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Original article

A cost/benefit study of paratuberculosis certification in French cattle herds

Barbara DUFOUR[a*], Régis POUILLOT[a], Benoît DURAND[b]

[a] Agence Française de Sécurité Sanitaire des Aliments, DERNS, 27–31 avenue du Général Leclerc, BP 19, 94701 Maisons-Alfort Cedex, France
[b] Agence Française de Sécurité Sanitaire des Aliments, LERPAZ, 22 rue Pierre Curie, BP 67, 94703 Maisons-Alfort Cedex, France

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Abstract – Paratuberculosis has received increasing attention in France because of the important losses this disease may provoke. The use of certification schemes has proven its effectiveness for the protection of healthy herds against diseases transmitted mainly by trade. The economic justification of such schemes in the particular case of paratuberculosis is studied, for French cattle herds, using a cost/benefit approach. The basic economical hypotheses and estimates have been proposed and carefully examined by a working group composed of paratuberculosis experts and field specialists. By adopting the point of view of a breeder that buys animals, we first estimated the benefits resulting from the non-introduction of the disease. They were then compared with the costs resulting from the fact that the vendor reports its own certification costs on the price of the animals he sells. Two average herds (the mean French beef herd and the mean French dairy herd), and two certification levels were studied. The results show that, currently, the use of the certification is not very economically profitable in French cattle herds. This conclusion, however should be reappraised if the certification costs decrease, for example with the commercialization of diagnostic tests on mixtures.

paratuberculosis / cost-benefit analysis / certification

1. INTRODUCTION

Paratuberculosis (or Johne's disease) is a chronic wasting disease due to *Mycobacterium avium* subsp. *paratuberculosis* infection, that may cause considerable production losses in cattle, sheep and goat herds [2]: in the United States, the direct costs induced yearly by this disease have been estimated in the dairy industry at US$ 200 to US$ 250 millions [10].

In France, increasing attention is being paid to this disease since a recent study revealed a cattle herd seroprevalence rate ranging from 0.02% to 4.57% according to the departement (French administrative subdivision) [12].

At the individual level, infection is characterized by a higher susceptibility of young animals and a prolonged incubation period with faecal bacteria excretion that starts long before the clinical signs appear.

* Corresponding author: bdufour@vet-alfort.fr

The whole infection course may also remain sub-clinical. As a consequence, the major transmission mode of paratuberculosis between herds is based upon the trade of live animals: healthy herds are usually contaminated with the purchase of an infected heifer.

For such trade-transmitted diseases, a very general way to protect healthy herds is the use of certification schemes: a set of requirements are defined that have to be met by the herds that sell animals, to ensure (as far as possible) a disease-free status of these herds. Therefore, when buying animals only in such certified herds, breeders reduce the risk of introducing the disease in their own herd. However, if certification schemes induce benefits (with this disease introduction risk reduction), they also induce additional costs for breeders who sell animals with, among other measures, the use of disease detection tests, often yearly. Therefore, before proposing a certification scheme, it is desirable to compare the avoided costs for the breeders who buy animals with the additional costs for the breeders who sell animals.

Several economic analyses have been conducted on paratuberculosis [1, 3–6, 8, 10, 13, 14]. These studies are, however, about the comparison of disease control plans at the herd level and are not interested in the specific problem of the use of certification schemes. Moreover, the computation of the disease costs is very dependent on the production system (herd size, production level, herd management…). Therefore, the results obtained in a given country can not be directly used in another one.

The objective of the work reported here was, in the context of the French cattle herds, to study the economic justification of the use of a paratuberculosis certification scheme. This work was initiated by a French association (ACERSA: "Association pour la certification en santé animale") that promotes the definition and use of certification schemes. A working group (see Appendix) has been created with paratuberculosis experts (scientists working on paratuberculosis and field specialists chosen for their implication in the control of paratuberculosis) to (i) propose paratuberculosis certification schemes, and (ii) evaluate the economic interest of these schemes, using a cost/benefit approach.

Two certification levels were defined by the group, and the cost/benefit analysis was conducted taking the point of view of a breeder who buys animals. In this context, the benefits are the avoided disease costs: they were estimated using an epidemiological model of the intra-herd disease dynamic. The costs correspond to an increase of the animal prices due to the application of the certification scheme by the breeder who sells the animals. The whole study was focused on average herds. Therefore, the purebred cattle market access issues (buyers choosing to purchase cattle from low-risk sources and not from herds known to be infected) were not taken into account.

2. MATERIALS AND METHODS

2.1. Estimation of the disease costs

A deterministic simulation model [11] was designed to generate the average paratuberculosis dynamics in a cattle herd, assuming that a single infected heifer was introduced in the herd at the beginning of the simulated period.

When estimating the disease costs, two kinds of losses were distinguished: the costs induced by the sick animals, and those induced by sub-clinically infected animals. Therefore, the epidemiological model was used to generate the two corresponding output variables: the yearly number of sick animals and the yearly number of sub-clinically infected animals.

Concerning the costs induced by the clinical cases, the following assumptions were made (in the epidemiological model as in the cost/benefit analysis):

(i) the breeder and his vet are able to recognize the disease signs, and the sick cows and their female calves are systematically culled, male calves being commercialized as veal calves,

(ii) before culling the animals, the vet tries to treat them, and laboratory tests (Ziehl and serology, the results of which are available in a few days) are used to confirm the diagnosis.

The cost due to a clinical case is the sum of the loss of the sick cow and of its female calf (the estimation of which depends on how these animals are replaced), the price of a vet's visit, of an anti-diarrheal treatment and of the laboratory tests. In dairy herds, the disease also induces costs due to the loss of the milk production of the clinical cases. The amount of these losses depends on when the disease onset occurs. According to the experts' opinions, it was assumed that, for 90% of the sick cows, the clinical signs appeared soon after calving (in this case, the loss is the entire yearly production); and that, for the other clinical cases, the disease onset occurred later, during lactation, the losses being then half of the yearly production. The additional costs induced by these losses were computed as the average amount of production lost by the profit realized by the breeder per liter of milk.

It is well known that, despite the fact that they do not show any clinical sign, the milk production of sub-clinically infected animals is lower than the production of healthy animals. According to the authors, this decrease is estimated in the literature at 5% to 25% of the yearly production [1, 6, 9, 10]. The upper estimation was kept and the yearly cost of a sub-clinically infected animal in a dairy herd was computed as the corresponding amount of production lost by the price of a liter of milk. Conversely, for beef herds, no precise data could be found in the literature about weight losses due to sub-clinical paratuberculosis. Therefore, it was assumed that in beef herds, sub-clinically infected animals did not generate any additional cost.

2.2. Estimation of the certification costs

Even if all the animals are tested, it is difficult to guarantee that a herd is paratuberculosis-free, because of the poor sensitivity of the available diagnostic tests and of the low within herd prevalence of infection. Furthermore, a clustering of false positives has been observed in some herds [7]. However, if a single control can not yield an absolute guarantee, when such controls are repeated over time and remain negative, the confidence level in the paratuberculosis-free status of the herd will increase. Taking into account, on the one hand the defaults of the currently available diagnostic tests and its corollary, the necessity of repeated negative controls to obtain a reasonable guarantee level; and, on the other hand, the heaviness of the conceivable protocols, the working group defined two certification levels denoted L1 and L2.

Herds having a favorable paratuberculosis background (no clinical cases for more than 3 years, no vaccination) were candidates at the first level: the L1 certification was obtained after a negative control of all the animals older than 24 months. This level was maintained if, every year, the control of the animals of more than 24 months introduced since the last control was negative, and if, every two years, the control of all the animals between 24 and 48 months was also negative.

Only herds having acquired the L1 level could be candidates at the L2 level. This second certification level would be obtained after two yearly successive negative controls of all the animals older than 24 months. The requirements that have to be met to maintain the certification level would be the same as for the L1 level, except that the biennial control would also concern the animals older than 48 months.

Several diagnostic methods can be used to obtain and to maintain the certification levels: direct methods, such as faecal culture (FC) or polymerase chain reaction (PCR), and indirect methods, such as ELISA on serum. Each of these methods has its own sensitivity and specificity characteristics, and various combinations, more or less costly, could be used. Only the less expensive of these combinations was taken into account, with the use of ELISA tests on serum.

2.3. Cost/benefit analysis

A cost/benefit analysis consists in a comparison of the benefits induced by some measure with its costs. Benefits and costs are typically not constant over time, and the difference between them is often first negative (the costs are initially higher than the benefits) before becoming positive (the benefits are higher than the costs). Therefore, the certification cost/benefit analysis consists, for a given year a (since the introduction of the certification), in computing the difference:

$$NB_x(a) = B_x(a) - C_x(a) \qquad (1)$$

where:

– $NB_x(a)$ is the yearly net benefit for a breeder that has always purchased animals in a herd having the certification level x ($x \in \{1, 2\}$ for the L1 and L2 certification levels) since the start of the certification program,

– $B_x(a)$ is the yearly certification benefit for this breeder,

– $C_x(a)$ is the yearly cost of the certification program for the year a if the animals are bought in a herd having the certification level x ($x \in \{1, 2\}$ for the L1 and L2 certification levels).

The point of view used in the study was that of a breeder who buys animals. For him, the certification costs are an increase of the price of the animals he buys, due to the fact that the vendor reports its own certification costs on this price and takes an additional profit from the certified status of its herd. For both certification levels, the number of animals tested every year varies; therefore, for the vendor the certification costs are not constant over time. It was assumed that, instead of directly reporting the yearly certification costs on the sold animals price, the vendor would report every year the yearly average certification cost (computed over a period of ten years).

Therefore, for a breeder who buys animals, the yearly certification cost is constant over time:

$$C_x(a) = C_x = n \frac{\rho}{m} \frac{1}{10} \sum_{1 \leq t \leq 10} C_x(t) \qquad (2)$$

where:

– n is the number of heifers purchased every year by the breeder,

– m is the number of heifers sold every year by the vendor,

– ρ is the margin of the vendor ($\rho \geq 1$),

– $c_x(t)$ is, for the vendor, the yearly certification cost, t years after the beginning of the certification scheme (with $x \in \{1, 2\}$ for the L1 and L2 certification levels).

Adopting the point of view of a breeder who buys animals, the certification benefits result from the fact that this certification decreases the disease introduction risk. More precisely, for a given year a after the start of the certification program, the benefit is:

$$B_x(a) = E_0(a) - E_x(a) \qquad (3)$$

where:

– $E_0(a)$ is the effective disease costs for a breeder that always purchased animals in a non-certified herd,

– $E_x(a)$ is the effective disease costs for a breeder that always purchased animals in a herd having the certification level x ($x \in \{1, 2\}$) since the start of the certification program.

To compute the effective disease costs, the disease introduction probability must be taken into account, since, for a given year a, the effective disease costs are the product of the probability for the disease to have been introduced during some year t (with $0 \leq t \leq a$) by the corresponding yearly disease cost:

$$E_x(a) = q_x(a)\, D(a) \qquad (4)$$

where:

– $q_x(a)$ is the probability for the disease to have been introduced in the herd during some year t (with $0 \leq t \leq a$), with $x \in \{0, 1, 2\}$ for, respectively, the absence of vendor certification, the L1 and the L2 vendor certification levels,

– $D(a)$ is the average yearly disease cost if the disease has been introduced in the herd during some year t (with $0 \leq t \leq a$),

Assuming that the probability for an introduced heifer to be infected remains constant during the studied period, the probability for the disease to be introduced during a given year is also constant over time:

$$p_x = 1 - (1 - \alpha(1 - \delta_x))^n \qquad (5)$$

where:

– p_x is the disease introduction probability, with $x \in \{0, 1, 2\}$ for, respectively, the absence of vendor certification, the L1 and the L2 vendor certification levels,

– α is the probability for an introduced heifer to be infected,

– δ_x is the efficacy of the certification ($x \in \{0, 1, 2\}$ for, respectively, the absence of vendor certification, the L1 and L2 vendor certification levels), with $\delta_0 = 0$, $0 < \delta_1 \leq 1$ and $0 < \delta_2 \leq 1$,

– n is the number of heifers introduced every year.

For a given year a, the probability that the disease has been introduced in the herd during some year t (with $0 \leq t \leq a$) is then:

$$q_x(a) = 1 - (1 - p_x)^a. \qquad (6)$$

The yearly disease costs are not constant over time: as the disease progresses inside an affected herd, the incidence increases, as the disease costs do. However, if the disease introduction probability α is constant, then the probability, for a given year a, that the disease has been introduced during the year t (with $0 \leq t \leq a$) is the same, whatever the year. The probability that the disease evolves in the herd since t years is thus the same, whatever the value of t ($0 \leq t \leq a$). Therefore, for a given year a, the yearly disease costs are the average disease costs for the first a years:

$$D(a) = \frac{1}{a} \sum_{0 \leq t \leq a} d_t \qquad (7)$$

where d_t is the yearly disease cost, if the disease evolves inside the herd since t years.

Two kinds of herds were distinguished in the study: dairy herds and beef herds. In both types of herds, the cost/benefit analysis was conducted using a time horizon of 15 years.

The epidemiological model used to generate the disease dynamics [11] has two kinds of parameters: epidemiological parameters that control the simulated disease transmission, and herd management parameters, that control herd population dynamics. The values of the epidemiological parameters were provided by the working group, and the simulation results were also validated by this group. Two sets of values were estimated for the herd management parameters: the first one describes a mean French dairy herd, and the second one describes a mean French beef herd. Both sets of parameter values (Tab. I) were derived from French agricultural statistics (SCESS, Institut d'Élevage) and from experts' opinions.

In France, dairy herds are rather small in size (on average 40 cows). The production (limited by quota) is on average 5 500 liters per lactation. The mean age at the first calving is about 2 years. Veal calves are slaughtered when they are 8 days old. By comparison with other countries, beef herds are small size herds (50 cows on average) with a rather intensive management system (pasture management following confinement during calving). The average

Table I. Herd management parameter values for a mean French beef herd and for a mean French dairy herd, estimated from agricultural statistics (a) and from expert opinions (b).

Parameter	Dairy herd	Beef herd
Number of cows*	40 (a)	50 (a)
Cow culling rate	33% (a)	20% (a)
Age at the first calving (years)	2 (a)	3 (a)
Mean milk production by (liters, per year and per cow)	5 500 (a)	
Mean number of heifers sold** per year by a mean vendor	6 (b)	10 (a)
Mean number of heifers bought*** per year by a mean buyer	1 (b)	2 (a)

* After first calving, ** sold for breeding, *** bought for renewal.

Table II. Unitary costs used to compute the disease costs and the certification costs (euros).

Nature	Cost
Disease costs:	
(i) Sick animals	
Anti-diarrhoeal treatment	30.5
Laboratory confirmation tests	15
Loss of a dairy cow and its female calf	1 067
Loss of a beef cow and its female calf*	1 829
Profit per liter of milk	0.1525
Veterinary visit	30.5
(ii) Sub-clinically infected animals	
Price of a milk liter	0.335
Certification costs, per animal:	
ELISA test	7.9

* Six months old animal.

age at the first calving is about 3 years. Veal calves are slaughtered when they are 6 months old.

The unitary costs used to compute the disease and certification costs are given in Table II. In France, there is no market for adult cows, sold and purchased for breeding. Therefore, the animals culled because of paratuberculosis are replaced by the purchase of pregnant heifers, and the losses induced by the culling of a sick cow are thus estimated by the price of a pregnant heifer. For the average dairy herd, the losses induced by the culling of a female calf were estimated by half (50% of the calves being females) of the margin made on an 8-day old veal calf. For the average beef herd, since there is no market in France for young beef veal, the losses induced by the culling of the female calf were estimated by half the margin which would have been made on the animals at 6 months of age. The yearly probability for an introduced heifer to be infected (α) was estimated by the prevalence of excreting animals in the French cattle population. According to field data [12], this prevalence was estimated at 2.5% for dairy cattle as for beef cattle.

The efficacy of the two certification levels L1 and L2 (i.e. the risk of the reduction of purchasing an infected heifer if the animal comes from a herd that has the corresponding certification level) was estimated by the working group at 95% for the L1 level and at 99% for the L2 level.

Finally, the cost/benefit calculations were conducted assuming a discount rate equal to its value in France in 2000: 2.5%, with two different vendor margin: $\rho = 1$ (the vendor does not make any profit), and $\rho = 3$.

3. RESULTS

3.1. Disease costs

According to the epidemiological model, the total number of clinical cases over 15 years was predicted to be 54.8 in a mean dairy herd, and 15.9 in a mean beef herd. The number of sub-clinical cases (number of case-years) was predicted to be 74.4 in a mean dairy herd, and 22.8 in a mean beef herd.

Table III. Estimated disease costs in a mean French beef herd and in a mean French dairy herd.

Year	Mean French beef herd			Mean French dairy herd		
	Clinical cases[a]	Sub-clinical cases[a]	Disease costs (€)	Clinical cases[a]	Sub-clinical cases[a]	Disease costs (€)
1	0.00	0.00	0	0.00	0.00	0
2	0.00	0.00	0	0.40	0.60	1 052
3	0.40	0.60	762	0.27	0.13	585
4	0.32	0.16	615	0.68	1.11	1 839
5	0.00	0.13	0	0.86	0.89	2 086
6	0.55	0.92	1 043	1.40	2.03	3 658
7	0.82	0.88	1 569	2.05	2.53	5 143
8	0.34	0.45	649	2.90	3.88	7 407
9	0.77	1.46	1 473	4.00	5.20	10 156
10	1.59	2.05	3 031	5.11	6.74	13 028
11	1.27	1.56	2 424	6.21	8.25	15 843
12	1.42	2.46	2 697	7.07	9.53	18 112
13	2.59	3.76	4 932	7.66	10.53	19 709
14	2.91	3.84	5 538	8.02	11.23	20 724
15	2.90	4.49	5 519	8.21	11.71	21 318

[a] Number of animals.

The estimation of the yearly losses induced by a clinical case yielded a value of 1 940 € in a mean dairy herd, and of 1 905 € in a mean beef herd. In a mean dairy herd, the additional losses due to the sub-clinical cases were estimated at 461 € per case.

The combination of these losses with the predicted dynamics computed by the epidemiological model gives the evolution of the yearly disease costs (Tab. III). The results showed that, at the 15th year, the yearly disease costs were about four times higher in a mean French dairy herd than in a mean French beef herd.

3.2. Certification costs

According to the herd management parameters given in Table I, and neglecting the heifers which were culled before the first calving, the average age structure of the herd can be computed. Let V be the age of the heifers at the first calving (in years), A the maximal age of a cow (in years), ρ the yearly culling rate of the cows, and H the number of heifers which calve for the first time each year. At the beginning of each year, the total number N of animals that will calve during the year (cows and heifers calving for the first time) can be computed as follows:

$$N = \sum_{a=v}^{A-1} H(1-\rho)^{a-v} = H\frac{1-(1-\rho)^{A-V}}{\rho}. \quad (8)$$

Solving this equation for H gives:

$$H = \frac{\rho}{1-(1-\rho)^{A-V}}. \quad (9)$$

The number of α years old animal N_α is therefore:

$$N_\alpha = H \quad \text{if } \alpha \le V,$$
$$N_\alpha = H(1-\rho)^{\alpha - V} \quad \text{if } \alpha > V. \quad (10)$$

The number of > 24 months animals can then be computed and yielded 40 animals in the mean dairy herd, and 60.7 in the

Table IV. Estimated yearly certification costs (€) for a breeder who buys animals, in a mean French beef herd and in a mean French dairy herd, according to the certification level of the vendor (L1 or L2) and to the vendors margin.

		Mean French beef herd		Mean French dairy herd	
		L1	L2	L1	L2
Margin	1	36	67	26	38
	3	107	200	79	114

mean beef herd. Among these animals, 22.3 were on average less than 48 months old in the mean dairy herd, whereas this figure was of 21.5 in the mean beef herd.

Using these figures and the unitary certification costs (Tab. II), the evolution of the certification cost for the vendor can be computed. Because of the cyclic nature of the studied certification schemes, these costs, after a first high value for the first year, fluctuated every year between two fixed points.

In the mean beef herd, the cost of the L1 certification level was estimated at 510 € the first year, and would then vary between 216 € the even years, and 46 € the odd years. The cost of the L2 certification level was the same as for the L1 level except for the even years, during which it was estimated at 526 €.

Because of a lower herd size, the estimation yielded lower values for the mean dairy herd with, for the L1 certification level, 347 € the first year, 215 € the following even years, and 38 € the odd years. The cost of the L2 certification level was estimated at 354 €.

3.3. Cost/benefit analysis

The constant yearly certification cost for the breeder who buys animals (C_x in Eq. (2)) is computed from the herd management parameters (the number of animals sold every year by the vendor, and the number of animals bought every year by the buyer) and from the certification costs.

Because of higher vendor certification costs (the herd size being higher in an average beef herd than in an average dairy herd) and because of a higher ratio: the yearly number of heifers bought (by a mean buyer) over the number of heifers sold (by a mean vendor), the yearly buyer certification cost estimates were higher in the mean beef herd than in the mean dairy herd (Tab. IV). According to equation (2), the vendor margin acts as a simple multiplicative factor on these cost estimates.

Due to the greater number of animals a breeder purchases every year, the introduction risk rose more quickly and reached higher values in the mean beef herd (Tab. V) than in the mean dairy herd (Tab. VI): at the 15th year, the estimated probability for the disease to have been introduced if the breeder buys animals in non-certified herds reached more than 50% (53.21%) in the mean beef herd and about 30% (31.6%) in the mean dairy herd. The non-linear effects of the certification schemes were marked since the preceding estimated probability did not exceed 4% in the mean beef herd and 2% in the mean dairy herd for a breeder having bought during 15 years all the introduced heifers in a L1 certified herd (and, respectively, 1% and 0.5% for an L2 certified vendor).

Because the disease is predicted to spread more quickly in the mean dairy herd than in the mean beef herd, because the animal-level disease costs are higher in the former, and despite a greater reduction of the introduction risk in the mean beef herd, the estimated yearly benefits induced by the certification were almost 3 times higher

Table V. In a mean French beef herd, evolution of the estimated probability for the disease to have been introduced if the breeder buys animals in a non-certified herd (q_0), and, if the breeder buys animals in an L1 (respectively L2) certificated herd, estimates of the same probability q_1 (respectively q_2), of the buyer yearly benefits B_1 (respectively B_2) induced by the certification, and of the yearly difference NB_1 (respectively NB_2) between these benefits and the buyer costs induced by the certification (vendor margin: 1).

Year	q_0 (%)	L1 certification level			L2 certification level		
		q_1 (%)	B_1 (€)	NB_1 (€)	q_2(%)	B_2 (€)	NB_2 (€)
1	4.94	0.25	0	–36	0.05	0	–67
2	9.63	0.50	0	–36	0.10	0	–67
3	14.09	0.75	34	–2	0.15	35	–31
4	18.33	1.00	60	24	0.20	62	–4
5	22.37	1.24	58	23	0.25	61	–6
6	26.20	1.49	100	64	0.30	104	38
7	29.84	1.74	160	125	0.35	168	102
8	33.31	1.98	182	146	0.40	191	124
9	36.60	2.23	233	198	0.45	245	179
10	39.73	2.47	341	305	0.50	359	292
11	42.71	2.71	420	385	0.55	443	377
12	45.54	2.96	506	471	0.60	534	468
13	48.23	3.20	665	629	0.65	702	636
14	50.78	3.44	836	801	0.70	885	818
15	53.21	3.68	999	963	0.75	1.058	992

in the mean dairy herd than in the mean beef herd (Tabs. V and VI): assuming an L1 certified vendor, at the 15th year, these benefits reached around 1 000 € in the mean beef herd, and 2 800 € in the mean dairy herd.

Despite the fact that the L2 certification scheme efficacy was estimated to be greater than the efficacy of the L1 certification scheme, the former did not bring significant additional benefits and these estimated yearly benefits were roughly the same, whatever the certification level of the vendor (Tabs. V and VI).

The estimated certification costs were greater for the mean beef herd than for the mean dairy herd, and the certification benefit estimates were lower for the former than for the latter. Therefore, the yearly difference between the benefits and the costs was more favorable for the mean dairy herd than for the mean beef herd: from initially negative values, this difference was predicted to become positive from the 3rd year in the mean dairy herd, and only from the 6th year in the mean beef herd. At the 15th year, this difference was predicted to reach approximately 3 000 € in the mean dairy herd, and 1 000 € in the mean beef herd.

Finally, Figure 1 shows the time evolution of the estimated cumulated discounted difference between the certification benefits and its costs for the four studied scenarios: a vendor L1 or L2 certification level, and a vendor margin of 1 or 3. A clear distinction between the mean beef herd and the mean dairy herd was observed, the benefit – cost difference being always greater for the latter than for the former. Moreover, for each herd type, the effect of the vendor margin was stronger than the effect of the certification

Table VI. In a mean French dairy herd, evolution of the estimated probability for the disease to have been introduced if the breeder buys animals in a non-certified herd (q_0), and, if the breeder buys animals in an L1 (respectively L2) certificated herd, estimates of the same probability q_1 (respectively q_2), of the buyer yearly benefits B_1 (respectively B_2) induced by the certification, and of the yearly difference NB_1 (respectively NB_2) between these benefits and the buyer costs induced by the certification (vendor margin: 1).

Year	q_0 (%)	L1 certification level			L2 certification level		
		q_1 (%)	B_1 (€)	NB_1 (€)	q_2 (%)	B_2 (€)	NB_2 (€)
1	2.50	0.12	0	–26	0.02	0	–38
2	4.94	0.25	25	–2	0.05	26	–12
3	7.31	0.37	38	12	0.07	39	2
4	9.63	0.50	79	53	0.10	83	45
5	11.89	0.62	125	99	0.12	131	93
6	14.09	0.75	205	179	0.15	214	176
7	16.24	0.87	315	289	0.17	330	292
8	18.33	1 00	472	446	0.20	493	456
9	20.38	1.12	683	657	0.22	715	677
10	22.37	1.24	950	923	0.25	994	956
11	24.31	1.37	1 268	1 242	0.27	1 328	1 290
12	26.20	1.49	1 625	1 599	0.30	1 703	1 665
13	28.05	1.61	2 005	1 979	0.32	2 103	2 065
14	29.84	1.74	2 396	2 370	0.35	2 514	2 476
15	31.60	1.86	2 789	2 763	0.37	2 928	2 890

level. For example, for the mean dairy herd and for both studied vendor margins, the final difference values were roughly identical, whatever the certification level of the vendor.

The delay for the estimate of the discounted cumulated difference between benefits and costs to become positive is an interesting indicator. For the mean dairy herd, with a vendor margin of 1, its value was of 3 years with the L1 certification level (4 years with the L2 certification level). If the vendor margin was 3, the difference became positive after 6 years with the L1 certification level (7 years with the L2 certification level). For the mean beef herd, the delays were longer: with a margin of 1, it was of 5 years with the L1 certification level (7 years with the L2 certification level), whereas with a margin of 3, the delay reached 9 years with the L1 certification level (12 years with the L2 certification level).

4. DISCUSSION

The epidemiological model used to generate the intra-herd paratuberculosis dynamics [11] was designed to simulate the disease progression from a single initial introduction of a single infected heifer. This is obviously not the only possible introduction modality: more than one infected heifer could be bought by the breeder, and/or such an event could occur more than once. However, the probabilities associated to these modalities are powers of the probability for a bought heifer to be infected. Therefore, if the latter probability is low (as in this study), these alternative introduction modalities can be neglected.

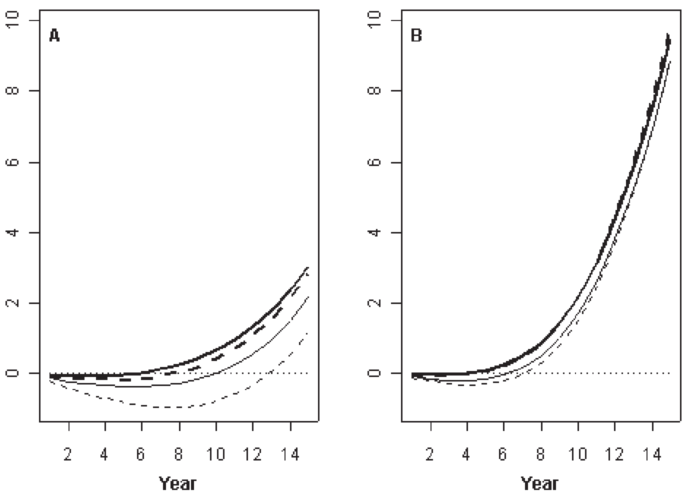

Figure 1. Evolution of the cumulated estimated discounted difference (× 1 000 €) between the certification benefit and its cost, in a mean French beef herd (A) and in a mean French dairy herd (B), with a vendor L1 (plain lines) and L2 (dashed lines) certification levels, and with a vendor margin of 1 (thick lines) and of 3 (thin lines).

A likely direct effect of a paratuberculosis certification scheme, if widely applied, would be a decrease in the disease prevalence. Our study was restricted to a herd-level analysis, and such a population-level effect could not be taken into account. The probability for a bought heifer to be infected would then decrease over time, and, as a consequence, the certification benefits would decrease.The epidemiological model used to generate the intra-herd paratuberculosis dynamics [11] was designed to simulate the disease progression from a single initial introduction of a single infected heifer. This is obviously not the only possible introduction modality: more than one infected heifer could be bought by the breeder, and/or such an event could occur more than once. However, the probabilities associated to these modalities are powers of the probability for a bought heifer to be infected. Therefore, if the latter probability is low (as in this study), these alternative introduction modalities can be neglected.

Despite the fact that, when the disease reaches a stable endemic state, the yearly incidence is predicted to be smaller in the mean beef herd than in the mean dairy herd [11], this difference was mainly due to the fact that, at the chosen time horizon (15 years), the disease had almost reached this endemic state in the mean dairy herd, whereas this was not the case in the mean beef herd, where the dynamics was predicted to be slower.

The cost/benefit analysis was conducted adopting the point of view of a breeder that buys animals. Therefore, the results were not valid for the vendor: in this case the benefits should integrate not only the avoided disease, but also the profits taken from the certified status of the sold animals.

If the vendor does not take any profit from its certified status (and applies a margin of 1), the results show that, for the mean dairy herd, it is relatively quickly (3 to

4 years) profitable to introduce only certified animals, whatever the vendor certification level. However, this no-profit scenario, considered as a baseline, is not very realistic and it seems possible that, on the contrary, certified vendors would like to take some profit from the certified status of the animals they sell. Assuming a corresponding margin of 3, the delays before it becomes profitable to introduce only certified animals are longer since for the mean dairy herd, they are roughly multiplied by two. Furthermore, in the mean beef herd, because of the slow progression of the disease, lower disease costs and greater certification costs, the delays were longer than for the mean dairy herd since, whatever the certification level and the vendor margin, it was not profitable to buy only certified animals before the 6th year (this delay reached a maximal value of 12 years with the L2 certification level and a vendor margin of 3).

Instead of the ELISA tests, several other laboratory methods could be used in the certification schemes, e.g. faecal culture or PCR. The effect of the laboratory test used (or of the test combinations used) on the delay for the certification to become profitable were studied (data not shown): because ELISA is the cheapest diagnostic method, the results were worse. However, other methods may have better intrinsic characteristics. For example, the specificity of faecal cultures is much better than the one of ELISA tests, and a lack of specificity would induce a greater number of false positive results with ELISA tests than with faecal cultures. Such false positive results would lead the corresponding vendors to lose their certification. The effect of diagnostic method specificity was not studied because the repercussion of the loss of certification on the price of certified animals cannot be easy estimated. However it seems reasonable to think that it would lead to an increase in the certification costs.

Finally, the main goal of this study was to produce a decision-making tool dedicated to the analysis of the costs and benefits of paratuberculosis certification schemes. Therefore, the economical model and the accompanying epidemiological model [11] should not be considered as general paratuberculosis models, but rather as decision-making dedicated models, the design of which has been strongly influenced by this goal. This study did not show that the use of certification schemes did bring important benefits. However, in the future, such a negative conclusion should be reappraised if the certifications costs decrease, for example thanks to the use of diagnostic tests on mixtures. Even though the whole study was dedicated to the French situation, the results should remain valid in other countries, if the production systems are similar. Finally, because the epidemiological and the economic models are relatively simple and have few parameters, they could also be adapted to other situations.

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Appendix

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