Association between product quality control and process quality control of bulk milk

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Abstract

Assessment of dairy-milk quality is based on product quality control (testing bulk-milk samples) and process quality control (auditing dairy farms). It is unknown whether process control improves product quality. To quantify possible association between product control and process control a statistical analysis was conducted. The analysis comprised 64.373 audit results on 26,953 dairy farms and all conducted lab tests of bulk-milk samples two, six or 12 months before the audit. Lab results included somatic cell count (SCC), total bacterial count (TBC), antimicrobial drug residues (ADR), level of butyric acid spores (BAS), freezing point depression (FPD), level of free fatty acid (FFA), and cleanliness of the milk (CLN). Results show that numerous audit variables are related to bulk-milk lab results, although the goodness of fit of the models is generally low. Cleanliness of cattle, berths, parlor and the tank room are positively correlated with superior product-quality, mainly with respect to SCC, TBC, BAS, FPD, FFA and CLN. Animal-health and/or veterinary medicine management relate to SCC, FPD, FFA, and CLN, the availability of drinking water to TBC, BAS, FFA, and CLN and maintenance of the milking equipment relates mainly to SCC, FPD, FFA. Summarizing, product quality control and process quality control of bulk milk are to some degree associated: if dairy farms are assessed negatively on specific audit aspects the bulk-milk quality is more likely to be inferior.

Keywords: bulk milk, quality, audit, certification scheme, monitoring

Introduction

Milk processing industries demand high-quality bulk milk from dairy producers. Bulk milk is routinely tested and milk-payment schemes are based on these lab results to stimulate high product quality. Moreover, to ensure first-class process-quality on dairy farms only certified farms are approved.

For the routine monitoring of bulk milk a sample from each bulk-milk delivery is taken and analyzed in the lab on composition and quality in the Netherlands. The analysis on the composition assesses fat, protein, lactose and urea levels. The analysis on quality includes somatic cell count (SCC), total bacterial count (TBC), antimicrobial drug residues (ADR), level of butyric acid spores (BAS), freezing point depression (FPD), level of free fatty acid (FFA), and cleanliness of milk (CLN). Tests frequency differs between quality aspects, ranging form every delivery (ADR), twice per month (SCC, TBC, FPD), once per month (BAS, CLN), to twice a year (FFA). The results accurately reveal product quality and provide an impression of hygiene management at farm level.

Payment schemes are an important incentive in controlling all bulk-milk quality parameters that are tested, such as SCC, TBC, ADR, BAS, FPD, FFA and CLN. Milk-payment schemes are also important motivators to enhance management practices on dairy farm, for example mastitis management (Valeeva et al., 2007) has been proven to be effective (Schukken et al., 1992). In the Netherlands the milk price is reduced with €0.25 to €0.38 per kg milk for the month if ADR are detected. A penalty is also issued of €0.005 per kg if SCC and FPD exceed the attention limit or if TBC exceeds its first attention limit. Moreover, the milk price is reduced with around €0.01 per kg if BAS, FFA or CLN exceed the attention limit or when TBC exceeds its second attention limit.

Other important tools for improving bulk-milk quality are quality-assurance programs or certification schemes for dairy farms. Such programs include rules and farm audits. By means of audits farms are assessed on numerous aspects using detailed checklists. The aspects include farm hygiene, veterinary medicine, animal health and welfare, milking equipment, parlor, tank room, feed and water management. Auditing these aspects is considered to be important to produce high quality milk at a defined performance (Herrick, 1993).

Also the aim of certification programs is to reach a defined performance of the product and process demanded by milk processing industries, and to make this perceptive to consumers. Furthermore, certification programs give farms a tangible approval of good practice and a tool for due diligence defense (Buzby and Frenzen, 1999, Henson and Holt, 2000). It proves that producers have taken all reasonable precautions and exercised all due diligence to avoid harm to another party. This means that if a farmer has implemented a good quality standard and all the requirements are followed in a right way and this can be proven by certification, it can be used as a defense of due diligence in liability law suits. The ‘approval of good practice’ distinguishes certification from the activities by national surveillance and control services, which do not go any further than evaluating if implemented systems fulfill the regulatory standards.

The certification schemes for dairy farms judge farm aspects that are possibly related to milk quality, animal health and animal welfare. It may motivate farmers to refine management procedures. Management practices used to improve milk quality involves multiple factors related to hygiene of the milking environment, hygiene of the environment in which cows are housed, hygiene of the milking equipment, udder hygiene and cow health.

Monitoring bulk milk (which is a product quality control tool) and certification schemes (which are process quality control tools) all aim to improve bulk milk quality. However, it is unknown whether the certification scheme relates to bulk milk quality. Therefore, the goal of this paper is to quantify the relation between milk quality criteria based on bulk milk lab results and the results of the farm audits performed for the quality assurance certification scheme.

Based on quantified relations the certification schemes can be improved and made more efficient so that (only) the relevant points are judged. Furthermore, milk quality information can be used as a prior to select the farms that should be controlled.

Material and Methods

Data was provided by Qlip NV, the Dutch organization that is responsible for the certification and auditing of dairy farms and that also tests all farm-milk deliveries to the processors on protein, fat, lactose, urea, SCC, TBC, ADR, BAS, FPD, FFA, and CLN. One dataset contained audit results of all dairy-farm audits and the other contained bulk-milk lab results of all farm-milk deliveries to the processors.

The merged data set included 64,373 farm audits conducted on 26,953 farms between January 2002 and April 2008 and summary statistics of all related lab results of the bulk-milk samples two, six or 12 months before the audit, which will be described later.

Farm audit data

Each farm-audit record included 271 binary checklist points (class variables) that indicate a possible deviation (indicated with one) from the desired farm situation (indicated with zero). These checklist points are distributed over 52 variable categories and are given in the left part of table 1. For example, within the variable category ‘Farm hygiene - Clothing’ two checklist points exist that have been scored 93 and 57 times as deviant during 64,373 farm audits, respectively. More precisely, only 0.23 percent of all farm audits had a deviation within the checklist points under the category ‘farm hygiene – clothing’.

Additionally, the dataset included 52 integer variables with the number of attention points given to a specific farm variable category where the baseline value is zero (right part of table 1). For example, in the variable category ‘Farm hygiene – Clothing’ 160 farm audits (or 0.25% of all audits) resulted in 1 to 50 penalty points. The maximum number of points given during a farm audit to this category is 8, whereas the mean number of points given over all farm audits is 0.01 with a standard deviation of 0.19 penalty points.

Next to the audit variables as listed in table 1, three other audit variables are included in the analysis to correct for auditor, audit type and audit result (i.e. approved, rejected, etc).

For most individual audit variables only for a small percentage of the 64,373 audits a deviation was observed (see the two '%Dev' columns in table 1), whereas 64.5% of farms have received at least on penalty points given by 'total number of points' at the bottom of table 1.

Table 1. Descriptive statistics of the checklist point variables and penalty point variables of 64,373 farm audits

	#	%	Class frequency in Checklist Points						%	Penalty Point frequency					
Variable category	class[1]	Dev[2]	1	2	3	4	5	>5	Dev	1-50	51-100	>100	Mean	Max[3]	SD[4]
Farm hygiene															
Clothing	2	0.23	93	57	-	-	-	-	0.25	160	0	0	0.01	8	0.19
Mangers	2	0.18	89	25	-	-	-	-	0.19	125	0	0	0.00	4	0.10
Vermin control	-	-	-	-	-	-	-	-	0.01	6	0	0	0.00	2	0.01
Storage	-	-	-	-	-	-	-	-	0.01	5	0	0	0.00	4	0.04
Others	1	4.02	2,586	-	-	-	-	-	4.65	2,992	0	0	0.10	50	0.61
Source water															
Quality insufficient	4	0.32	125	41	30	8	-	-	0.14	60	28	2	0.07	150	2.48
Quality others	4	0.64	321	90	2	1	-	-	-	-	-	-	-	-	-
Report	9	4.07	1,294	1,266	16	12	11	20	0.81	231	150	139	0.46	153	6.38
Veterinarian registration	5	2.06	1,218	100	5	2	2	-	0.02	11	0	0	0.00	6	0.05
Veterinary medicine															
Unregistered veterinarian	2	0.05	27	2	-	-	-	-	-	-	-	-	-	-	-
Invoice	2	0.76	480	9	-	-	-	-	0.11	74	0	0	0.00	1	0.03
In general	3	0.43	182	93	1	-	-	-	0.27	177	0	0	0.14	50	2.62
Labeling	2	4.02	1,875	716	-	-	-	-	0.87	560	0	0	0.01	3	0.16
Storage	7	6.76	1,424	1,336	1,315	248	23	5	4.45	2,867	0	0	0.06	7	0.33
Registration young stock	3	18.50	10,591	1,206	112	-	-	-	24.16	15,553	0	0	0.40	10	0.96
Registration dairy cows	4	8.54	4,783	597	109	8	-	-	-	-	-	-	-	-	-
Admission	7	2.07	734	497	58	41	4	1	1.99	1,279	0	0	0.05	7	0.39
Animal welfare															
Drinking water	2	0.27	171	4	-	-	-	-	-	-	-	-	-	-	-
Housing	4	0.45	170	64	44	14	-	-	0.38	242	0	0	0.01	8	0.20
Young stock	1	0.22	139	-	-	-	-	-	0.28	180	0	0	0.01	6	0.16
Dairy cattle	1	0.27	176	-	-	-	-	-	0.29	189	0	0	0.02	6	0.30
Not judged	2	9.87	3,856	2,499	-	-	-	-	-	-	-	-	-	-	-
Entrance	2	0.01	7	1	-	-	-	-	0.02	12	0	0	0.00	50	0.22
Cattle	1	0.06	40	-	-	-	-	-	0.08	49	0	0	0.00	11	0.18
Animal health															
Administration	7	9.65	5,319	277	273	206	92	44	10.17	6,549	0	0	0.16	12	0.61
Identification	2	3.13	1,984	33	-	-	-	-	3.64	2,340	0	0	0.05	6	0.30
Materials	1	0.16	101	-	-	-	-	-	0.17	108	0	0	0.01	5	0.20
Housing	-	-	-	-	-	-	-	-	0.02	16	0	0	0.00	3	0.05
Drinking water	-	-	-	-	-	-	-	-	0.03	20	0	0	0.00	1	0.02
Leptospirosis	-	-	-	-	-	-	-	-	0.01	4	0	0	0.00	50	0.39
Collection (truck)															
In general	-	-	-	-	-	-	-	-	2.47	1,587	0	0	0.05	11	0.36
Hygiene	4	0.37	137	62	34	6	-	-	-	-	-	-	-	-	-
Equipment	13	2.48	636	363	212	202	69	116	-	-	-	-	-	-	-
Milking administration	1	0.00	1	-	-	-	-	-	-	-	-	-	-	-	-
Milking equipment															
In general	3	0.24	125	14	13	-	-	-	-	-	-	-	-	-	-
Equipment	-	-	-	-	-	-	-	-	0.22	139	0	0	0.01	6	0.27
Hygiene	-	-	-	-	-	-	-	-	0.22	139	0	0	0.01	6	0.27
Maintenance	10	6.63	3,161	510	212	158	132	96	2.56	1,268	367	15	0.53	104	5.20
Others	2	1.15	739	2	-	-	-	-	0.00	2	0	0	0.00	3	0.02
Parlor															
Hygiene	16	6.56	1,463	833	484	483	213	744	6.52	4,198	0	0	0.18	50	0.82
Organization	20	9.12	2,596	849	671	634	340	783	8.54	5,497	0	0	0.16	12	0.58
Tank room															
Equipment	12	1.34	533	176	41	30	27	55	0.40	255	0	0	0.02	6	0.27
Hygiene	18	6.43	1,608	510	482	383	346	812	6.42	4,129	1	0	0.15	54	0.73
Organization	22	13.48	2,071	1,349	1,219	918	628	2,495	12.53	8,057	6	0	0.25	55	1.27
Others	2	0.10	52	11	-	-	-	-	0.02	11	0	0	0.00	3	0.04
Tank maintenance	7	2.63	1,576	41	34	29	10	5	1.67	823	251	0	0.33	51	3.98
Feed															
Purchase	7	3.61	1,124	958	205	13	13	10	0.96	615	5	0	0.28	100	3.65
Quality	-	-	-	-	-	-	-	-	0.03	21	0	0	0.00	5	0.07
Storage	4	2.26	1,416	39	2	1	-	-	2.80	1,804	0	0	0.04	4	0.25
Plant prot. products storage	-	-	-	-	-	-	-	-	0.01	4	0	0	0.00	2	0.02
Others	5	0.27	122	31	18	3	1	-	-	-	-	-	-	-	-
Total number of points									64.51	39,927	1,223	341	4.20	256	12.09

[1] '# class' indicates the number of check list points within a variable category; [2] '% dev' is the percentage of farm audits with a deviation within the variable category; [3] 'Max' is the maximum; [4] 'SD' is the standard deviation

Bulk-milk lab result data

The lab results included *SCC*, *TBC*, *ADR*, *BAS*, *FPD*, *FFA*, and *CLN*. For a time horizon of two, six or twelve months before each farm audit, all lab results were aggregated to a summary variable (figure 1).

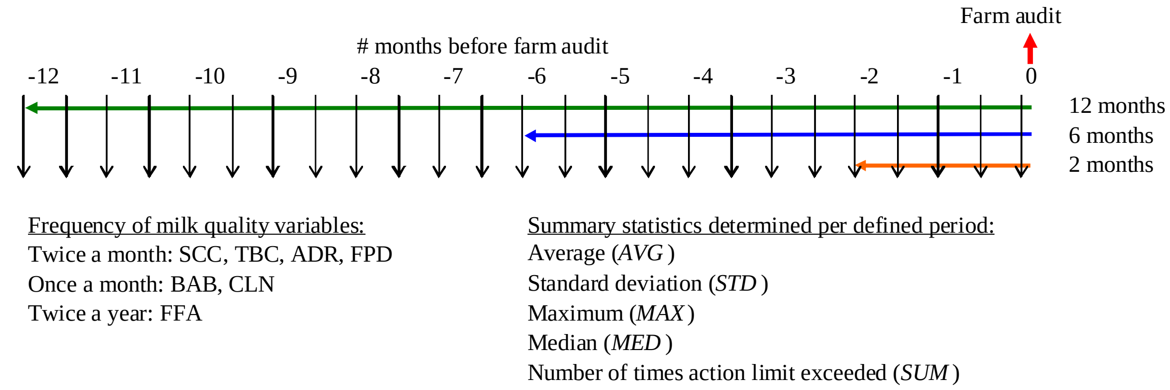

Figure 1. Schematic overview of how milk quality lab results were aggregated to a summary variable of the bulk milk lab results variables

For the quantitative lab results the average (*AVG*), standard deviation (*STD*), median (*MED*) and maximum (*MAX*) are calculated. For each nominal measurement (*ADR*, *BAS*, *CLN*) the number of lab results that exceed the attention level is counted (*SUM*). The various lab result variables cover the period between January 1st 2002 and April 1st 2008. Table 2 shows only the aggregated lab result variables of the seven models presented in this paper, although 60 models have been fitted in total. For example, the variable SCC12AVG represents the average of the SCC results of 24 tank milk samples delivered in 12 months previous to a farm audit. Hence, the minimum SCC12AVG was 19, the average 220, the maximum 1038 and the number of missing values is 14,385 (most of farm audits during the first months of 2002). In addition to the lab result variables as listed in table 2, the milk processing plant is included in the analysis to correct for its influence.

Table 2. Summary statistics of the lab result variables of bulk milk per audit.

Variable	**Min**	**Average**	**Max**	**Missing**
SCC12AVG[1]	19	220	1038	14385
TBC12AVG	0	10	999[2]	1969
ADR12SUM	0	0	16	1118
BAS12SUM	0	1	15	14963
FPD12AVG	333	521	547	5084
FFA12AVG	8	43	824	19271
CLN12SUM	0	0	8	2008

[1] First three characters represent a milk-quality criterion, the number in the middle the period in months prior to a farm audit, and the last three characters the summary statistic of lab results of the criterion during the defined period, where SCC represents somatic cell count (*1000 cells/ml), TBC total bacterial count (*1000 cfu/ml), ADR the presence of antimicrobial drug residues (# in period), BAS level of butyric acid bacteria (# in period), FPD freezing point depression (* -1/100°C), FFA level of free fatty acid (mmol/10.000gr fat), and CLN cleanliness of the milk (# in period) and where. AVG means average, STD standard deviation, MAX maximum, MED median, and SUM number of times that the attention limit is exceeded.
[2] The maximum is probably higher than 999 since the display had only three numbers.

SCC is tested twice a month. An increased SCC in bulk milk may be caused by cows with udder health problems, poor milking technique or malfunctioning equipment. The SCC test is done by adding a colorant to the milk and counting automatically the glowing cells under a microscope. A good SCC is below 150,000 cells per ml, whereas the attention level is 250,000.

TBC counts the total number of bacteria in the bulk milk and is a measure of hygiene during milking and storage of milk. An increased TBC can be caused by careless milking, inadequate cooling, cows with udder health problems, inadequate or no detergent, to cold cleaning water, insufficient turbulence during cleaning, blind corners not reached during cleaning, worn parts of the milking machine, etcetera. The number of bacterial colonies is automatically counted. Good-quality bulk milk has a TBC of 20,000 colony forming units (cfu) per ml, whereas the first attention level is 100,000 cfu per ml and the second 250,000.

ADR should not be detected in bulk milk. This can be prevented by keeping to the waiting period of antibiotics, a comprehensive veterinary administration, clear marking of treated animals, thoroughly rinsing the milking equipment that is used for treated animals and ensuring good working valves in the milk lines. The milk samples are examined with a growth inhibitor test for five groups of antibiotics: sulfonamides, beta-lactam residues (penicillin and cephalosporin), amino glycosides, macrolides, and tetracyclines. A positive test result implies a penalty to the farmer.

BAS is a measure for silage quality which is influenced by housing hygiene. The level of BAS (including other gas-forming bacteria in the milk) is determined by adding a growth medium to the milk which makes spores of butyric acid bacteria germinate after heating to 80°C. This results in gas formation that can be assessed after four days. Two tubes per sample are tested resulting in three possible outcomes: -/-, +/- and +/+. A good level of BAS is -/-, where the attention level is +/-.

FPD is an indicator for possible contamination of bulk milk with water. To reduce the risk FPD it is necessary to prevent water entering the milking lines during milking and cleaning. The freezing point of milk is within narrow limits, because it depends highly on the composition of blood that flows through the udder which is very constant. Little percent extra water in the milk thereby is detected directly.

FFA originates from lipolysis of milk fat: a high level of FFA makes the milk rancid. This can be prevented by a proper construction and operation of the milking installation (low-lying and descending milk lines, no air leaks or entry during pumping). Cows long in production or with short milk intervals can result in elevated levels. The level of FFA is determined with an infrared measurement. Bulk milk is valued well if the level of FFA is below 0.5 mmol per 100 gram of fat, whereas the attention level is 1.0 mmol per 100 gram fat.

CLN is a measure of cleanliness during milking. CLN is tested by sucking the milk through a filter of cotton wool which is then visually assessed on sediment. When contaminated with e.g. sand, hair, skin flakes or straw the CLN is classified as 1 or 2, where class 2 is the attention level. Clean milk is classified as class 1.

Statistical analysis

A multivariable regression analysis is used to test the relation between the dependent variable (i.e. a bulk-milk test-result variable) and predictor variables (i.e. the audit variables).

FPD variables are normally distributed and therefore the models for these variables are written as:

$$y = \beta_0 + \beta_1 \cdot x_1 + ... + \beta_p \cdot x_p + e \tag{1}$$

where, y is a specific bulk-milk test, i.e., FPD, β_0 the constant, β_1 the estimate of audit variable x_1, β_p the estimate of audit variable x_p, and e the error term.

Variables for SCC, TPC and FFA were not normally distributed. For SCC the natural logarithm was calculated. The models for the SCC variables are written as:

$$y = EXP(\beta_0 + \beta_1 \cdot x_1 + ... + \beta_p \cdot x_p + e) \tag{2}$$

For the TPC and FFA variables the tenth logarithm was calculated. These models are written as:

$$y = LOG(\beta_0 + \beta_1 \cdot x_1 + ... + \beta_p \cdot x_p + e) \quad (3)$$

Variables for ADR, BAS and CLN are counts and are therefore Poisson distributed. For these variables a logistic regression model has been fitted using the log-link function (hence referred to as *LogLink*). These models can be written as:

$$LN(E(y)) = \beta_0 + \beta_1 \cdot x_1 + ... + \beta_p \cdot x_p + e \quad (4)$$

First, all audit variables were tested in a univariable analyses and ranked based on their P-value. The audit variables with a P-value >0.25 were excluded for the multivariable analyses. Second, all selected audit variables were included in the model as ranked based on the P-value in the univariable analyses. Then, variables with highest P-values where P>0.05 were removed one by one until all variables in the model met the criterion of P-value<0.05 (backward procedure of GENSTAT, 11th edition).

Results

Based on the goodness of fit of the models (R^2 values for the models for FFA, FDP, SCC and TBC and the log likelihood ratios of the models for CLN, ADR and BAS) the models for the average values or sums of the 12 months period before a farm audit were chosen to be presented in this paper. Tables 3 and 4 show the final models for the selected quality variables: *LogLink(CLN12SUM), Log(FFA12AVG), LogLink(ADR12SUM), FPD12AVG, LN(SCC12AVG), LogLink(BAS12SUM),* and *LOG(TBC12AVG).* All models are presented in comparison to a farm that delivers milk to milk plant A, is judged by auditor A for a standard audit and is approved without any deviation (the so-called baseline situation).

Some audit variables did not have a significant relation with any of the lab results. If only looking to the checklist point variables, this was the case for the following eight variables, 'Farm hygiene – Storage', 'Source water – Quality others', 'Veterinary medicine – Unregistered veterinarian', 'Animal health – Housing', 'Milking administration', 'Milking equipment – In general', 'Milking equipment – Equipment', and 'Milking equipment – Hygiene'. These variables are not depicted in the result tables 4 and 5. Within the penalty point variables there are more audit variables not relating to any lab-result variable. On the other hand, there are three categories that relate to all lab result variables (i.e. 'Veterinary medicine – In general', 'Animal health – Administration', and 'Parlor hygiene') and there are three categories that relate to six out of seven lab result variables (i.e. Veterinary medicine – Storage', 'Veterinary medicine – Registration of young stock', and 'Animal welfare – Dairy cattle').

SCC

The final model for *LN(SCC12AVG)* includes a constant, the dairy plant, the auditor, audit type, audit result and the variables that are given in table 4. Farms where a second audit has been performed have increased levels of SCC. Also, disapproved farms have increased SCC levels and blocked farms (i.e. who are not allowed to deliver bulk milk) have the highest levels. In total 48 variables as listed in table 2 are significantly related to SCC numbers. The 15 most influential audit variables (i.e. where the expected value is most deviant from the baseline situation) for SCC are depicted in figure 1.

Table 4. Estimates of the normalized models for SCC, TBC, ADR and BAS

<table>
<tr><th></th><th colspan="2">LN(SCC12AVG)</th><th colspan="2">LOG(TBC12AVG)</th><th colspan="2">LogLink(ADR12SUM)</th><th colspan="2">LogLink(BAS12SUM)</th></tr>
<tr><th>Variables</th><th>C or P[1]</th><th>Estimate</th><th>C or P</th><th>Estimate</th><th>C or P</th><th>Estimate</th><th>C or P</th><th>Estimate</th></tr>
<tr><td>Constant</td><td></td><td>5.34 **</td><td></td><td>0.91 **</td><td></td><td>-2.83 **</td><td></td><td>-1.05 **</td></tr>
<tr><td>Farm hygiene</td><td></td><td></td><td></td><td></td><td></td><td></td><td></td><td></td></tr>
<tr><td>Clothing</td><td></td><td></td><td>P</td><td>0.02 **</td><td></td><td></td><td></td><td></td></tr>
<tr><td>Mangers</td><td>C 1|2[2]</td><td>0.12 **</td><td>P</td><td>0.05 **</td><td></td><td></td><td></td><td></td></tr>
<tr><td>Vermin control</td><td></td><td></td><td></td><td></td><td></td><td></td><td>P</td><td>0.71 **</td></tr>
<tr><td>Others</td><td></td><td></td><td>C 1|1</td><td>0.03 **</td><td>C</td><td>0.21 **</td><td>C 1|1</td><td>-0.12 **</td></tr>
<tr><td>Source water</td><td></td><td></td><td></td><td></td><td></td><td></td><td></td><td></td></tr>
<tr><td>Quality - insufficient</td><td></td><td></td><td></td><td></td><td></td><td></td><td>P</td><td>0.00 **</td></tr>
<tr><td>Report</td><td></td><td></td><td>C 2|9</td><td>-0.02| 0.02 **</td><td></td><td></td><td>C 1|9</td><td>-0.32 **</td></tr>
<tr><td>Veterinarian registration</td><td>C 1|5</td><td>-0.48 *</td><td></td><td></td><td></td><td></td><td></td><td></td></tr>
<tr><td>Veterinary medicine</td><td></td><td></td><td></td><td></td><td></td><td></td><td></td><td></td></tr>
<tr><td>Invoice</td><td></td><td></td><td>C 2|2</td><td>0.05| 0.27 **</td><td></td><td></td><td>P</td><td>0.34 **</td></tr>
<tr><td>In general</td><td>P</td><td>0.00 **</td><td>P</td><td>0.00 **</td><td>p</td><td>0.01 **</td><td>C 2|3</td><td>-0.63| 0.33 *,**</td></tr>
<tr><td>Labeling</td><td>P</td><td>0.02 *</td><td>C 1|2</td><td>0.04 **</td><td></td><td></td><td></td><td></td></tr>
<tr><td>Storage</td><td>C 3|7[3]</td><td>0.05| 0.14 **</td><td>C 4|7</td><td>0.04| 0.17 **</td><td></td><td></td><td>C 3|7</td><td>0.09| 0.33 *,**</td></tr>
<tr><td>Registration young stock</td><td></td><td></td><td>C 3|3</td><td>-0.11| 0.02 **</td><td>C 2|3</td><td>-0.42| 0.19 **</td><td>CP 2|3</td><td>-0.18| 0.03 **</td></tr>
<tr><td>Registration dairy cows</td><td>C 2|4</td><td>0.03| 0.07 **</td><td>C 2|4</td><td>0.02| 0.08 **</td><td>C 2|4</td><td>-1.68| 0.26 **</td><td></td><td></td></tr>
<tr><td>Admission</td><td></td><td></td><td></td><td></td><td></td><td></td><td>P</td><td>-0.03 **</td></tr>
<tr><td>Animal welfare</td><td></td><td></td><td></td><td></td><td></td><td></td><td></td><td></td></tr>
<tr><td>Drinking water</td><td>C 1|2</td><td>0.08 **</td><td>C 2|2</td><td>0.07| 0.51 **</td><td></td><td></td><td>C 2|2</td><td>0.31| 0.66 *,**</td></tr>
<tr><td>Housing</td><td>P</td><td>0.02 *</td><td>C 2|4</td><td>0.10| 0.24 **</td><td></td><td></td><td>C 2|4</td><td>0.28| 0.39 **</td></tr>
<tr><td>Young stock</td><td>P</td><td>0.04 **</td><td>P</td><td>0.04 **</td><td></td><td></td><td>P</td><td>0.12 **</td></tr>
<tr><td>Dairy cattle</td><td>C 1|1</td><td>0.11 **</td><td>P</td><td>0.02 **</td><td>C 1|1</td><td>-0.98 **</td><td>C 1|1</td><td>0.41 **</td></tr>
<tr><td>Not judged</td><td>C 2|2</td><td>0.04| 0.04 **</td><td></td><td></td><td></td><td></td><td>C 2|2</td><td>0.08| 0.14 **</td></tr>
<tr><td>Entrance</td><td></td><td></td><td></td><td></td><td></td><td></td><td></td><td></td></tr>
<tr><td>Cattle</td><td></td><td></td><td></td><td></td><td></td><td></td><td>P</td><td>0.08 **</td></tr>
<tr><td>Animal health</td><td></td><td></td><td></td><td></td><td></td><td></td><td></td><td></td></tr>
<tr><td>Administration</td><td>C 5|7</td><td>0.04| 0.18 *,**</td><td>C 3|7</td><td>-0.17| 0.07 **</td><td>CP 1|7</td><td>-2.39| 0.10 **</td><td>P</td><td>0.03 **</td></tr>
<tr><td>Identification</td><td>C 1|2</td><td>0.06 **</td><td>CP 1|2</td><td>-0.01| 0.06 *,**</td><td>P</td><td>0.13 **</td><td>P</td><td>-0.04 **</td></tr>
<tr><td>Materials</td><td></td><td></td><td></td><td></td><td></td><td></td><td>C 1|1</td><td>0.28 **</td></tr>
<tr><td>Drinking water</td><td></td><td></td><td></td><td></td><td></td><td></td><td></td><td></td></tr>
<tr><td>Leptospirosis</td><td></td><td></td><td>P</td><td>0.01 **</td><td></td><td></td><td></td><td></td></tr>
<tr><td>Collection (truck)</td><td></td><td></td><td></td><td></td><td></td><td></td><td></td><td></td></tr>
<tr><td>In general</td><td>P</td><td>0.02 **</td><td>P</td><td>-0.03 *</td><td></td><td></td><td></td><td></td></tr>
<tr><td>Hygiene</td><td></td><td></td><td>C 3|4</td><td>0.13| 0.22 **</td><td></td><td></td><td>C 2|4</td><td>0.19| 0.65 **</td></tr>
<tr><td>Equipment</td><td></td><td></td><td>C 7|13</td><td>-0.24| 0.19 **</td><td></td><td></td><td></td><td></td></tr>
<tr><td>Milking equipment</td><td></td><td></td><td></td><td></td><td></td><td></td><td></td><td></td></tr>
<tr><td>Maintenance</td><td>C 5|10</td><td>0.03| 0.21 *,**</td><td>C 6|10</td><td>0.06| 0.28 **</td><td></td><td></td><td></td><td></td></tr>
<tr><td>Others</td><td></td><td></td><td>CP 1|2</td><td>0.05| 0.16 **</td><td></td><td></td><td>C 1|2</td><td>-0.13 **</td></tr>
<tr><td>Parlor</td><td></td><td></td><td></td><td></td><td></td><td></td><td></td><td></td></tr>
<tr><td>Hygiene</td><td>C 3|16</td><td>0.04| 0.27 *,**</td><td>C 10|16</td><td>0.04| 0.26 *,**</td><td>P</td><td>0.05 **</td><td>P</td><td>0.04 **</td></tr>
<tr><td>Organization</td><td>C 4|20</td><td>0.03| 0.21 *,**</td><td>CP 13|20</td><td>-0.35| 0.21 *,**</td><td></td><td></td><td>P</td><td>0.04 **</td></tr>
<tr><td>Tank room</td><td></td><td></td><td></td><td></td><td></td><td></td><td></td><td></td></tr>
<tr><td>Equipment</td><td></td><td></td><td>C 5|12</td><td>0.05| 0.63 *,**</td><td></td><td></td><td></td><td></td></tr>
<tr><td>Hygiene</td><td>C 6|18</td><td>0.04| 0.06 **</td><td>C 12|18</td><td>0.06| 1.11 **</td><td></td><td></td><td>P</td><td>0.03 **</td></tr>
<tr><td>Organization</td><td>C 3|22</td><td>0.04| 0.10 **</td><td>C 14|22</td><td>0.02| 0.28 *,**</td><td></td><td></td><td></td><td></td></tr>
<tr><td>Others</td><td></td><td></td><td>P</td><td>0.09 **</td><td></td><td></td><td></td><td></td></tr>
<tr><td>Tank maintenance</td><td>C 1|7</td><td>0.04 **</td><td>C 2|7</td><td>0.03| 0.19 **</td><td></td><td></td><td>P</td><td>0.01 **</td></tr>
<tr><td>Feed</td><td></td><td></td><td></td><td></td><td></td><td></td><td></td><td></td></tr>
<tr><td>Purchase</td><td>C 1|7</td><td>-0.11 **</td><td>C 2|7</td><td>-0.03| 0.05 *,**</td><td></td><td></td><td></td><td></td></tr>
<tr><td>Quality</td><td>P</td><td>0.04 *</td><td>P</td><td>0.05 **</td><td></td><td></td><td>P</td><td>0.2 **</td></tr>
<tr><td>Storage</td><td>C 1|4</td><td>0.03 **</td><td>C 2|4</td><td>0.04| 0.19 **</td><td></td><td></td><td></td><td></td></tr>
<tr><td>Plant-prot.prod storage</td><td></td><td></td><td></td><td></td><td></td><td></td><td></td><td></td></tr>
<tr><td>Others</td><td></td><td></td><td>C 2|5</td><td>-0.17|-0.14 **</td><td></td><td></td><td></td><td></td></tr>
<tr><td>Total number of points</td><td></td><td></td><td>P</td><td>0 **</td><td>P</td><td>0 **</td><td></td><td></td></tr>
</table>

[1] C is checklist point variable and P is penalty point variable
[2] Number of classes that differ significantly from having 'no deviation' is given relatively to total number of deviant classes
[3] If more classes differ significantly from having 'no deviation' the minimum and maximum estimates are given. P<0.05 is indicated with * and P<0.001 with **. The standard errors of the estimates are not given due to space limitations.

Table 5. Estimates of the normalized models for SCC, BAS and TBC

	FPD12AVG		*Log(FFA12AVG)*		*LogLink(CLN12SUM)*	
Variables	C or P[1]	Estimate	C or P	Estimate	C[a] or P	Estimate[b]
Constant		518.18 **		3.67 **		-3.47 **
Farm hygiene						
Clothing					P	0.2 **
Mangers						
Vermin control						
Others			P	-0.01 **		
Source water						
Quality - insufficient			C 2|4[2,3]	-0.08|-0.06 *,**		
Report			C 1|9	-0.11 **		
Veterinarian registration						
Veterinary medicine						
Invoice			C 1|2	0.04 *		
In general	CP 2|3	-0.22|10.04 *	C 1|3	0.07 **	P	0.03 **
Labeling						
Storage	CP 2|7	-1.46|-0.64 *	CP 1|7	0.15| 0.20 *,**	C 2|7	0.33| 1.74 *,**
Registration - young stock	C 1|3	-0.12 *	C 1|3	-0.03 **	C 2|3	-1.43|-0.42 **
Registration - dairy cows	C 1|4	-0.22 *		-		
Admission	C 1|7	-0.61 *	C 3|7	-0.71|-0.04 **		
Animal welfare						
Drinking water			C 1|2	0.39 **	C 1|2	1.34 **
Housing	C 2|4	-3.91|-1.83 *,**	P	-0.01 *		
Young stock			C 1|1	0.09 **	C 1|1	1.79 **
Dairy cattle			C 1|1	0.13 **	P	0.17 **
Not judged			C 2|2	0.02| 0.03 **		
Entrance	P	-0.31 **				
Cattle	C 1|1	-2.86 **			P	0.21 **
Animal health						
Administration	C 2|7	-2.32|-0.22 **	C 1|7	0.21 **	P	0.15 **
Identification	C 1|2	-0.34 **				
Materials						
Drinking water					P	1.79 **
Leptospirosis			P	-0.01 *		
Collection (truck)						
In general						
Hygiene			P	0.02 **		
Equipment	C 1|13	-1.09 **	C 1|13	0.07 **		
Milking equipment						
Maintenance	C 2|10	-1.12|-0.56 **	C 5|10	0.04| 0.33 **	P	0.02 **
Others	C 1|2	0.5 *				
Parlor						
Hygiene	P	-0.09 **	C 7|16	-0.09| 0.47 **	P	0.07 **
Organization	C 3|20	-1.69|-0.41 **	C 8|20	-0.18| 0.44 *,**		
Tank room						
Equipment			C 2|12	0.10| 0.14 *,**		
Hygiene	P	-0.09 **	C 1|18	0.11 **		
Organization						
Others	C 1|2	-4.87 **	C 1|2	0.12 **		
Tank maintenance	C 1|7	-0.53 **	C 2|7	0.10| 0.21 *,**		
Feed						
Purchase			C 2|7	-0.05|-0.03 *,**		
Quality						
Storage	C	-8.38|-1.94 *,**	P	-0.01 *		
Plant protection products storage			P	0.24 **		
Others						
Total number of points	p	-0.01 **				

[1] C is checklist point variable and P is penalty point variable
[2] Number of classes that differ significantly from having 'no deviation' is given relatively to total number of deviant classes
[3] If more classes differ significantly from having 'no deviation' the minimum and maximum estimates are given. P<0.05 is indicated with * and P<0.001 with **. The standard errors of the estimates are not given due to space limitations.

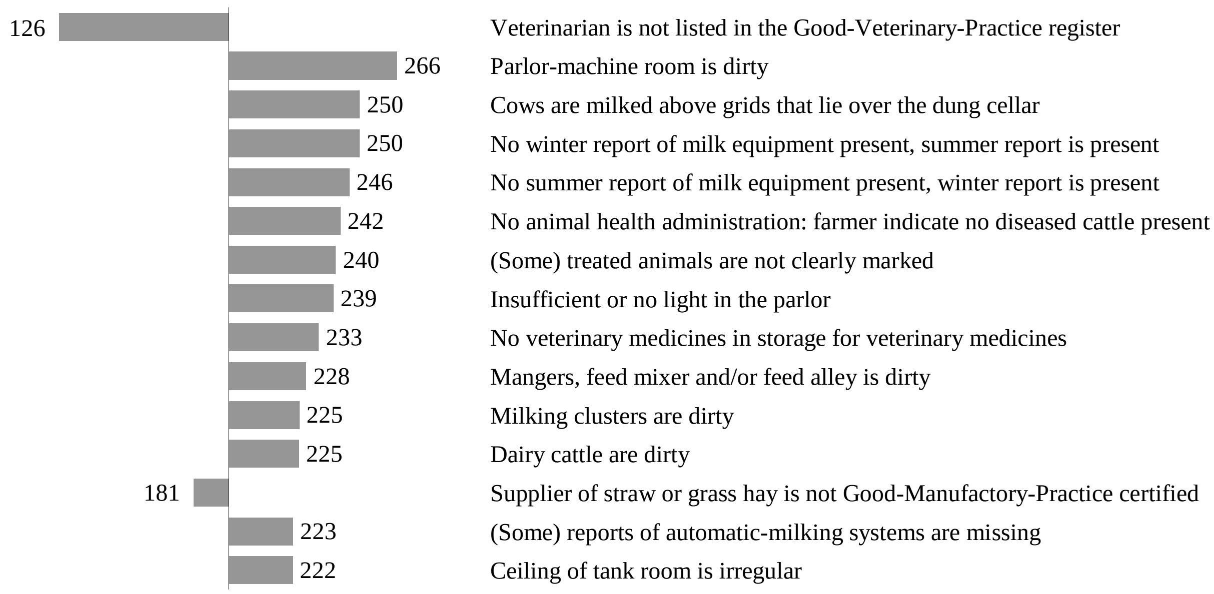

Figure 1. Most influential audit variables for SCC with expected values for each single deviation from standard. The expected value of SCC is 202 (*1000 cells/ml).

Results show that if the parlor, control room, mangers, feed mixer, feed alley, milking clusters or the dairy cows are dirty the SCC is increased. For example, if a farm has a dirty parlor (as a single deviation) it has an estimated SSC of 266,000 cells per ml.

Furthermore, if the maintenance of the (automatic) milking system is poor (reports are missing) the SCC is also increased. And if there are no veterinary medicines present and/or there is no animal health administration because the farmer thinks that there are no diseased animals the SCC is also increased. Two variables are related to a lower SCC level than the baseline level, namely the veterinarian is not listed in the Good-Veterinary-Practice register and that the supplier of straw is not 'Good-Manufactory-Practice' certified. The direction of the latter two estimates are not in line with common sense and are not plausible.

TBC

The final model for *LOG(TBC12AVG)* includes a constant, the auditor, audit type, audit result and the variables that are listed in table 4. In total 117 variables as listed in table 2 are significantly related with TBC. The 15 most influential ones are ranked in figure 2.

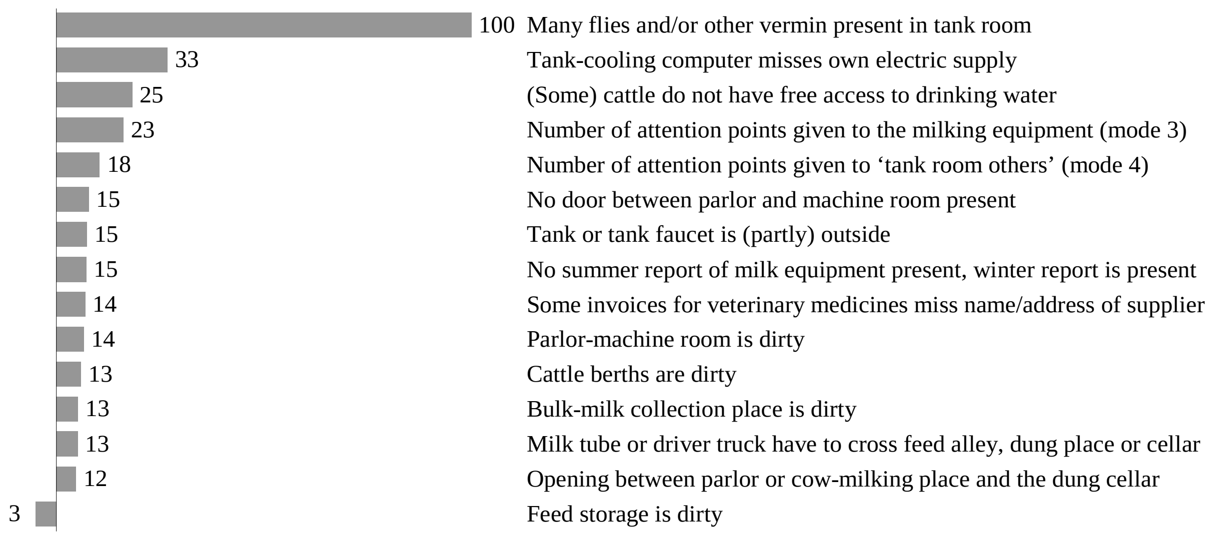

Figure 2. Most influential audit variables for TBC with expected values indicated for each single deviation from the standard. The expected value for TBC is 8.1 (*1000 cells/ml).

It can be concluded that if the tank room is managed poor (i.e. a lot of flies or vermin present, no own electric supply for the tank cooling computer or if the tank or its faucet is out side) the TBC is increased. For example, if there are many flies in the tank room the expected value for the average TBC in the 12 months before the audit is 10,000 cfu/ml (100 *100 cfu/ml). Also, if the milk equipment is managed poor or if the parlor-control room is dirty or has no door the TBC is increased. Moreover, the cattle management is also important: if cattle have no free access to drinking water, have dirty berths and if the feed storage is dirty the TBC is also increased.

ADR

The sum of ADR in the twelve months prior a farm audit, *Logit(ADR12SUM),* included the variables as listed in table 4, a constant, audit type and audit result. Higher values for *ADR12SUM* are related to an audit type 'an additional audit' and an audit result 'disapproved'. In total 12 variables as listed in table 2 related to the number of bulk milk deliveries tested positive for ADR in the twelve months prior a farm audit. These are ranked based on their effect in figure 3.

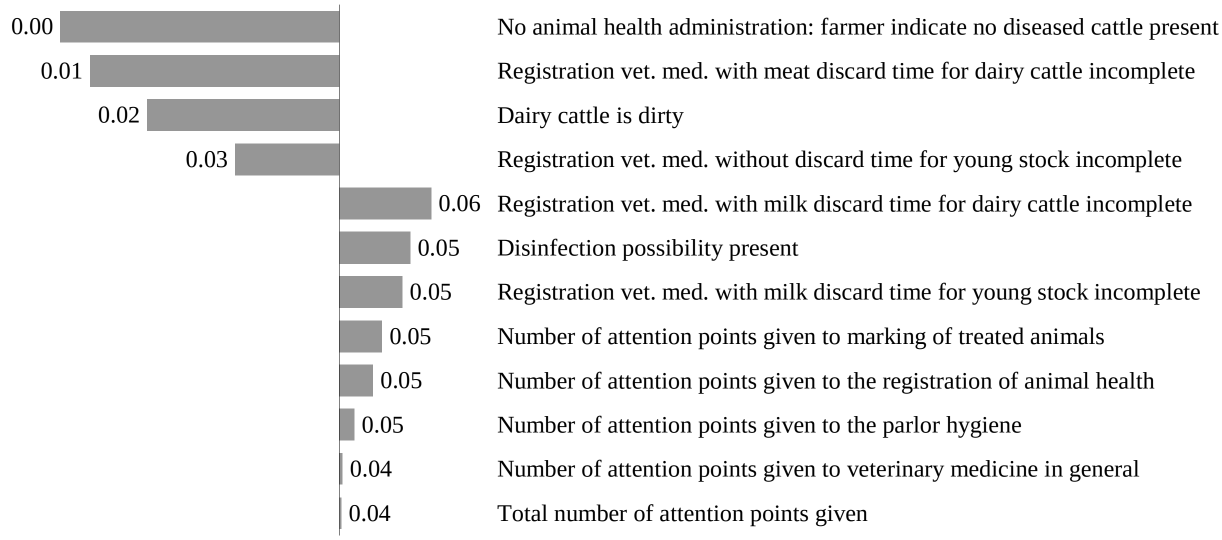

Figure 3. Most influential audit variables for ADR with expected values for each single deviation from the standard. The expected value for ADR is 0.04 times detected in 12 months.

A poor registration of veterinary medicines used for dairy cattle decreased the risk of ADR while registration of veterinary medicines for young stock increased the risk of having ADR in bulk milk. Furthermore a poor marking and registration of animal health increased the ADR risk too. If the farmer believed that there were no diseased animals and/or the cattle were dirty the risk of ADR in bulk milk was lower.

BAS

The final model for the number of times that BAS are found in bulk milk in 12 months before an audit, *Logit(BAS12SUM)*, includes a constant, audit type and the variables as given in table 4. Farms with a second audit have higher BAS levels. In total 35 variables as listed in table 2 are significantly related to the level of BAS. The 15 most influential variables are ranked in figure 4.

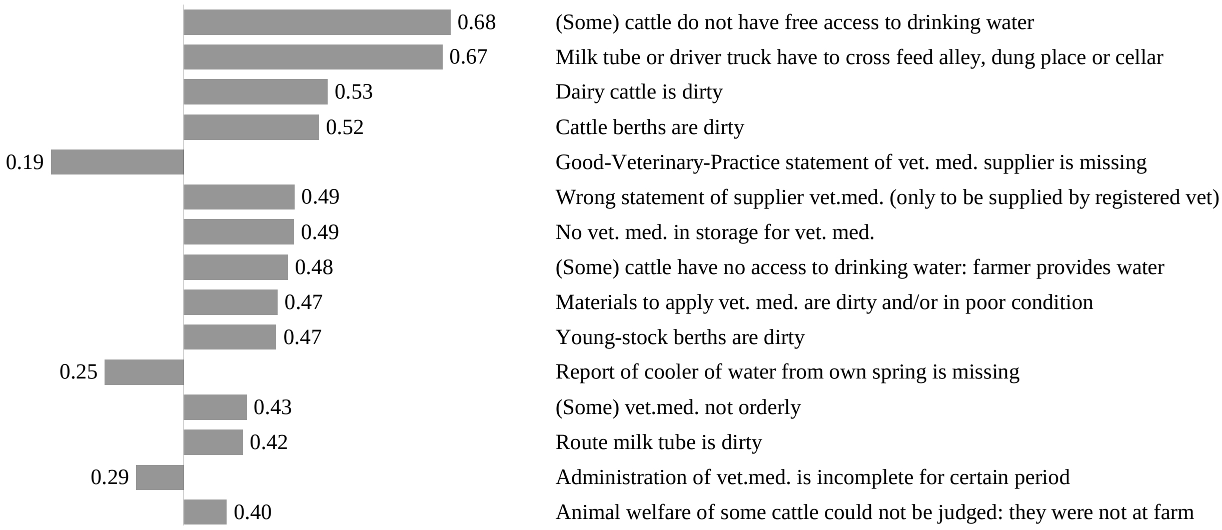

Figure 4. Most influential audit variables for BAS with expected values for each single deviation from the standard. The expected value for BAS is 0.35 times detected in 12 months.

It can be concluded that dirty dairy cattle, dirty cattle berths also for young stock, and no free access for cattle to drinking water increase the BAS levels. Also, if the milk tube is dirty or crosses a feed alley or a dung place or cellar the BAS levels are also increased. And if the management of veterinary medicine and application materials is poor the BAS levels are also increased, however the BAS level is decreased when the Good Veterinary Practice statement of the supplier is missing.

FPD

The final model for *FPD12AVG* includes a constant, the auditor, audit type, audit results and the variables that are listed in table 5. Some audit types are related to a lower FPD and others to a higher, whereas farms that are disapproved have a slightly lower FPD. In total 28 variables as listed in table 2 are significantly related to FPD. The 15 most influential variables are ranked in figure 5.

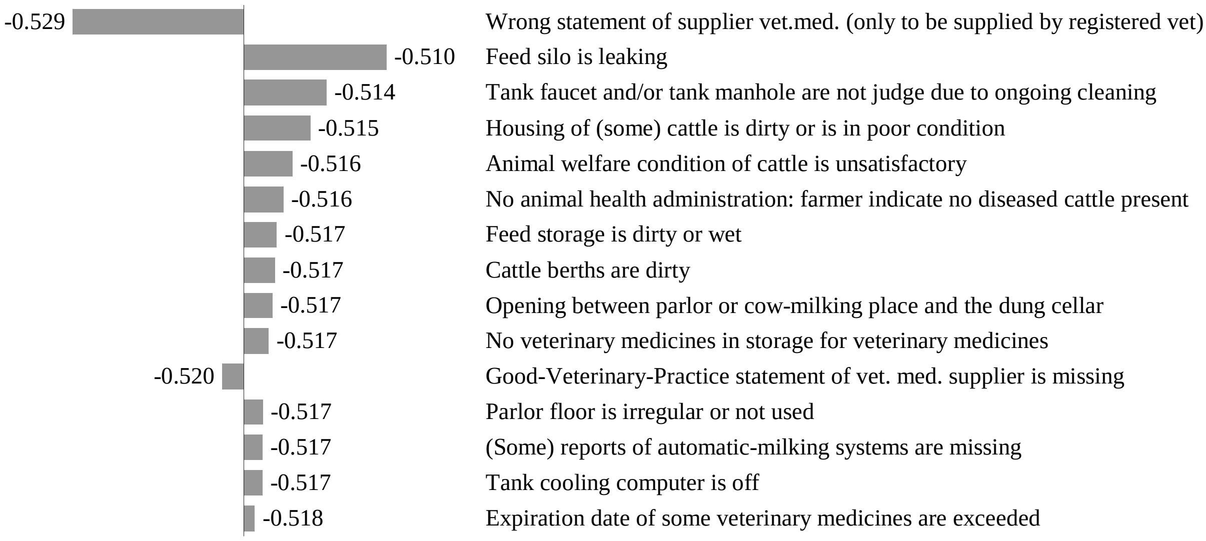

Figure 5. Most influential variables for FPD with the estimated values for each single deviation from the standard. The expected value for FPD is -0.518°C.

It can be concluded that a lot of different variables are related to an increase in freezing point. If the cattle welfare is managed poor, where the berths are dirty and the housing in poor condition and where the feed storage is dirty and wet the freezing point can be increased. Furthermore, if there are no veterinary medicines or if some medicines exceed the expiration date and/or the farmer indicates that there are no diseased animals present the freezing point is increased.

The freezing point of milk is related to various different judgment criteria varying from milk tank room to the storage of veterinary drugs.

FFA

The final model for *Log(FFA12AVG)* includes a constant, the auditor, audit type, audit result and variables listed in table 5. In total 54 variables other than the constant, auditors, audit types or audit results are related to the FFA level in bulk milk. The 15 most influential variables for the average level of FFA in the twelve months prior a farm audit are (with the expected value between parentheses):

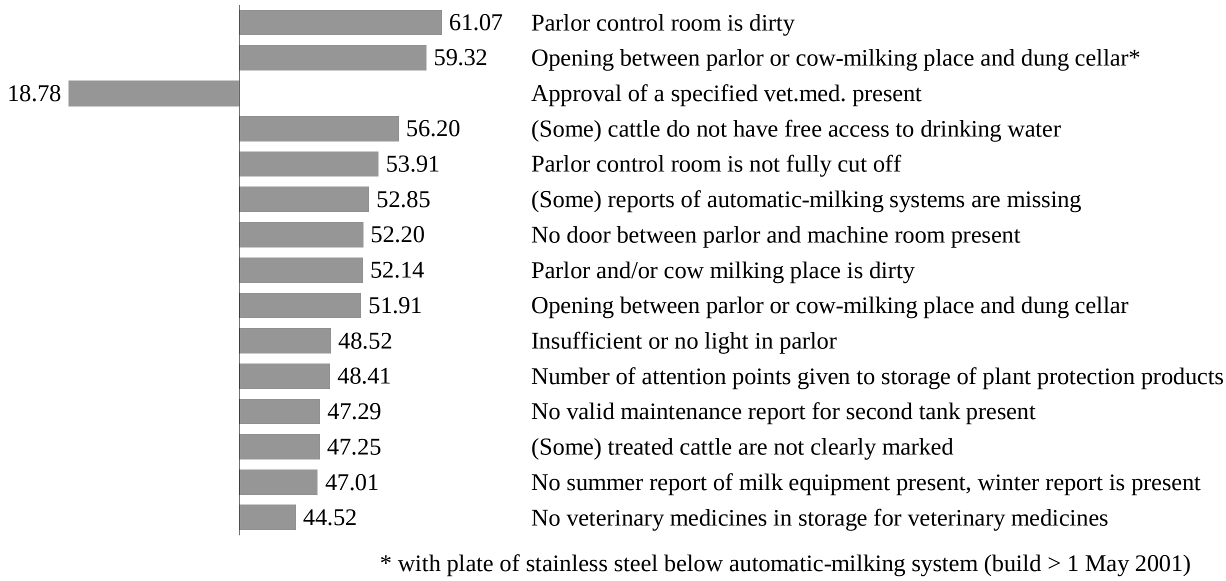

Figure 6. Most influential variables for FFA with the estimated values for each single deviation from the standard. The expected value for FFA is 38.17 (mmol/10,000gr fat).

Management (including the maintenance) and the building of the parlor and/or automatic milking systems were associated with inferior levels of FFA in bulk milk. Also, an increase in FFA levels is expected on farms where cattle do not have free access to drinking water and where treated animals are not clearly marked.

CLN

The final model for *Logit(CLN12SUM)* includes a constant, the audit result and variables listed in table 5. Farms that are disapproved have often exceeded the attention level for CLN. In total 14 variables as listed in table 2 were related to CLN. These are ranked based on their importance here, where the expected value for *CLN12SUM* is given between the parentheses:

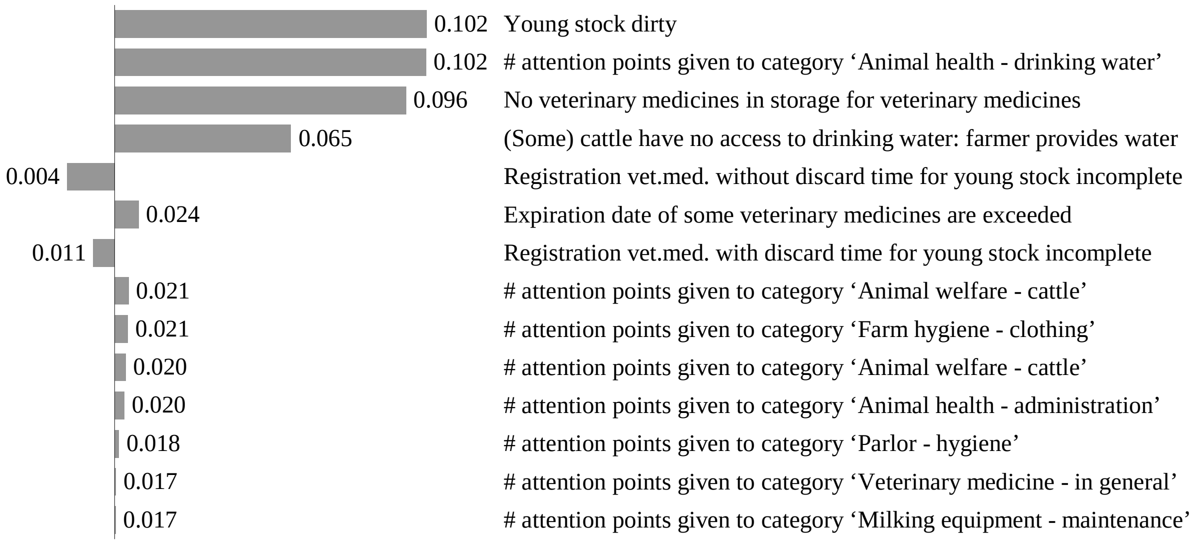

Figure 7. Most influential variables for CLN with the estimated values for each single deviation from the standard. The expected value for CLN is 0.017 times detected in 12 months.

It can be concluded that the cleanliness of bulk milk is worse if young stock is dirty, the drinking management is not adequate and when the veterinary medicines are poorly managed.

Discussion

To quantify the relation between product control and process control, test results of bulk-milk samples and audit results were compared. It was shown that numerous audit variables are significant associated with bulk-milk lab results. Cleaner cattle, berths, parlor and the tank room are associated with superior product-quality, mainly with respect to SCC, TBC, BAS, FPD, FFA and CLN. Animal-health and/or veterinary medicine management relate to SCC, FPD, FFA, and CLN, the availability of drinking water to TBC, BAS, FFA, and CLN and maintenance of the milking equipment relates mainly to SCC, FPD, and FFA.

The particular data set used was unique in that it contained extensive information on farm audits (271 checklist elements) as well as 7 different lab tests of bulk-milk samples. Moreover, the 6.5 years times series comprised 64,373 audit results on 26,953 dairy farms and all conducted lab tests of bulk-milk samples. Although the richness of the dataset it should be stressed that not all checklist estimates have the same robustness. In particular, estimates are non-robust to outliers for those with limited variation. However, for the majority of checklist elements sufficient variation was present enabling to estimate significant and robust associations.

The estimated associations did not prove that the observed differences in process-control quality, as assessed by means of audits, caused changes in the product-control test. Distinguishing causal from non-causal associations in epidemiological non-experimental data is by definition unattainable. A number of aspects of an association be considered in attempting to confirm causality (Hill, 1965), like strength and plausibility. Strength refers to the numerical strength of the correlation, and the high levels of correlations in this study are more convincing that a causal effect is at work. Plausibility refers to the scientific credibility of the relationship. In the current study, the direction of the majority of the significant estimates is in line with scientific knowledge that these checklist elements do affect the milk-quality test results in that way. However, violations have been observed. These anomalies mainly have been occurred as a result of limited observations for the categories with deviation from the desired farm situation.

The question that remains is what the criterion standard is for product quality. Because not all possible tests are conducted for all deliveries, the sample outcomes of these diagnostic tests or benchmarks cannot be regarded as the definitive quality standard. The results could also be interpreted in the context of the findings stemming from the farm audits. It should be recognized that the checklist elements in the evaluated audits are, in different degrees, subjective in nature. Although some of the elements are fact-based, the majority is subjective to the evaluator's perspective, opinion, or interpretation. The inherent bias of the evaluator's caused difference between this audited value and the true value of the parameter being estimated. Dummy variables are introduced in the model to correct for these phenomena.

Some audit variables are related to all lab-result variables, whereas some are related to none. Based on the results of this study the audit checklist might be reconsidered and more focused on product-quality. This might result in shorter audits and thus more efficient process control.

In a study to test whether dairy farmers that participate in a quality assurance program with certification adopt better strategies to mitigate the risk of ADR in bulk milk appeared to adopt only a few prudent drug-use practices. This, while in the quality assurance program special materials were developed to assist in the promotion of disease prevention, client communication, and residue prevention practices on farms ((Gibbons-Burgener et al., 2000)),

We conclude from the conducted data analysis that product quaility control and process quaility control of bulk milk are correlated. If dairy farms are assessed negatively on specific audit aspects the bulk-milk quality is more likely to be inferior. However, the proportion of the total variance in bulk-milk test explained by audits ranged between 5% and 10%, depending on the specific bulk-milk test examined. Thus auditing dairy farms provides additional information on the performance of product-quality and process-quality.

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