work, of 4 years and more): 21%

In the analysis only the herd of the young and the adults is considered. The calves (with an age lesser than 1 year) are assumed to be non-receptive to CBPP (Provost et al., 1987) and are separated from the main herd (from *della*) in the practices of the study zone, they are thus assumed to have no epidemiological role. Consequently, the average herd analysed in the CBA is supposed to be composed of 27 percent of young's, 48% of cows and 25% of oxen. It is composed of 20 heads with a renewal rate of 10% per year, i.e. 10% of animals are removed (slaughter, sale, death) while another 10% is introduced (purchase, birth...).

4.1.4 Compared control strategies

The main criteria for choosing the control strategies proposed for the analysis is their feasibility on the field. Hence, sanitary slaughtering has been excluded because, on the one hand, there is a problem of acceptability by breeders for socio-cultural reasons, as described in many other systems in Africa (Provost, 1974a), and on the other, because of the absence of a reimbursement system (by the government or any other institution) in the present context. This situation has a few chances to develop in the short or medium run due to the high cost of this type of strategy, a cost that the Ethiopian government can not finance at present.

Because of these practical sand feasibility reasons, the proposed strategies are preferably less costly and are placed at individual level. They do not allow the eradication of the disease but aim at its control in the short run at the herd level. The proposed strategies compared in the CBA are presented in detail in table XIII.

Table XIII: CBPP control strategies compared in the CBA

Strategy	Description	Source of data/parameters
S0	No strategy	Literature
S1	Treatment of sick animals (Oxytetracycline10%, 1 injection 10-20ml)	Boji district
S2	Yearly full herd vaccination (one single shot: T1sr)	Literature + simulation
S3	Combination of S1 + S2	Boji district (S1), literature (S2) + simulation
S4	Multiple vaccination (3 shots of T1 sr)	Total protection (100%), no spread of CBPP

Strategy 0, a situation with no intervention, was not observed during the herd monitoring because in case of a disease, farmers intervened by a more or less minor modification of their practices. The epidemiological parameters used in the epidemio-economic model described here after will thus be obtained from bibliographical data that relate to situations with no intervention.

Strategy 1 is the one observed on the field during the case study as described in previously (Chapter 3): clinically diseased animals were treated by an injection of oxytetracycline and were sometimes isolated during the clinical phase. The model's parameters will be calculated from results observed in reality.

Strategy 2 is the single vaccination, as carried out sometimes by veterinary services in Ethiopia during CBPP outbreaks, but not observed on the field in the case of Boji. Results of vaccine trials (Thiaucourt et al., 2000) will allow simulating this strategy.

Strategy 1 and 2 are theoretically " compatible" and " independent" : they can be performed separately but the performance of one of these does not exclude the performance of the other simultaneously (Bribier and Michaïlof, 1995) . Hence it would be suitable to also study the combined strategy 1+2. This concerns strategy 3. In reality, these strategies (1+2) are not always compatible because of the budget constraint in particular, as some farmers have no access to cash assets to invest in two strategies, and for practical reasons of access to services.

The last strategy proposed (4th.Strategy) draws its inspiration from international recommendations that suggest the successive massive vaccinations alleged to bring about a total protection (Provost, 1996): a protocol of three injections (at 0, 2 months and 6 months) the first year has been retained. It is " technically incompatible" with strategies 1, 2 and 3: its carrying out excludes that of the others. 3rd strategy is likewise incompatible with others.

4.2 Epidemio-economic simulation model

An epidemio- economic model is used to simulate the various strategies previously proposed. It is integrated in the "cost - benefit analysis" as described later on. It concerns the combination of an epidemiological compartment model (Lesnoff et al., 2003b) and of an economic model (Figure 2). The economic model, by distinguishing " epidemio-production categories" of animals, allows calculating an individual gross margin per animal and a gross margin of the herd, the latter being then used for calculating acceptability indicators of the CBA, and comparing CBPP control strategies.

4.2.1 The Epidemiological Model

4.2.1.1 Compartment model of Lesnoff et al.

This is a compartment model of within-herd spread of CBPP, described by Lesnoff et al. (2003b). Animals are categorised into six states: S, E, I_S, I_C, Q and R (Figure 4).

(1) State S represents healthy and susceptible animals.
(2) State E represents the latency period between contamination (inhalation of *MmmSC*) and *MmmSC* excretion.
(3) It was suggested that *MmmSC* excretion may occur before the apparition of lesions in the lung (Belli et al., 1989; Masiga et al., 1996). Cattle in this situation were grouped in state I_S, together with animals in the early stage of acute lesions, and animals experiencing sub-clinical forms (without symptoms).
(4) Early lesions develop and generate symptoms (transition to state I_C). Acute and hyper-acute forms were grouped in state I_C, i.e. the most infective animals (Provost et al., 1987). Cattle in progressive sequestration phase and potentially infective were also grouped in this state.
(5) State Q represents cattle for which acute lesions (I_S and I_C) evolved into sequestra containing viable *MmmSC*, i.e. chronic carriers.
(6) Cattle with acute lesions directly evolving into non-infective fibrotic scars were categorised in state R. They were assumed to be immunised against CBPP (Windsor and Masiga, 1977; Provost et al., 1987) and were grouped with naturally resistant animals.

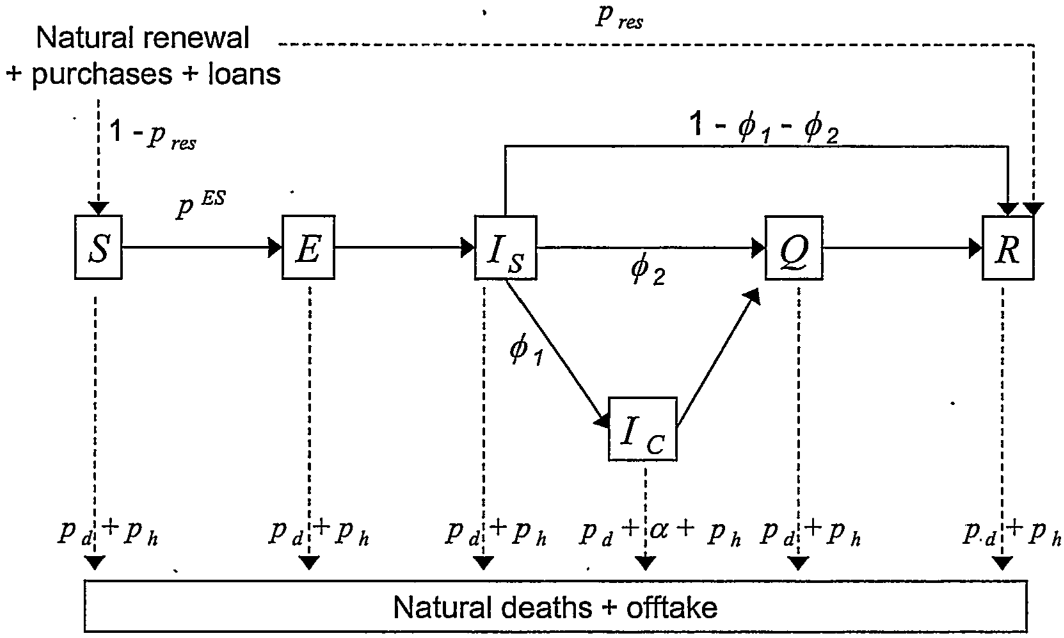


Figure 4: CBPP within-herd spread compartment model (from Lesnoff et al., 2003b)

Herd size was arbitrarily set to 20 heads of cattle. The within-herd spread of CBPP was simulated on a weekly basis after introduction of one animal in state I_C in the herd. By simulation and starting from a known initial situation, the model allows obtaining the within-herd distribution of animals at a time in each of the compartments.
Model parameters and equations are presented in the original paper (Lesnoff et al., 2003b).
A set of epidemiological reference parameters (Table XIV), representing CBPP spread in an untreated and unvaccinated herd (corresponds to strategy 0), was determined from literature (except β, the transmission parameter).

Table XIV: Parameter values considered in the CBPP within-herd spread model (from Lesnoff et al., 2003b)

Parameter	Epidemiological meaning	Reference value
τ	Average duration in *E* (week)	3.0
κ	Average duration in *Is* (week)	2.0
μ	Average duration in I_C (week)	4.0
ϕ_1	Transition between *Is* and I_C (%)	50.0
ϕ_2	Transition between *Is* and *Q* (%)	30.0
v_1	Ratio of contamination power between I_C and I_S	10.0
p_{res}	Natural resistance (%)[a]	10.0
α	CBPP mortality in I_C (% per week)	7.5
p_d	Basic natural mortality (% per week)	0.1
p_h	Offtake (% per week)	0.2

[a] corresponds to the rate of animals initially (at t=0) resistant: R/(R+S) at t=0

4.2.1.2 Use of the model for the CBA (in the case of Boji) and the values of parameters

Some rules have to be previously set for the use of the model of Lesnoff et al. (2003b) for the CBA in the case of Boji district:

- The model is limited to a time horizon of one year, assuming that almost all epidemiological events that follow the introduction of the PPCB into a herd happen in this period.

- The starting point of the simulation (t = 0) corresponds to the introduction of a diseased animal (compartment Ic) into the herd, this initially diseased animal not being taken into account after in the incidence calculations.

- Dead or exploited animals are systematically replaced (by one year old young or by buying) into the herd, except if death is caused by CBPP. The model thus assumes that the population is in equilibrium (stable number of members) without CBPP. On the other hand, animals that die from CBPP are subtracted from the herd until the end of the one-year period. It is in fact assumed that the apparition of the CBPP among a herd, which is an unforeseen event and whose evolution is rapid, does not leave the farmer time to mobilise the resources necessary for the renewal of the diseases it cause.

- Compartment Q is suppressed, as a consequence of considering the hypothesis that Chronic *MmmSC* carriers (holding sequestra) were non-infective, a hypothesis raised by certain authors like Windsor and Masiga (1977) and by the results of the autopsies and bacteriological analyses undertaken on animals of the herd monitoring in Boji (Sintayehu et al., 2002). No sequestra was observed in the lungs of 12 animals affected by PPCB, and that were slaughtered and on which an autopsy was made more than six months after the symptoms. Bacteriological results obtained from samples (thoracic ganglions) taken from those 12 animals didn't reveal the presence of the pathogenic agent. Ic and Is thus go directly to compartment R.

- Only animals with an age greater than one year are considered in the model (a general case in the model of Lesnoff et al., not specific to the case of Boji). The young animals are in fact considered by the literature as non- receptive to PPCB (Provost et al., 1987). In Boji, the calves are separated from the other members of the herd, which reinforces the choice of not giving them an epidemiological role.

- Transmission parameter β was set to 4, as suggested per Lesnoff et al. (2003b) analysis of the model. This parameter corresponds to the product between the weekly-average number of contacts of an animal with other cattle and the probability of CBPP transmission when an animal in state S contacts another animal in state I_C.

To run the model under various CBPP control strategies, certain parameters have to be modified, as described in table XV.

Table XV. Values of the modified parameters of the compartment model according to CBPP control strategies

Strategy	Parameter		
	p_{res} (%)	β	α (% per week)
S0	10	4	7.5
S1	10	0.639	2.5
S2	50	4	7.5
S3	50	0.639	2.5
S4	100	0	0

Sources of data for the new parameters are of two types: results of the herd monitoring and the literature. Vaccine trials have showed that a single vaccination with T1 sr or T1/44 vaccine brings about a rate of protection that varies between 33 and 67% (Thiaucourt et al., 2000). An average rate of 50% has been retained. Several closer vaccinations (three injections in one year), according to the protocol recommended by a group of experts FAO/OIE/OAU in 1970 in Lagos (Provost, 1996) are believed to bring about a total protection. The results of the herd monitoring have showed that in the context of Boji case fatality rate of clinical CBPP cases was 10%, which corresponds to $\alpha = 2.5\%$ (as the average duration in Ic is fixed to four weeks). The cumulative incidence over a period of one year was 43.8% in the herds classified as with good or "complete" health management (therapeutic coverage > 80% of clinical cases and isolation of clinical cases). Based on this figure it was possible to estimate a transmission parameter β equal to 0.639. The weak value of this parameter is due to the reduction of contacts between diseased and healthy animals (because of isolation of the diseased) and probably to the reduction of the infectious power of treated animals (for which the pathogenic agent has probably been controlled).

4.2.2 Epidemio-Production categories

For the requirements of the epidemio-economic model, defining "epidemio-production categories Xij" of animals is necessary. These correspond to the combination of "epidemiological categories Ei" and "production categories Zj".

The "epidemiological categories Ei" correspond to individual health status inferred from the results of the epidemiological simulation (with the compartment model) for a period of one year. The correspondence is as follows:

- **Animals of category E1: "apparently healthy"**: animals of the herd that have not shown clinical signs of CBPP (Compartments S, E, Is, Q or R) during the simulated period (one year).
- **Animals of category E2: "diseased"**: animals that have shown clinical signs of PPCB (which have thus passed by the compartment Ic) during the simulated period.
- **Animals of category E3: "died of CBPP"**: animals that died of clinical CBPP during the simulated period.

The "production categories Zj" take into account the sex and the type of production of animals. These categories are three in number:

- **Z1: heifers and young males** (non-productive animals, from 1 to 3 years of age)
- **Z2: cows** (productive females (milk), of 4 years of age or above)
- **Z3: oxen** (Productive males for work, of 4 years of age or above)

By crossing categories Ei and Zj, "epidemio-production categories" of animals are obtained. Each animal of category Xij belongs to the epidemiological category Ei and to the production category Zj. The epidemio- production categories, which are nine in number, are presented in table XVI.

Table XVI: Epidemio-production categories Xij of animals
(i: individual health status per animal; j: type of animal)

Epidemiological Category Ei	Production category Zj		
	Z1: Heifer and young male	Z2: Cow	Z3: Ox
E1: "Apparently Healthy"	X11	X12	X13
E2: "Diseased"	X21	X22	X23
E3: "Died of CBPP"	X31	X32	X33

4.2.3 Individual Gross Margin (IGM)

4.1.3.1 Definition and Formulas

An indicator allows to link the epidemiological model and the economic model; it is the individual gross margin. It is defined as the difference between the revenues (outputs) and variable costs (inputs) of each animal of the herd for a period *t*. Structural expenses (fixed costs) are not taken into account in the calculation; they are assumed to be constant and independent of CBPP.

The average individual gross margin $IGM_{ij}(t)$ during the period *t* for an animal of the epidemio-production category Xij is calculated according to Equation [1]:

Equation [1]

$$\mathbf{IGM}_{ij}\mathbf{(t)} = \mathbf{R}_{ij}\mathbf{(t)} - \mathbf{C}_{ij}\mathbf{(t)}$$

(*i* = health status of the animal; *j* = type of animal)

Where: $\mathbf{R}_{ij}\mathbf{(t)}$ = revenues from production (consumed or sold) of an animal of the epidemio-production category Xij during the period *t*.

$\mathbf{C}_{ij}\mathbf{(t)}$ = production costs of an animal of the epidemio-production category Xij (with the exception of costs of control of CBPP) during the period *t*.

$R_{ij}(t)$ is calculated according to Equation [2]:

Equation [2]

$$\mathbf{R}_{ij}\mathbf{(t)} = \mathbf{T}_{ij}\mathbf{(t)} + \mathbf{M}_{ij}\mathbf{(t)} + \mathbf{F}_{ij}\mathbf{(t)} + \mathbf{O}_{ij}\mathbf{(t)}$$

(*i* = health status of the animal; *j* = type of animal)

Where: $\mathbf{T}_{ij}\mathbf{(t)}$ = Estimated average revenues from a category Xij animal's work during the period *t*.

$\mathbf{M}_{ij}\mathbf{(t)}$ = Estimated average revenues from a category Xij animal's dairy production during the period *t*.

$\mathbf{F}_{ij}\mathbf{(t)}$ = Estimated average revenues from a category Xij animal's manure production during the period *t*.

$\mathbf{O}_{ij}\mathbf{(t)}$ = Estimated average revenues from a category Xij animal's offtake (sales and slaughtering) during the period *t*.

$C_{ij}(t)$ is calculated according to Equation [3]:

Equation [3]

$$\mathbf{C}_{ij}(\mathbf{t}) = \mathbf{Tr}_{ij}(\mathbf{t}) + \mathbf{Fe}_{ij}(\mathbf{t}) + \mathbf{Ra}_{ij}(\mathbf{t})$$

(i = health status of the animal; j = type of animal)

Where: $\mathbf{Tr}_{ij}(\mathbf{t})$ = Estimated average costs of medical treatments (excepting those against CBPP) of a category Xij animal during the period *t*.

$\mathbf{Fe}_{ij}(\mathbf{t})$ = Estimated average costs of feeding (supplements only and not the grazing) of a category Xij animal during the period *t*.

$\mathbf{Ra}_{ij}(\mathbf{t})$ = Costs of repurchase in case of death (due to PPCB only) of a category Xij animal.

Although animals that died from CBPP are not replaced in the course of epidemiological simulation, they are assumed to be renewed by buying at the end of the period (one-year), so as to take into account the cost of these losses by death in the CBA. For the requirements of the CBA, the costs of CBPP control strategies are not considered in the calculation of the IGM. In fact these costs have to be considered apart to allow the calculation of the indicators of strategies' acceptability.

4.1.3.2 Estimate of the values of revenues and production costs.

Values of revenues and production costs necessary for the calculation of individual gross margins are obtained from Table V for "apparently healthy" animals (epidemiological category E1). These values are the outcomes of the herd monitoring in Boji over a period of one year during the year 2001 (Laval and Assegid Workalemahu, 2002).

For animals that "died from CBPP" (epidemiological category E3), individual revenues are assumed to be equivalent to half of the revenues from "apparently healthy" animals, assuming that the dead animal had lived with a normal production on average half of the duration t. Similarly, production costs include half of the costs of apparently healthy animals but also include the cost of repurchase of an animal of the same production category at the end of the period t (that is at the end of the simulated year).

Finally, for "diseased " animals (epidemiological category E2), the revenues and production costs are estimated at a valuation based on the observations made among diseased herds in Boji. It was observed that diseased animals were in general separated from production (be it to milk for the cows or the work for the oxen) for two months, so that they recover. Hence, the costs of feeding and revenues from productions are lessened by 15% a year for animals that were affected by clinical CBPP and that have survived. The revenue from offtake (Oij) has been assumed to be null in the year because these animals, being diseased, have few chances of being slaughtered or sold (or at a lesser price) because they have lost weight.

4.2.4 Herd gross margin (HGM)

The gross margin is defined as the difference between the products (or gross outputs) of an activity and the variable costs of this activity (Brown, 1979). In the case described here, the activity is cattle rearing in a farm of the Boji district.

HGMx (t) is defined as the gross margin of a herd of 20 animals (with a 10% renewal rate) managed according to strategy *x* (strategies 0 to 4) over the duration *t*. The formula proposed for its calculation differs in comparison to the classical calculation: HGMx (t) is calculated by summing the individual gross margins of the animals of the herd over the duration *t* according to Equation [4].

Equation [4]

$$HGM_x(t) = \sum_{i,j} n_{ij}(t).IGM_{ij}(t)$$

$$= n_{11}(t).IGM_{11}(t) + n_{12}(t).IGM_{12}(t) + \ldots + n_{ij}(t).IGM_{ij}(t) + \ldots + n_{33}(t).IGM_{33}(t)$$

(*x*= type of CBPP control strategy)
(*i*= individual health status per animal, *j*= type of animal)

The composition of the herd by epidemio-production categories is known, thanks to the results of simulation with the compartment model. It is assumed that CBPP spreads identically within the different production categories of animals (above one year of age) and that the herd is invariably composed of 27 % of young, 48% of cows and 25% of oxen. This hypothesis is reinforced by Provost et al. (1987) who do not consider age (beyond one year) or sex effect on the receptivity of animals to CBPP.
As in the calculation of IGM, structural costs (or "fixed costs ") are not taken into account in the calculation of the HGM; they are assumed to be constant and independent of CBPP.
The epidemio-economic model thus allows obtaining a general indicator that portrays the economic performance of the herd: the herd gross margin.
This is the "output" of the model. It is used to calculate the acceptability criteria of the CBA's and finally to compare different CBPP control strategies.

4.3 Estimate and comparison of costs and benefits of CBPP control strategies

4.3.1 Estimate of the costs of CBPP control strategies

Costs of strategies are identified by Kx (t), costs of the strategy *x* over the duration *t*. Costs are assumed to be null for strategy 0 (no intervention).

For strategies 1 and 3, the unit cost of the treatment (injection of oxytetracycline) of a diseased animal is estimated by using the results of the herd monitoring in Boji. Only animals that have gone through a clinical CBPP (epidemiological category E2) can receive a treatment and be taken into account in the calculation of the total cost of treatments among an infected herd. The simulation with the compartment model allows knowing the number of animals that were diseased and therefore treated.

For the calculation of the unit cost of the vaccination (strategies 2 and 4), two types of costs have to be considered: the fixed costs and the variable costs. Fixed costs include operation expenses and depreciation of the rolling stock (vehicles), cold chain materials and others, fixed salaries of the staff, administration and office expenses. Variable costs essentially include unit doses of vaccine (taking into account losses) and the per diems of the staff. Only sale price of the dose of CBPP vaccine was available at the national veterinary institute (NVI) of Debre-Zeit (Ethiopia). For other costs data on the vaccination campaigns obtained from recent literature allowed to make a reasonable estimate. Finally, a concise study was made to assess the acceptability of cost recovery of vaccination by the farmers (consent to pay, CTP), the latter being alleged to finance the vaccination according to the study characteristics (cf. 4.1.1). After explanation of limits of the vaccination, 70 farmers involved in the herd monitoring have been asked about the amount in Birr that they were disposed to pay per animal to vaccinate their herds against CBPP.

Cost of vaccination per herd (single or triple following the strategy considered) corresponds to the unit cost of vaccine multiplied by the number of animals in the herd, taking into account the rate of renewal; the renewed animals are assumed to be also vaccinated and are included in the calculation of the total cost of vaccination at herds level.

$Vc_x^r(t)$, the "value of costs" of a strategy x with respect to a reference strategy r for a herd of 20 animals (with a 10% renewal rate) over the duration t is calculated according to Equation [5]:

Equation [5]

$$Vc_x^r(t) = K_x(t) - K_r(t)$$

(x= type of CBPP control strategy; r = reference strategy)

4.3.2 Estimate of the benefits of CBPP control strategies

The gross margin of the herd HGMx (t) contributes to the calculation of Vb_x^r (t), the "Monetary value of benefits" of strategy x with respect to a reference strategy r for a herd of 20 animals (with a 10% renewal rate) over the duration t. Vb_x^r (t) is calculated according to Equation [6]:

Equation [6]

$$Vb_x^r(t) = HGM_x(t) - HGM_r(t)$$

(x = type of CBPP control strategy; r = reference strategy)

Vb_x^r (t) will particularly depend on the reference strategy chosen. Two cases will be analysed: one which will take strategy 0 (no intervention) as a reference strategy and the other will take strategy 1 (the one observed on the field; with treatment of sick animals).

4.3.3 Comparison of costs and benefits.

The comparison of costs and benefits is classically made in CBA by the use of three "acceptability criteria" (or "investment criteria"): the Net Present Value (NPV), the Benefit-cost ratio BCR, and the Internal Rate of Return (IRR) (Squire and van der Tak 1975, Bridier and Michailov, 1995; Brent, 1998). The IRR of a strategy corresponds to the discount rate which should have been applied so that the present value of benefits be equal to the present value of costs (i.e. NPV = 0). It will not be calculated here because, in our case, as the time horizon is limited to one year, the values of benefits and costs are not subject to a discount. For the same reason, the denomination "Net Present Value" is modified in our analysis into the denomination "Net Value" (NV).

NV_x^r (t) and BCR_x^r (t), the net value and the benefit-cost ratio of strategy *x* with respect to reference strategy *r* over the duration *t* are computed according to equations [7].

Equations [7]

$$\mathbf{NV}_x^r\ \mathbf{(t) = Vb}_x^r\ \mathbf{(t) - Vc}_x^r\ \mathbf{(t)}$$

$$\mathbf{BCR}_x^r\ \mathbf{(t) = Vb}_x^r\ \mathbf{(t) / Vc}_x^r\ \mathbf{(t)}$$

(*x* = type of CBPP control strategy; *r* = reference strategy)

Acceptability of strategies:

If NV_x^r (t) ≥ 0 or if BCR_x^r (t) ≥ 1, therefore strategy *x* is acceptable.

Classification of strategies:

Rules for selecting strategies have been defined by Squire and van der Tak (1975) and more recently by Brent (1998). For strategies that are mutually exclusive (" incompatible" strategies), it is advised to retain the strategy with the highest NV. However, in case of budget constraint (constraint on the initial investment), the BCR is a preferable classification criterion (Brent, 1998). The NV, by simply subtracting costs from benefits, hardly allows to take account of the relative importance of costs. In a context of a subsistence economy, this investment is a constraint. BCRs allow to discriminate against costly investments by ways of selecting the strategies with largest benefits per unit of costs.

In this study the strategies proposed in the CBA are incompatible and farmers face a budget constraint. The costs of the proposed CBPP control strategies are assumed to be acceptable by the farmers, but because of the difficulties of access to cash, the less costly strategies are to be given a privilege. Hence, the BCR is retained as a criterion of classification of strategies in the CBA in the case of the district of Boji.

4.4 Sensitivity analysis

Certain parameters used in the CBA have uncertain values, the variation of which can have a non-negligible effect on the results of the analysis. In the sensitivity analysis, certain parameters are modified either separately, or several at the same time. Three types of parameters are concerned.

- Parameters of within-herd CBPP spread without intervention (naive situation, strategy 0). They were not observed on the field and their values in literature are highly variable. The virulence of CBPP may vary with respect to *Mmm*SC strain and hence to geographical zones, to the type of expression (epidemic or endemic) (Provost et al. 1987)...
- Parameters concerning the efficiency of control strategies. An uncertainty exists about the efficiency of antibiotic treatments, these being subject only to rare studies, and about the rate of protection conferred by the vaccines used (Yaya et al., 1999; Thiaucourt et al., 2000).
- Animal production and economics parameters. The values of these parameters are mostly obtained from field surveys. Their accuracy is open to criticism, particularly because of a context of subsistence economy in which several products are not commercialised and have no market price. Losses caused by CBPP on diseased animals have not been accurately estimated. On the other hand, the cost of treatments and vaccines can have a determinant effect on the adoption of strategies by the farmers in the context of a budget constraint.

The sensibility analysis will consist of varying the value of these parameters (the detail of which is shown hereafter) in the epidemio-economic model and of analysing the effect of these variations on the results of the CBA.

4.4.1 Variation of within-herd CBPP spread parameters without intervention

The variation of the values of certain parameters of the compartment model for the situation without intervention (strategy 0) is presented in table XVII. Two series of parameters are proposed: those of a situation assumed with lesser virulence and those of a situation with high virulence.

Table XVII: Sensibility analysis: variation of values of certain parameters of the compartment model for strategy 0 (no intervention)

Parameter	**Low virulence**	**Reference value**	**High virulence**
β : transmission parameter	2	4	8
μ : Average duration in I_C (week)	2	4	6
ϕ_1 : Transition between I_S and I_C (%)	30	50	70
ν_1 : Ratio of contamination power between I_C and I_S	30	10	5
α: CBPP mortality in I_C (% per week)	7,5	7,5	10,0

4.4.2 Variation of strategies' efficiency

The sensitivity analysis of the efficiency of strategies will be carried out on strategies 1, 2 and 3. For strategy 1 (treatments), the variation will concern the transmission parameter β and the mortality α of clinical cases. For strategy 2, the variation will concern the natural protection (p_{res}). For strategy 3, a combination of the extreme values presented for strategies 1 and 2 will be proposed. New parameters are proposed in table XVIII for two situations, one with a lesser efficiency of the strategies and the other with a greater efficiency.

Table XVIII: Sensibility analysis: variation of certain parameters of the compartment model with respect to the efficiency of strategies

CBPP control strategy[a]	Strategy efficiency low	Strategy efficiency initial	Strategy efficiency high
S0	Not modified	p_{res} = 0.1 ; β = 4 ; α = 7,5 %	Not modified
S1	p_{res} = 0.1 ; β = 1 ; α = 5,0 %	p_{res} = 0.1 ; β = 0,639 ; α = 2,5 %	P_{res} = 0.1 ; β = 0,5 ; α = 1,0 %
S2	p_{res} = 0.3 ; β = 4 ; α = 7,5 %	p_{res} = 0.5 ; β = 4 ; α = 7,5 %	p_{res} = 0.7 ; β = 4 ; α = 7,5 %
S3	p_{res} = 0.3 ; β = 1 ; α = 5,0 %	p_{res} = 0.5 ; β = 0,639 ; α = 2,5 %	p_{res} = 0.7 ; β = 0,5 ; α = 1,0 %

[a] Type of strategy : S0, no intervention ; S1, treatment of sick animals with oxytetracycline ; S2, Yearly full herd vaccination (1 injection) ; S3, combination of S1 + S2. Parameters of S4 (multiple vaccination) were not modified since it is supposed optimal (100% protection).

4.4.3 Variation of animal production and economics parameters

Monetary values of inputs (i.e. production costs) and of certain animal productions were obtained from the results of the herd monitoring in Boji. An uncertainty exists about these values, particularly for those that are not locally marketed. Concerned animal productions are animal work, milk and manure. An analysis of the effect of the over-estimate of their values, by doubling them, on the results of the CBA, is proposed. The cost of grazing resources has not been taken into account in the estimation of the production costs. Hence testing the effect of an over-estimate of production costs (feeding and veterinary cares) by a factor of 10 is proposed.

The decrease of animal productions (but also of feeding inputs) caused by CBPP for diseased animals was fixed at 15% over the year. Higher values, of 30% and 50% of losses, are tested in the sensitivity analysis.

Finally, an important uncertainty exists regarding the cost of strategies: different values are tested for the cost of antibiotic treatments and the cost of the dose of vaccine. As regards to treatments, in general, farmers practised only one injection in the district of Boji (Chapter 3); however, a normal use of antibiotics requires two or three injections, except if it is a long acting treatment

(Oxytetracycline 20% LA for instance), which is more costly. Therefore, costs over-estimated by two and three times their initial value are proposed for the sensitivity analysis. For vaccination strategies, under-estimated (by half) and over-estimated (doubled) cost values of vaccine dose are tested.

5 Cost benefit analysis: Results

5.1 Individual gross margins by epidemio-production category Xij

The detail of estimated individual gross margins by epidemio-zootechnical category Xij is presented in Table IXX. The estimated values of IGMs are small and only productive animals (cows and oxen) generate consistent revenues. IGMs of animals that died of PPCB are negative, which is due to the cost of replacement (Raij).

For the requirements of the sensitivity analysis, some monetary values deemed uncertain regarding certain inputs and animal productions are submitted to variation, which allows to propose two modified values for the IGMs of each epidemio-production category Xij of animals: one under-estimated and the other over-estimated.

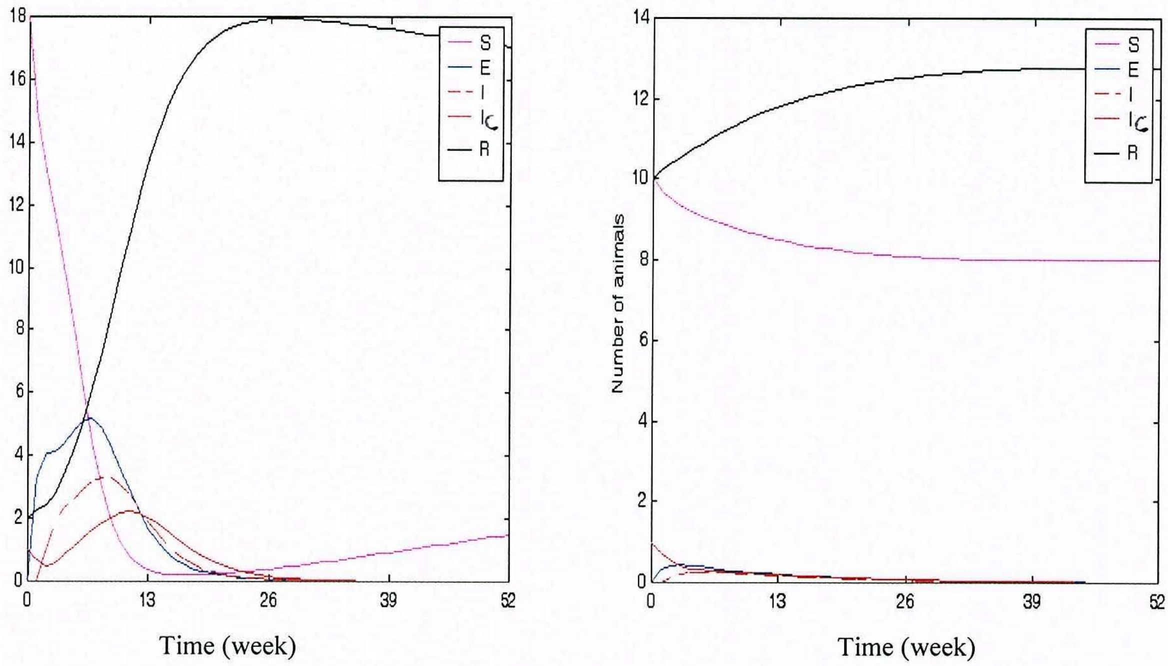
Table IXX: Individual gross margins (IGM) per epidemio-production category of animal and their modified values with respect to market prices variations
(Ethiopian Birr; 1 Birr= 0.125 Euro)

	Epidemio-production category X_{ij}								
	Apparently healthy (E_1)			Diseased (E_2)			Died of CBPP (E_3)		
	Young (X_{11})	Cow (X_{12})	Ox (X_{13})	Young (X_{21})	Cow (X_{22})	Ox (X_{23})	Young (X_{31})	Cow (X_{32})	Ox (X_{33})
IGM_{ij}	20,55	170,70	347,05	13,35	126,05	251,50	-277,10	-409,90	-356,90
Under-estimated IGM_{ij}	18,30	112,65	253,00	11,10	75,65	170,55	-278,45	-439,15	-404,65
Over-estimated IGM_{ij}	36,55	303,35	602,55	26,95	258,00	512,10	-269,10	-332,45	-203,70

(i = Individual health status ; j = type of animal)

5.2 Results of epidemiological simulation

Figure 5 shows the graphical results of an epidemiological simulation using the determinist compartment model of Lesnoff et al. (2003b) for a herd of 20 animals (with few renewal) managed according to two strategies: strategy 0 (no intervention) and strategy 3 (treatment of clinical cases and single vaccination). The different curves depict the evolution of the number of animals in each compartment. The parameters used are those described in tables XIV and XV.



Strategy 0 : no intervention

Strategy 3 : treatment of sick animals + herd vaccination (1 injection)

Figure 5: A determinist simulation of within-herd CBPP spread after introducing an Ic animal. Two strategies (S0 and S3) are modelled for a herd of 20 animals.

The different curves depict the evolution of the number of animals in each compartment.
(Compartments: S: healthy and susceptible, E: latent phase, I: sub- clinical form, Ic: clinical form, R: cured or resistant)

Strategy 0 shows a peak of sub-clinical and clinical forms in the first 3 months, then a progressive extinction of the disease, the number of resistant animals (R) reaching almost the hole of the herd in 6 months. Strategy 3 shows that, of 20 animals, half (10) are already resistant at t=0 thanks to vaccine protection and that no epidemic peak is observed (the number of animals being infected is hardly evident).

The results of the simulation over a year (after introducing a diseased animal Ic), expressed in cumulative number of animals of the herd per epidemiological category Ei, are presented in Table XX. The results correspond to the cumulative incidence (number of new cases) over a period of one year, for the diseased (excluding those that die) and the dead (of CBPP) considered separately.

Table XX: Results of epidemiological simulation over a year (cumulative incidence) per strategy for a herd of 20 animals (cumulative number of animals per epidemiological category Ei)

Epidemiological Category Ei	CBPP control strategy[a]				
	S0	S1	S2	S3	S4
E1: "Apparently Healthy"	8.99	15.67	13.92	18.73	20
E2: "Diseased"	8.57	3.90	4.67	1.10	0
E3: "Died of CBPP"	2.44	0.43	1.41	0.17	0

[a] Type of strategy : S0, no intervention ; S1, treatment of sick animals with oxytetracycline ; S2, Yearly full herd vaccination (1 injection) ; S3, combination of S1 + S2 ; S4, multiple vaccination (3 injections) and full protection.

5.3 Costs of CBPP control strategies

The cost of antibiotic treatment (oxytetracycline 10%, single injection in 80% of cases) paid by the farmers of Boji was on average 8.60 Birr per treated animal according to the results of the herd monitoring. The cost of a dose of vaccine T1sr produced at the National Veterinary Institute of Debre Zeit was 0.20 Birr in 2001. The overall cost (vaccine dose + other costs) of combined Rinderpest/CBPP vaccination undertaken by PARC (Pan African Rinderpest Campaign) in Ethiopia was on average between 1989 and 1996, 0.27 ECU per vaccinated animal (Tambi et al , 1999). In 1996, one ECU was equivalent to 0.625 Euro and one Birr to 0.137 Euro. Therefore, the unit cost of Rinderpest/CBPP vaccination was 1.2 Birr. An analysis of the costs of CBPP vaccination campaign in Senegal in 1995-96 has shown that vaccine doses contributed 23% of the total costs of the campaign (Ly et al., 1998). If this proportion were the same in Ethiopia, the unit cost of CBPP vaccination would be 1 Birr, cost which has been retained in the analysis.

The answers for the questions about farmers' consent to pay (CTP) had an estimated median of 1 Birr (Min:0; Max: 10). This supports the choice of 1 Birr retained for the unit cost of the vaccination in the analysis; at this cost the majority of the farmers would in fact be in favour of a vaccination for which they will pay. Nevertheless, the acceptability of repeated vaccinations (strategy S4) at 1 Birr per injection (and hence 3 Birr as a whole) has not been tested.

The unit cost of the vaccination being relatively uncertain, the variation of its value is subject to the sensitivity analysis: an under-estimated value of 0.5 Birr and an over-estimated value of 2 Birr per injection are tested. Similarly variations of the cost of antibiotic treatment at Boji, estimated at 8.60 birr, are tested. In general, farmers practised only one injection to limit this cost, but a normal use of oxytetracycline requires two or three injections, or the use of Long Acting preparations, which are more costly. Two over-estimated costs, one at 17.2 Birr (twice the cost of a single injection) and the other at 25.80 Birr (three times the cost of a single injection) per diseased animal are therefore tested in the sensitivity analysis.

The detail of the values of costs (Vc_x^r) of strategies x is presented in Table XXI.

Table XXI: Value of costs (Vc_x^r) of CBPP control strategies x (with respect to reference strategies r: S0 and S1) for a herd of 20 animals in Boji district over a year (Ethiopian Birr ; 1 Birr = 0.125 euro)

CBPP control Strategies[a] x	Reference strategy r	
	S0	S1
S1	$Vc_1^0 = 37.24$	-
S2	$Vc_2^0 = 22.00$	$Vc_2^1 = -15.24$
S3	$Vc_3^0 = 32.92$	$Vc_3^1 = -4.32$
S4	$Vc_4^0 = 66.00$	$Vc_4^1 = 28.76$

[a] Type of strategy : S0, no intervention ; S1, treatment of sick animals with oxytetracycline ; S2, Yearly full herd vaccination (1 injection) ; S3, combination of S1 + S2 ; S4, multiple vaccination (3 injections) and full protection.

It is interesting to notice that single vaccination combined with treatment (strategy 3) has a cost lower to that of strategy 1 (single treatment), which explains the negative value of Vc_3^1. The repeated vaccinations (strategy 4) have a cost distinctly greater that those of other strategies.

5.4 Annual herd gross margins (HGMxy) and benefits of CBPP control strategies

The results of the calculation of the herd gross margins HGM_x and of Monetary values of benefits Vb_x^r of strategies x over a year are given in table XXII. The negative value of Vb_2^1 shows that S2 is less effective than S1.

Table XXII: Annual Herd Gross Margin (HGM_x) of a herd of 20 animals in Boji district under CBPP control strategy x and Monetary value of benefits (Vb_x^r) of strategies x with respect to reference strategies r (S0 and S1) over a year (Ethiopian Birr; 1 Birr = 0.125 Euro)

CBPP control strategies[a] x	MBT_x	Vb_x^0	Vb_x^1
S0	$MBT_0 = 1774.70$	-	-
S1	$MBT_1 = 3070.69$	$Vb_1^0 = 1295.99$	-
S2	$MBT_2 = 2509.98$	$Vb_2^0 = 735.28$	$Vb_2^1 = -560.71$
S3	$MBT_3 = 3342.03$	$Vb_3^0 = 1567.33$	$Vb_3^1 = 271.35$
S4	$MBT_4 = 3484.94$	$Vb_4^0 = 1710.24$	$Vb_4^1 = 414.25$

[a] Type of strategy : S0, no intervention ; S1, treatment of sick animals with oxytetracycline ; S2, Yearly full herd vaccination (1 injection) ; S3, combination of S1 + S2 ; S4, multiple vaccination (3 injections) and full protection.

5.5 Comparison of costs and benefits of CBPP control strategies

The results of the calculation of acceptability criteria for different CBPP control strategies are presented in table XXIII.

Table XXIII: Comparison of costs and benefits of CBPP control strategies for a herd of 20 heads over a year (NV_x^r and BCR_x^r, net value and benefit-cost ratio of strategy *x* with respect to reference strategy *r*)

CBPP control strategies[a] *x*	NV_x^0 (Birr[b])	NV_x^1 (Birr)	BCR_x^0
S1	$NV_1^0 = 1258.74$	-	$BCR_1^0 = 34.80$
S2	$NV_2^0 = 713.28$	$NV_2^1 = -545.47$	$BCR_2^0 = 33.42$
S3	$NV_3^0 = 1534.41$	$NV_3^1 = 275.66$	$BCR_3^0 = 47.61$
S4	$NV_4^0 = 1644.24$	$NV_4^1 = 385.49$	$BCR_4^0 = 25.91$

[a] Type of strategy : S0, no intervention ; S1, treatment of sick animals with oxytetracycline ; S2, Yearly full herd vaccination (1 injection) ; S3, combination of S1 + S2 ; S4, multiple vaccination (3 injections) and full protection.
[b] 1 Birr = 0,125 euro

Acceptability of Strategies

All the proposed strategies are fully acceptable if the reference strategy is the strategy with no intervention (strategy 0), with net values (NV) always positive and benefit cost ratios (BCR) by far greater than 1.

If the reference strategy is strategy 1, that is the one practised by farmers of Boji (with treatment of the diseased without vaccination), strategy 2 (single vaccination without treatment) thus becomes unacceptable with a largely negative NV, strategies 3 and 4 still remaining acceptable but with distinctly lesser NVs. So, in a context where farmers can treat diseased animals (access to treatments) the single vaccination without treatment of diseased animals is economically unacceptable; it is therefore preferable to treat diseased animals.

Classification of Strategies

By taking the BCR as criterion of classification as recommended for a context assumed with a budget constraint (Brent, 1998), CBPP control strategies are ranked as follows:

1st : Strategy 3 (treatment of diseased animals combined with yearly single vaccination of the whole herd)
2nd: Strategy 1 (treatment of diseased animals only)
3rd: Strategy 2 (yearly single vaccination of the whole herd, without treatment)
4th: Strategy 4 (several vaccinations (3) of the whole herd within a year)

BCRs of strategies 1 and 2 have comparable values and it is difficult to state a preference (the strategy of reference being strategy 0).

Therefore, from the viewpoint of the farmers of Boji, the treatment of diseased animals seems financially a good method for controlling CBPP. If it is associated to a single vaccination, it becomes the best strategy.

A graphical representation of results of the CBA is proposed in figure 6. The costs of strategies being placed on the X-axis and their benefits on the Y-axis, the slopes coefficient of the lines So-Si correspond to the BCR of each strategy *i*. Strategies with the highest slopes are the better-classified ones.

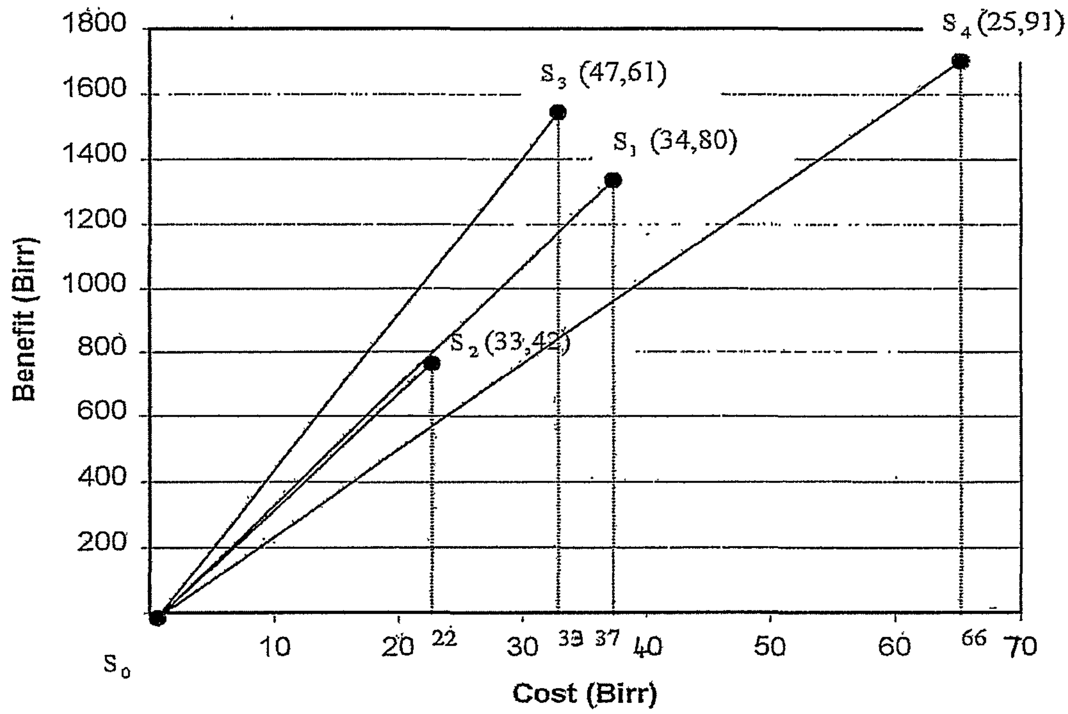


Figure 6: Cost-benefit plane : graphic representation of the results of the CBA of CBPP control strategies for a herd of 20 heads over a year (strategies S1, S2, S3 and S4 with respect to S0)

BCR in brackets; it corresponds to the slopes coefficient of lines $S_0 S_i$ (i = 1, 2, 3, 4)

5.6 Results of the sensitivity analysis

5.6.1 Sensitivity analysis varying epidemiological and strategies efficiency parameters

The effect of variation of CBPP virulence and strategies efficiency parameters (as described in tables XVII and XVIII) on the acceptability criteria of strategies is presented in Annex I A. The variation of these parameters has an important effect on the results of the CBA, the classification of strategies being largely modified. It is particularly noticed that for a lesser virulence of CBPP, strategy 1 (treatments) comes to be classified the best with a very high BCR of 64.02. For a high virulence, it is on the contrary strategy 2 (single vaccination) which is the best with a BCR equal to 68.66. As regards to the effect of strategies, one can see that the values of NVs and BCRs are logically lowered for a weak efficiency and raised for a higher efficiency. It is noticeable that for a weak efficiency, strategy 4 is the best, the latter still remaining an optimal strategy with a protection assumed to be total. For a higher efficiency, strategy 3 remains, as the initial values, classified first.

5.6.2 Sensitivity analysis varying animal production and economics parameters.

Annex I B. proposes the results of the sensitivity analysis for a variation of certain animal production and economics parameters. Under-estimated and over-estimated IGMs as well as modified IGMs for diseased animals are tested according to the variation of monetary values of inputs and/or animal productions as proposed in Chapter 4.4.3 and shown in Table IXX. The variation of the values of these parameters has little influence on the results of the CBA, the classification of strategies remaining identical.

Finally the results of the sensibility analysis are presented in Annex I C. for a modification of the cost of strategies (antibiotic treatments and doses of vaccine) as described in Chapter 4.4.3. These variations have, as expected, a non-negligible effect on the results of the CBA. In a context of budget constraint a variation of costs of strategies logically modifies their classification. However, strategy 4 still remains the last if the BCR is taken as a criterion of comparison but remains the first if it is the NV.

6 Discussion and recommendations

6.1 Discussion of the results of health (CBPP) monitoring

As an effect of financial and operational constraints, public animal health services were not effective in the control of CBPP and farmers thus turned to a private and individual management of the disease. Although not recommended (Provost, 1996), they applied antibiotic treatments to sick animals.
In the literature no information is available on cELISA serological status of animals naturally resistant to CBPP in an infected herd. If resistant animals are supposed negative to cELISA, then our results with strategy P/N herds (29.4% negative) would be comparable or higher to resistance rates described by different authors: Curasson (1942) (35%); Bygrave et al. (1968) (10.3%); Lindley (1971) (3%); Provost et al. (1987) (25%); Masiga et al. (1996) (21%).

The incidence study showed a strategy effect on cumulative incidence rates. CI were lower in herds under strategy C than strategy P/N. Isolation of sick animals, by way of reduction of contacts between infected and healthy animals, may reduce within-herd spread of the disease. Treatments may reduce both incidence, through a lower *Mmm*SC excretion from cured animals, and lower case fatality rates. Bacteriological findings did not show evidence of the presence of *Mmm*SC in samples (thoracic lymph nodes, lungs) collected from previously CBPP affected cattle treated with oxytetracycline in Boji district (Sintayehu et al., 2002). The use of antibiotic treatment therefore seemed to reduce mycoplasma viability and, as also suggested by Provost's (1974b) results and Roeder and Rweyemamu (1995b), should better be considered as an option to CBPP control. In addition the hypothesis that infected animals could transmit the disease after clinical recovery has never been tested adequately, as per Windsor and Masiga (1977) results. Nevertheless if antibiotics use had to be widespread, further preliminary investigation on secondary effects should be undertaken, especially concerning *Mmm*SC carriage after treatment.

The observed decrease of P_C in time could be explained by the statement from Provost et al. (1987) of a *Mmm*SC decline of virulence during an epidemic. The average value of P_C, estimated at 47.8%, may be slightly heightened (to 53.8%) if additional clinical cases observed by farmers (7 cases) prior to the monitoring would been included in the calculation.

Clinical signs observed in our study, including an accelerated respiratory frequency, were in accordance with symptoms usually described for the acute form of CBPP (Martel et al., 1985; Provost et al., 1987; Egwu et al., 1996; Masiga et al., 1996).

Estimated case fatality rate of 9.7% was lower than 50% usually described (Lindley, 1971; Provost et al., 1987; Masiga et al., 1996). CBPP was not the first cause of mortality in affected herds. The importance of other diseases such as anthrax and black leg may not be under-estimated in Boji district.

6.2 *Discussion of the results of the CBA*

The results are in favour of the use of antibiotic treatments (to cure sick animals) associated with vaccination of the whole herd (one single injection) to control CBPP. From the farmer viewpoint antibiotics are logically cost-effective since they reduce mortality. This positive effect and its cost-effectiveness were shown through the results of the CBA, which are hence dependant on a context of antibiotics availability (i.e. health system providing antibiotics).
A strategy combining partial vaccination (single injection protects partially) and management of sick animals using treatment has never been proposed in the literature (as far as the knowledge of the authors is concerned) as a CBPP control strategy. Provost (1974a) mentioned that vaccination associated to sanitary preventive strategies such as isolation of sick animals could be an option, but totally excluded the use of antibiotics. Provost (1967 ; 1996) advised against the use of partial vaccinations that are assumed to be ineffective when eradication of CBPP is the objective. To live with the disease is usually not proposed.
Nevertheless the conclusions of recent meetings of CBPP consultative groups (FAO/OIE/OAU/IAEA Consultative group, 2000) and of the FAO electronic conference on CBPP (FAO, 2002) suggested to reconsider a private management of CBPP and the use of antibiotics for CBPP control in Africa. Our results therefore support the ongoing new alternatives recently suggested and will have major implications in recommendations rising.

Our results have three main limitations:

- **The viewpoint.** In this CBA the farmers' viewpoint was chosen. Results may differ if other stakeholders would be considered. Strategies proposed from the national and international viewpoints usually focus on mass vaccinations and/or stamping out strategies (Provost, 1996), which is different from our results. Nevertheless no cost-benefit analysis has been carried out to support these commonly proposed strategies in the African context.
- **The farming system.** Our results are specific to one system (mixed crop-livestock) in one limited geographic area; the results may vary in other systems or regions of Ethiopia or Africa. In particular in pastoral area where livestock management is very different (herd size and grouping) the dynamics of the disease may differ and thus the results of the CBA.
- **Effect of antibiotics.** The lack of scientific knowledge on the efficiency of antibiotics in the long term (chronic carriers) and on the secondary effects (resistance), especially when under-dosage is practiced as observed in Boji, is a major limitation of our results.

The results of the sensitivity analysis show that the ranking of suggested strategies may vary according to CBPP virulence. In case of high virulence of *Mmm*Sc strain or of very receptive animals (in case of introduction of CBPP in a free area for instance) the analysis shows that vaccination strategy (strategy S2: single vaccination) would become the best alternative and would be more cost-effective than if combined with treatments (i.e. strategy S3). On the contrary in a situation with low virulence of CBPP (endemic situation for instance) treatment of sick animals without vaccination of the herd (strategy S1) would appear as the most appropriate option, and vaccination inadequate. The cost attributed to the different strategies highly determines their ranking (and therefore the results of the CBA), which shows the interest of reducing the production cost or/and delivery cost of strategies such as vaccines and treatments to facilitate their adoption by farmers.

6.3 Recommendations

6.3.1 At local level

The recommendations at local level aim at building awareness and capacity so that farmers could control CBPP by themselves. Farmers' sensitisation on CBPP risk factors management (isolation of animals, restriction of movement...) and appropriate use of antibiotics may significantly help to reduce the spread and impact of the disease. Organisation of animal health service delivery at the community level would be the best option if the institutional context is favourable (privatisation context); Professional Organisations would permit to deliver vaccines, good quality drugs and organise vaccination campaigns according to farmers' decisions and participation (at their own cost).

Development of CBPP control at local level would require the participation of local extension services and, for the establishment of Professional Organisations the involvement of other partners such as NGOs and development agencies.

6.3.2 At national level

Three directions should be followed:

- Institutional reform to promote the involvement of livestock owners in the management of animal disease (professional organisation and/or participatory approach),
- Better integration of private sector (drug vendors, community animal health workers) within the animal health system,
- Increase of the resources of public services (staff, budget...), especially for a more efficient delivery of preventive strategies against contagious diseases (vaccination campaigns).

6.3.3 Research perspectives

- **On-going research**: between herd spread of CBPP (Boji district, spatial approach, PA51 Project, ILRI)
- **Research suggestions**
  - CBPP spread in other systems (pastoral),
  - On station therapeutic trials on antibiotics efficacy against CBPP,
  - Pilot studies on the proposed approach (professional organisations, participatory approach) / ex-post assessment after implementation,
  - Improvement of vaccines (vaccine coverage and delivery).

The transfer of research results is a major issue. Other stakeholders must be involved if such results aim at being applied: these include local and national authorities, development agencies, NGOs and livestock owners communities.

7 Conclusion

This study, by way of estimation of epidemiological parameters and conducting a CBA, showed the role of herd level health management strategies in the limitation of CBPP spread at herd level and the apparently cost-effectiveness of treatments of sick animals.
In the current African context, most of the countries can not afford nor properly organise the strategies for optimal control of CBPP usually recommended (mass vaccination, control of cattle movement, stamping out) (Provost, 1996 ; Windsor, 2000). As far as the disease is nowadays spreading dramatically within the continent, there is an urgent necessity to identify complementary and low input CBPP control strategies that farmers could implement by themselves. Such strategies may not aim at eradicating CBPP but at reducing its impact at farm level. The results of this CBA show the interest of CBPP private management and short term options in an area where livestock market is localised (since the impact of disease on trade is limited) and where the disease is newly emerging (since there is no indigenous knowledge of the disease). Nevertheless the use of antibiotic treatments would require further study before being widely recommended in Africa.

Annex I A. : Sensitivity analysis: effect of the variation of CBPP virulence and strategies efficiency parameters on the results of the CBA (NV and BCR)

CBPP control Strategy [a]	(NV_x^0)[b] and (BCR_x^0)[c]	Initial values	CBPP virulence		Strategy efficiency	
			Low	High	Low	High
S1	NV_1^0 (Birr)[d]	1258,74	287,23	2314,10	638,95	1491,06
	BCR_1^0	34,80	64,02	22,67	10,49	63,14
S2	NV_2^0 (Birr)	713,28	197,87	1488,48	342,02	1099,49
	BCR_2^0	33,42	9,99	68,66	16,55	50,98
S3	NV_3^0 (Birr)	1534,41	289,50	3065,00	1002,27	1645,83
	BCR_3^0	47,61	12,90	52,00	16,71	65,48
S4	NV_4^0 (Birr)	1644,24	294,73	3482,95	1644,24	1644,24
	BCR_4^0	25,91	5,47	53,77	25,91	25,91

[a] Type of strategy : S0, no intervention ; S1, treatment of sick animals with oxytetracycline ; S2, Yearly full herd vaccination (1 injection) ; S3, combination of S1 + S2 ; S4, multiple vaccination (3 injections) and full protection.

[b] NV_x^0 = net value of strategy x with respect to reference strategy 0

[c] RBC_x^0 = benefit-cost ratio of strategy x with respect to reference strategy 0

[d] 1 Birr = 0,125 euro

Annex I B.: Sensitivity analysis : effect of variation of animal production and economics parameters on the results of the CBA (NV and BCR)

CBPP control strategy [a]	(NV_x^0)[b] and (BCR_x^0)[c]	Type of variation: Initial IGM	Under-estimated IGM	Over-estimated IGM	30% of losses for diseased animals	50% of losses for diseased animals
S1	NV_1^0 (Birr)[d]	1258,74	1174,93	1366,56	1363,88	1504,12
	BCR_1^0	34,80	32,55	37,70	37,63	41,39
S2	NV_2^0 (Birr)	713,28	659,92	768,14	801,08	918,20
	BCR_2^0	33,42	31,00	35,92	37,41	42,74
S3	NV_3^0 (Birr)	1534,41	1424,58	1655,61	1702,58	1926,90
	BCR_3^0	47,61	44,27	51,29	52,72	59,53
S4	NV_4^0 (Birr)	1644,24	1522,45	1774,37	1837,17	2094,53
	BCR_4^0	25,91	24,07	27,88	28;84	32,74

[a] Type of strategy : S0, no intervention ; S1, treatment of sick animals with oxytetracycline ; S2, Yearly full herd vaccination (1 injection) ; S3, combination of S1 + S2 ; S4, multiple vaccination (3 injections) and full protection.

[b] NV_x^0 = net value of strategy x with respect to reference strategy 0

[c] RBC_x^0 = benefit-cost ratio of strategy x with respect to reference strategy 0

[d] 1 Birr = 0,125 euro

Annex I C.: Sensitivity analysis: effect of the variation of costs of strategies (Vc) on the results of the CBA (NV and BCR)

CBPP control strategy [a]	$(Vc_x^0)^b$, $(NV_x^0)^c$ and $(BCR_x^0)^d$	Initial analysis	Over-estimated treatment (cost x2)	Over-estimated treatment (cost x3)	Under-estimated vaccine (cost x0,5)	Over-estimated vaccine (cost x2)
S1	Vc_1^0 (Birr)[e]	37,24	74,48	111,71	37,24	37,24
	NV_1^0 (Birr)	1258,74	1221,51	1184,27	1258,74	1258,74
	BCR_1^0	34,80	17,40	11,60	34,80	34,80
S2	Vc_2^0 (Birr)	22,00	22,00	22,00	11,00	44,00
	NV_2^0 (Birr)	713,28	713,28	713,28	724,28	691,28
	BCR_2^0	33,42	33,42	33,42	66,84	16,71
S3	Vc_3^0 (Birr)	32,92	43,84	54,77	21,92	54,92
	NV_3^0 (Birr)	1534,41	1523,48	1512,56	1545,41	1512,41
	BCR_3^0	47,61	35,75	28,62	71,50	28,54
S4	Vc_4^0 (Birr)	66,00	66,00	66,00	33,00	132,00
	NV_4^0 (Birr)	1644,24	1644,24	1644,24	1677,24	1578,24
	BCR_4^0	25,91	25,91	25,91	51,83	12,96

[a] Type of strategy : S0, no intervention ; S1, treatment of sick animals with oxytetracycline ; S2, Yearly full herd vaccination (1 injection) ; S3, combination of S1 + S2 ; S4, multiple vaccination (3 injections) and full protection.

[b] Vc_x^0 = value of costs of a strategy x with respect to reference strategy 0

[c] NV_x^0 = net value of strategy x with respect to reference strategy 0

[d] RBC_x^0 = benefit-cost ratio of strategy x with respect to reference strategy 0

[e] 1 Birr = 0,125 euro

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