Impact matrix analysis and cost-benefit calculations to improve management practices regarding health status in organic dairy farming

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- Deliverable -

D9.5 – Normative simulation models for the economic evaluation of therapies in broiler and pig farms

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Executive Summary

This document provides a description of normative simulation models for broiler and pig farms that can be used to simulate the economic impact of infection diseases. The models can simulate various infections, diagnostic protocols and treatments. The models were demonstrated on infectious diseases in broilers and fattening pigs that cause growth impairment or increase mortality. These simulations give an indication of the economic importance of the cure rate that treatments have for these infectious diseases and how much financial gain could potentially be achieved by improving diagnostic procedures. Improved diagnostics may also be useful for the reduction of the use of antibiotics. As infections can be diagnosed earlier less animals may be infected which may reduce the amount of antibiotics required to treat animals or increase to possibilities to use alternative treatments. The results of the simulations indicate that earlier diagnosis and hence earlier start of treatment will increase the potential of treatments or strategies to deal with an infection. The findings of our study indicate that improved diagnostics will increase labour income of broiler and fattening pig farms, which means that there is financial room to improve diagnostics. Furthermore the simulations give an indication of the financial effect (i.e. changes in costs like death animals and revenues delivered live weight resulting in changes in the labour income of the farm) of various cure rates, which is useful in comparing treatment with antibiotics with alternative treatments.

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1 Introduction

In poultry gastro-intestinal infections are common diseases. These infections cause a lower growth, a reduced feed intake, lower feed conversion rate and higher mortality (Remus et al., 2014). Therefore infectious diseases cause economic losses by lower meat production, higher feed costs and higher health care costs. There is not much known on the financial consequences of these infectious diseases. Some studies on the costs of coccidiosis and respiratory infections with *M. gallisepticum* have been published (Foster, 1949, Williams, 1999, Bennett et al., 2013). However these studies use economic models that are either limited to a specific pathogen and disease or are old. For fattening pigs respiratory infections are a common disease (Straw et al., 2006). These infections can cause some form of pneumonia which is in general treated with antibiotics (Straw et al., 2006). On Dutch broiler farms the reasons for treatment were digestive diseases (33%), respiratory diseases (25%), locomotive diseases (32%) and first week problems (18%) in 2014 (Animal Health Service, 2015).

The use of antibiotics in livestock farming is associated with the occurrence of antimicrobial resistance. Pathogens resistant to antimicrobial drugs can cause health threats in both veterinary and human medicine (ECDC/EFSA/EMA, 2015). The general policy is to reduce the amount of antibiotics used in order to reduce the risk on antimicrobial resistance. This policy increases the interest in alternative treatments and preventive measures. In work package 9 the IMPRO project aims to elucidate the effectiveness and appropriateness of alternative remedies as an integrated part of operational management on livestock farms. Within this goal the efficacy of alternative treatments is important. Farmers will only adopt alternative treatments voluntarily if these treatments have a clear benefit for instance in terms of costs and efficacy. Another factor is the use of proper diagnostics for infectious disease. A correctly diagnosed infection can be treated both appropriately and timely. There might be potential to reduce the use of antibiotics and especially broad spectrum antibiotics when an infectious disease is diagnosed correctly at an early stage. At an early stage the number of infected and the number of severely ill animals shall be lower than on a later stage of the infection. Furthermore at an early stage of the infection the farmer could use alternative measures more effectively, for instance by adjusting the provided feed or the ventilation system. For application in practice it is important to know how effective alternative treatments and alternative measures are in reducing disease and what their financial effect will be. The financial effects of treatments comprises of all changes in costs (e.g. treatment costs or number of death animals) and revenues (e.g. amount of delivered live weight), which ultimately affects the labour income of a farm.

Residues of antibiotics are not allowed to be present in animal products that are sold for human consumption. This requirement prohibits the use of antibiotics shortly before slaughter of fattening pigs and broilers and in laying hens altogether. As a consequence, of this practice the use of antibiotics is low in laying hens but substantial in broilers (Animal Health Service, 2015) and fattening pigs. Therefore, the health management on broiler and fattening pig farms is important to control infectious disease and by consequence the use of antibiotics. Management practices that can be used to control infectious disease regard themes like: farm hygiene, housing conditions and feeding. Another important factor is the diagnostics of diseases. When animals get infected, an early diagnosis will enable a farmer and his vet to control the infectious disease and prevent it from spreading over the farm. So, fast and accurate diagnostic procedures may help to reduce the number of sick animals, the cost disease and use of antibiotics compared to current practice. For adoption in practice it is important to know what the financial consequences of improving diagnostics are. Farmers might be willing to adopt practice that could save them costs or increase

their revenues. As much is still unknown about the value of diagnostics and the cost of disease it is important to gain insight in these matters.

The aim was to develop normative simulation models that can be used to analyse the costs of infectious diseases on poultry and pig farms, the financial effect of treatment effectiveness and illustrate the potential benefits of improved diagnostic procedures in terms of financial gains.

2 Part A: Value of diagnostic methods on broiler farms

2.1 Material and methods

2.1.1 Normative simulation models

For the evaluation of diagnostics, treatment efficacy and estimation of the costs of infectious disease in broiler farms normative simulations models were developed. Each model simulates one production round on the farm from arrival of the animals on the farm until the moment the animals are sold for slaughter. The models simulate the weight gain of an average animal during the round. Two scenarios were simulated for broiler farms. First an infection with coccidiosis is simulated, which causes a decrease in weight gain (simulation of a parasitic infection). A coccidiosis infection imposes a risk on a secondary infection with necrotic enteritis which additionally increases mortality (simulation of a bacterial infection).

Infection dynamics were modelled with a Reed-Frost model, Formula 1. For each day the chance of an animal to become infected (Pi_t) was estimated based on the number of infected animals in the previous period ($Infected_{t-1}$), the total number of animals in the previous period (N_{t-1}) and the transmission rate parameter (β). The number of infected animals in period t was simulated with a binomial distribution using N_t trials and Pi_t as probability.

$$Infected_t = Binomial(N_t, Pi_t = 1 - e^{-\frac{\beta * Infected_{t-1}}{N_{t-1}}}) \quad (1)$$

2.1.2 Broiler model

The total revenues (TRE) of broiler farms were calculated by Formula 2 and consisted of the total amount of meat delivered (WD in kg of live weight) times the price received (SPB in € per kg of live weight). The total amount of delivered meat was estimated by the number of delivered broilers, which is the number of purchased broilers minus the mortality and the delivery weight of an individual bird.

$$TRE = WD * SPB \quad (2)$$

The total costs (TCO) were calculated by Formula 3. The TCO consisted of the costs for purchased broilers ($Cost_{purchase}$), costs for feed ($Cost_{feed}$), costs for health care ($Cost_{health}$), costs of buildings ($Cost_{buildings}$), costs of the interest rate of livestock ($Cost_{irl}$), delivery costs ($Cost_{delivery}$), costs for water, heating and electricity ($Cost_{whe}$), general costs and manure disposal ($Cost_{gm}$), costs for litter ($Cost_{litter}$), costs due to mortality ($Cost_{mortality}$) and costs for labour ($Cost_{labour}$).

$$TCO = Cost_{purchase} + Cost_{feed} + Cost_{health} + Cost_{buildings} + Cost_{irl} + Cost_{delivery} + Cost_{whe} + Cost_{gm} + Cost_{litter} + Cost_{mortality} + Cost_{labour} \quad (3)$$

The number of broilers on day *t* in health class s was estimated by Formula 4, as the result of transition from one health class (*s*) to the other and mortality within these health classes.

$$Broiler_{t,s} = Broiler_{t=0} + \sum_{0-t}(Trans_{in} - Mort_{s} - Trans_{out}) \quad (4)$$

The cumulative feed costs over the growth period were estimated by Formula 5. This included the feed consumed by uninfected, infected and dead broilers.

$$Cost_{feed} = PF * \sum_{t0-41} WG_{t,s=unifected} * Broiler_{s=unifected} * FCR_{i=uninfected} + WG_{t,s=ifected} * Broiler_{s=unifected} * FCR_{i=infected} \quad (5)$$

Formula 6 describes the weight gain function used to estimate the weight gain of an average bird on day *t* in health class *s*.

$$WG_{t,s} = a_{s} * day_{t}^{2} + b_{s} * day_{t} + c_{s} \quad (6)$$

The weight gain function was estimated based on the optimal curve of ROS-308 Broilers and was adjusted to reach a slaughter weight of 2.3 kg (Vermeij, 2014) at 42 days of age. With the ROS data a daily FCR was estimated for healthy birds. For sick animals an adjustment factor was estimated (1.0892) based on the average FCR over a growth period of healthy birds 1.56 and birds infected with pooled *Eimeria* species 1.710 (Kipper et al., 2013).

The cumulative delivered weight at slaughtering of both uninfected and infected broilers were estimated by Formula 7.

$$WD = \sum_{t0-41} WG_{t,s=uninfected} * Broiler_{s=uninfected} + WG_{t,s=infected} * Broiler_{s=uninfected} \quad (7)$$

Health care costs were estimated by using formula 8.

$$Cost_{health} = Broiler_{t=42,s=both} * HC + AB * PAD \quad (8)$$

The costs for the buildings were estimated by Formula 9. The annual costs of the building (depreciated annual replacement value, annual interest paid and annual maintenance) were allocated to the rounds per year and the number of broilers that could be housed within the building.

$$Cost_{buildings} = (\frac{RVBI * FS}{N/R} * DPB) + (\frac{RVBI * FS}{N/R} * \frac{NIR}{2}) + (\frac{RVBI * FS}{N/R} * MB) \quad (9)$$

The average investment in a delivered broiler was estimated by Formula 10. This includes the purchased value, meat value, delivery costs and the building costs.

$$AIB = PP + ((WD * SPB) - DC - Cost_{building} / DLBroiler) / 2 \quad (10)$$

The costs of interest rate of livestock were estimated by Formula 11.

$$Cost_{irl} = NIRcor * AIB * Broiler_{t=42,s=both} \quad (11)$$

Delivery costs were estimated by Formula 12.

$$Cost_{delivery} = Broiler_{t=42,s=both} * DC \quad (12)$$

Costs of water, heating and electricity were estimated by Formula 13.

$$Cost_{whe} = Broiler_{t=42,s=both} * WHE \quad (13)$$

General and manure costs were estimated by Formula 14.

$$Cost_{gm} = Broiler_{t=42,s=both} * GMC \quad (14)$$

Costs for litter were estimated by Formula 15.

$$Cost_{litter} = Broiler_{t=42,s=both} * L \quad (15)$$

The number of delivered broilers was estimated by Formula 16. The number of broilers at t=0 was assumed to be uninfected, from this number of broilers, the broilers that died during the growth period was subtracted.

$$DLbroiler = Broiler_{t=0,s=uninfected} - (MORT_{uninfected} + MORT_{infected}) = Broiler_{t=0,s=uninfected} - (\quad (16)$$
$$\sum_{t=0-42}(Binomial(P_{uninfected}, n = Broiler_{t,s=uninfected}))$$
$$+ \sum_{t=0-42}(Binomial(P_{infected}, n = Broiler_{t,s=infected})))$$

The costs of mortality were estimated by Formula 17. The costs of purchase, feed, health care, interest, water heating and electricity, manure and general costs and litter were included.

$$Cost_{mortality} = (MORT_{uninfected} + MORT_{infected}) * PP + \quad (17)$$
$$\frac{Cost_{feed} + Cost_{health} + Cost_{irl} + Cost_{whe} + Cost_{gm} + Cost_{litter}}{Broiler_{t=42,s=both}} \Big/ 2 * (MORT_{uninfected} + MORT_{infec}$$

The labour costs per round were estimated by Formula 18.

$$Cost_{labour} = LP * LH * PL \quad (18)$$

The amount of antibiotics used per production round was estimated by Formula 19.

$$AB = \sum_{t=0=41} (Broiler_{t,s=\inf ected} + Broiler_{t,s=un\inf ected}) * Doses * Treatdays \quad (19)$$

In Table 1 the input parameters for the normative simulation models are summarised. Inputs were based on literature, expert opinion (a veterinarian specialised in poultry was consulted) of the expertise of the authors of this report.

Table 1: Input parameters for the broiler simulation model, with their respective units and references.

Input parameter	Abbreviation	Value	Unit	Reference
Farm characteristics				
Number of broilers on day t=0 in health class s=uninfected	$Broiler_{t=0,s=un\inf ected}$	25,000	Broilers	Expert opinion
Number of broilers on day t=0 in health class s=infected	$Broiler_{t=0,s=\inf ected}$	0	Broilers	Authors
Feed conversion ratio	$FCR_{i=un\inf ected}$	1.57	kg feed/kg growth	(Kipper et al., 2013)
	$FCR_{i=\inf ected}$	1.71	kg feed/kg growth	(Kipper et al., 2013)
Parameters weight gain function				
Uninfected				Based on the curve of ROS
a		-0.04673	-	
b		3.824468	-	
c		0	-	
Infected				Estimated to have 10% lower growth
a		-0.04205	-	
b		3.442022	-	
c		0	-	
Barn inputs				
Replacement value of buildings and inventory	$RVBI$	300	€/m^2	
Farm size	FS	25,000	Broilers	Expert opinion

Number of broilers per m^2	N	42	Broilers/m^2	Expert opinion
Rounds	R	7.02	Rounds/year	
Depreciation of buildings	DPB	5	%/year	Authors
Nominal interest rate	NIR	5	%	Authors
Maintenance costs of buildings	MB	1.5	€/year	Authors
Length of growth period	LGP	41	days	(Vermeij, 2014)
Corrected nominal interest rate	$NIRcor$	3.34	% (=NIR/(365/LGP))	Authors
Infection characteristics				
Mortality chance	$P_{Infected}$ $P_{Uninfected}$	10 3.5 (35% of this mortality occurs in the first week)	%	Expert opinion
Labour and treatment				
Labour hours	LH	2,300	Hours/year	Authors
Labour	LP	0.6	Full time equivalent	Authors
Number of doses of antibiotics used	$Doses$	1	Number per treatment day	Authors
Length of treatment	$Treatdays$	6	Days/treatment	Authors
Prices				
Sales price of broiler	SPB	0.835	€ / kg of live weight	(Vermeij, 2014)
Feed price	PF	31.5	€ / 100 kg	(Vermeij, 2014)
Health care	HC	0.05	€ / delivered broiler	Authors
Antibiotics price	PAD	0.05	€ / doses	Authors
Delivery cost	DC	0.045	€ / delivered broiler	(Vermeij, 2014)
Waste, heating and electricity costs	WHE	0.1	€ / delivered broiler	(Vermeij, 2014)
General costs and manure disposal	GMC	0.022	€ / delivered broiler	Authors
Litter costs	L	0.01	€ / delivered broiler	(Vermeij, 2014)
Purchase price	PP	0.265	€ / broiler	Authors
Labour price	PL	18	€ / hour	

2.1.3 Simulation scenarios

The broiler model was used to simulate two types of infectious diseases a gastro-intestinal parasite (like coccidiosis) and a bacterial infection (like necrotic enteritis). The parasite was assumed to decrease the daily growth curve with 10%, whereas the bacterium was assumed to also increase mortality by 10%. Infections were assumed to first occur within the second (40%) and third (60%) week of the growth period, with regard to possible treatments. It was assumed that after detection

treatment would be started immediately. Incubation effects were assumed for growth impairment, increased mortality and treatment effect. For growth impairment, the effect assumed to be at 50% of the total impairment between day 0-3 after infection and at 100% from day 4 onwards. For increased mortality, the effect was assumed to be at 35% of the total mortality increase between day 3-5 after infection, 55% between day 5-7 and at 100% from day 7 onwards. For treatment, the effect was assumed to be at 0% of the total cure rate between day 0-1 after infection, 10% between day 1-3, 50% between day 3-5 and at 100% from day 5 onwards.

To evaluate the merit of improved diagnosis three moments of diagnosis where defined. Early diagnosis enabled a start of treatment at 7 days after the first broiler was infected, intermediate and late were 14 and 21 days after the first infection, respectively. The type of disease and treatment may influence the effect that an improved diagnostic method has. Therefore three transmission rates (β) and cure rates (i.e. probability that an infected animal is cured by the treatment) were evaluated in combination with the moments of diagnosis. In Table 2 the various settings are described. Twenty-seven simulations were conducted for both the parasite and the bacterial infection in order to use all possible combinations of settings for moment of diagnosis, transmission factor and cure rate. In general, model convergence was reached within 4,000 iteration, to be on the safe side, in each simulation 10,000 iterations were conducted. All simulations were conducted in Microsoft Excel® with the add-in software @Risk® for Excel (Pallisade Decision Tools, 2010).

Table 2: Simulation settings for moment of diagnosis, transmission factor and cure rate of the treatment in the broiler simulation model.

	Start of treatment	Transmission factor (β)	Cure rate of treatment
Low	7 days	0.501	0.25
Intermediate	14 days	0.6	0.5
High	21 days	0.735	0.75

2.2 Results

2.2.1 Parasitic infection

For a parasitic infection in broilers simulations were conducted and the average labour income per round is presented under three transmission rates, slow, medium and fast in Table 3.

Table 3: Mean labour income (€/round) of a broiler farm per round with the corresponding 90% confidence interval (CI), for a parasitic infection with slow, medium and fast transmission rates. Labour income was simulated under, late, intermediate and early start

Transmission rate	Time of diagnosis	Cure rate	Mean	5% C.I.	95% C.I.
Slow	Late	Low	5,986	5,496	7,204
Medium	Late	Low	5,824	5,121	7,133
Fast	Late	Low	5,426	4,577	6,599
Slow	Late	Medium	6,181	5,520	8,256
Medium	Late	Medium	6,074	5,184	8,418
Fast	Late	Medium	5,686	4,658	7,967
Slow	Late	High	6,228	5,478	9,064
Medium	Late	High	6,148	5,053	9,436
Fast	Late	High	5,769	4,482	9,028

Slow	Intermediate	Low	6,071	5,730	6,599
Medium	Intermediate	Low	6,293	5,683	7,271
Fast	Intermediate	Low	6,303	5,171	7,876
Slow	Intermediate	Medium	6,063	5,722	6,850
Medium	Intermediate	Medium	6,371	5,588	7,957
Fast	Intermediate	Medium	6,556	5,197	9,252
Slow	Intermediate	High	6,027	5,684	6,942
Medium	Intermediate	High	6,341	5,577	8,459
Fast	Intermediate	High	6,608	5,243	9,684
Slow	Early	Low	5,841	5,728	5,968
Medium	Early	Low	5,996	5,783	6,195
Fast	Early	Low	6,235	5,836	6,550
Slow	Early	Medium	5,780	5,694	5,869
Medium	Early	Medium	5,828	5,719	5,966
Fast	Early	Medium	5,969	5,771	6,286
Slow	Early	High	5,766	5,683	5,848
Medium	Early	High	5,777	5,689	5,868
Fast	Early	High	5,819	5,709	5,986

Under a slow transmission rate, the confidence intervals for the labour income per production round overlap for cure rates when the treatment had started on the same moment The differences in labour income ranged from ~230 to ~280 € / production round. The medium and high cure rates increased the labour income per round significantly when treatment was started early over late and intermediate start of treatment. Under a medium transmission rate for early start of treatment for parasitic infection the confidence intervals did not overlap with a late start of treatment. High and medium cure rates with an early start of treatment resulted in a significantly higher labour income, when those treatments were started late or intermediate. The differences in labour income ranged from ~430 to 550 € / round. Under a fast transmission rate, for an early start of treatment with a high cure rate labour income was significantly higher than for medium and low cure rates. For medium and high cure rates with an early start of treatment labour income was significantly higher than for treatments that had started later. The differences in labour income ranged from ~600 to ~910 € / round. This is illustrated graphically by Figure 1.

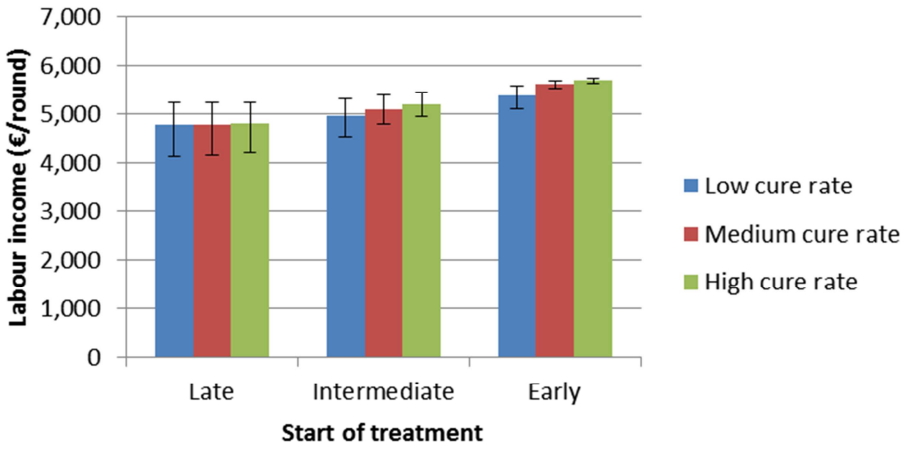

Figure 1: Labour income of a broiler farm per round, for a parasitic infection spreading at a fast transmission rate. Labour income was simulated under, late, intermediate and early start of treatment and for low, medium and high cure rates.

A faster transmission rate causes higher losses than a slow transmission rate did. At a low cure rate and late start of treatment the fast transmission rate caused labour income to decrease by ~700 and ~410 €/round, compared to a slow and medium transmission rate. At a high cure rate and early start of treatment the fast transmission rate caused labour income to decrease ~60 and ~50 €/round, compared to a slow and medium transmission rate.

2.2.2 Bacterial infection

For a bacterial infection in broilers, simulations were conducted and the average labour income per round is presented under three transmission rates, slow, medium and fast in Table 4.

Table 4: Mean labour income (€/round) of a broiler farm per round with the corresponding 90% confidence interval (CI), for a bacterial infection with low, medium and high transmission rates. Labour income was simulated under, late, intermediate and early start

Transmission rate	Time of diagnosis	Cure rate	Mean	5% C.I.	95% C.I.
Slow	Late	Low	5,988	5,483	7,217
Medium	Late	Low	5,822	5,113	7,127
Fast	Late	Low	5,423	4,576	6,581
Slow	Late	Medium	6,184	5,514	8,257
Medium	Late	Medium	6,072	5,171	8,408
Fast	Late	Medium	5,683	4,642	7,942
Slow	Late	High	6,232	5,468	9,054
Medium	Late	High	6,147	5,055	9,415
Fast	Late	High	5,765	4,485	8,965
Slow	Intermediate	Low	6,070	5,729	6,592
Medium	Intermediate	Low	6,294	5,689	7,268
Fast	Intermediate	Low	6,304	5,184	7,879
Slow	Intermediate	Medium	6,061	5,725	6,842
Medium	Intermediate	Medium	6,373	5,588	7,941

Fast	Intermediate	Medium	6,559	5,191	9,262
Slow	Intermediate	High	6,024	5,688	6,904
Medium	Intermediate	High	6,343	5,572	8,434
Fast	Intermediate	High	6,613	5,237	9,698
Slow	Early	Low	5,841	5,729	5,968
Medium	Early	Low	5,997	5,787	6,188
Fast	Early	Low	6,238	5,846	6,546
Slow	Early	Medium	5,780	5,695	5,868
Medium	Early	Medium	5,829	5,722	5,965
Fast	Early	Medium	5,971	5,775	6,284
Slow	Early	High	5,766	5,683	5,847
Medium	Early	High	5,777	5,691	5,867
Fast	Early	High	5,820	5,710	5,984

Under a slow transmission rate, the confidence intervals for the labour income per round overlap for cure rates when the treatment had started on the same moment. For early start of treatment for a bacterial infection the confidence intervals did not overlap with late start of treatment. The differences in labour income ranged from ~230 to ~280 € / round. Under a medium transmission rate, for early start of treatment for parasitic infection labour income increased significantly compared with a late start of treatment regardless of the cure rate. The differences in labour income ranged from ~430 to 550 € / round. Under a fast transmission rate, for medium and high cure rates with an early start of treatment labour income increased significantly compared with those of treatments that had started later. The differences in labour income ranged from ~600 to ~920 € / round. This is illustrated graphically by Figure 2.

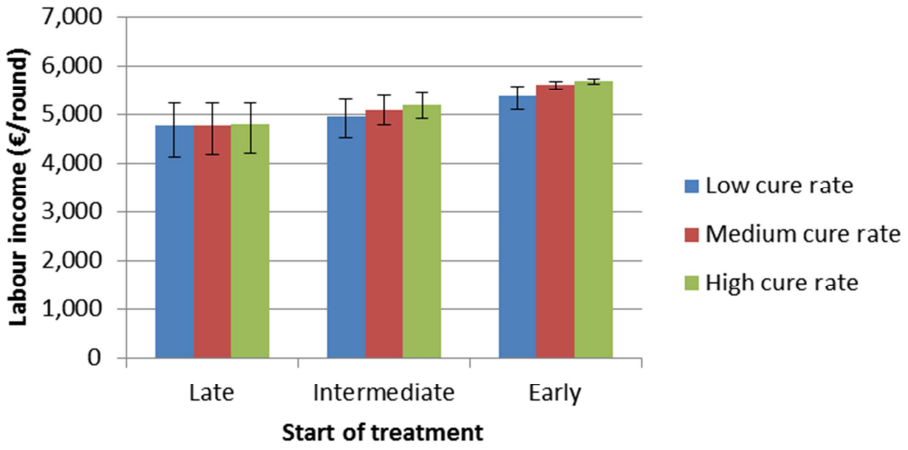

Figure 2: Labour income of a broiler farm per round, for a bacterial infection with a fast transmission rate. Labour income was simulated under, late, intermediate and early detection and for low, medium and high cure rates.

A faster transmission rate cause higher losses than slow transmission rate did. At a low cure rate and late start of treatment the fast transmission rate caused labour income to decrease ~700 and

~420 €/round, compared to a slow and medium transmission rate. At a high cure rate and early start of treatment the fast transmission rate caused labour income to decrease ~60 and ~50 €/round, compared to a slow and a medium transmission rate.

In each of the simulated scenarios an infection occurred and therefore costs of disease were incurred. So in all scenarios the labour income was below the potential labour income which would be incurred when all broilers would grow along the growth curve of healthy animals and only average mortality would occur. The mortality and feed costs had the highest influence on the labour income per round.

2.3 Discussion

A higher cure rate resulted in in higher labour income in all scenarios, however these increases were not significant when compared with cure rates of treatments that started at the same moment and under the same transmission rate. Under medium and fast transmission rates, medium and high cure rates significantly increased labour income when treatment was started earlier. On average better therapies (with a higher cure rate) and improved diagnostics (enabling earlier start of treatment) could increase labour income with about 200, 400 and 600 €/round for infections that spread slowly, intermediately or fast, respectively.

The growth period of broilers is only 42 days, this makes the time window for the diagnosis and treatment of an infection narrow. A period of 21 days between first infection and the start of treatment is therefore unrealistic in practice. For this conceptual study it indicates the value of diagnostics and the need to identify and diagnose problems quickly.

The feed conversion rates used in these simulations were based on healthy broilers and broilers infected with pooled *Eimeria* species (Kipper et al., 2013). In practice different *Eimeria* infections are possible, which would result in different feed conversion rates (Kipper et al., 2013). Furthermore the feed conversion rate was assumed to remain constant over the whole growth period, whereas in reality it will related to body weight. The feed cost of disease will therefore be under- or overestimated by our model depending on the moment in the growth period in which infection occurs.

3 Part B: Value of diagnostic methods on fattening pig farms

3.1 Material and methods

3.1.1 Normative simulation models

For the evaluation of diagnostics, treatment efficacy and estimation of the costs of infectious disease in fattening pig farms normative simulation models were developed. Each model simulates one round on the farm from arrival of the animals on the farm until the moment the animals are sold for slaughter. The models simulate the weight gain of an average animal during the round. For fattening pigs an infection with *Actinobacillus pleuropneumoniae* is simulated, which causes a decrease in weight gain and increases mortality.

Infection dynamics were model with a Reed-Frost model Formula 20. For each day the chance of an animal to become infected (Pi_t) was estimated based on the number of infected animals in the previous period ($Infected_{t-1}$), the total number of animals in the previous period (N_{t-1}) and the

transmission rate parameter (β). The number of infected animals in period t was simulated with a binomial distribution using N_t trials and Pi_t as probability.

$$Infected_t = Binomial(N_t, Pi_t = 1 - e^{-\frac{\beta * Infected_{t-1}}{N_{t-1}}}) \quad (20)$$

3.1.2 Fattening pig model

The total revenues (TRE) of fattening pig farms were calculated by Formula 21 and consisted of the total amount of meat delivered (WD in kg) times the price received (PFP in € / kg). The total amount of delivered meat was estimated by the number of delivered broilers, which is the number of purchased broilers minus the mortality and the slaughter weight of an individual bird. The slaughter weight of an individual pig was estimated by multiplying its live weight by the slaughter to live weight ratio.

$$TRE = WD * SLWR * PFP \quad (21)$$

The total costs (TCO) were calculated by Formula 22. The TCO consisted of: the costs for purchased piglets ($Cost_{purchase}$), costs for feed ($Cost_{feed}$), costs for health care ($Cost_{health}$), costs of buildings ($Cost_{buildings}$), costs of the interest rate of livestock ($Cost_{irl}$), delivery costs ($Cost_{delivery}$), costs for water, heating and electricity ($Cost_{whe}$), general costs and manure disposal ($Cost_{gm}$), costs for litter ($Cost_{litter}$), costs due to mortality ($Cost_{mortality}$) and costs for labour ($Cost_{labour}$).

$$TCO = Cost_{purchase} + Cost_{feed} + Cost_{health} + Cost_{buildings} + Cost_{irl} + Cost_{delivery} + Cost_{whe} + Cost_{gm} + Cost_{litter} + Cost_{mortality} + Cost_{labour} \quad (22)$$

The number of fattening pigs on day t in health class s was estimated by Formula 23, as the result of transition to and from health class *s* and mortality within health class *s*.

$$Pig_{t,s} = Pig_{t=0} + \sum_{0-t}(Trans_{in} - Mort_s - Trans_{out}) \quad (23)$$

The cumulative feed costs over the growth period were estimated by Formula 24. This included the feed consumed by uninfected, infected and dead fattening pigs.

$$Cost_{feed} = PF * \sum_{t0-dd} WG_{t,s=unifected} * Pig_{s=unifected} * FCR_{i=un\,\mathrm{inf}\,ected} + WG_{t,s=ifected} * Pig_{s=unifected} * FCR_{i=\mathrm{inf}\,ected} \quad (24)$$

The weight gain function was estimated based on the optimal curve suggested by Boehringer Ingelheim (2008) and was adjusted to reach a slaughter weight of 118 kg (Vermeij, 2014) at 182

days of age. With the data a daily FCR was estimated for healthy birds. For sick animals an adjustment factor of 1.10 was assumed based on Straw et al. (1990).

Formula 25 describes the weight gain function used to estimate the weight gain of an average bird on day *t* in health class *s*.

$$WG_{t,s} = a_s * day_t^3 + b_s * day_t^2 + c_s * day_t + d \quad (25)$$

Formula 26 was used to estimate the day of delivery within the fattening period. Fattening pigs were assumed to be delivered when the average fattening pig reached the desired slaughter weight.

$$dd = t\{\text{When WD} \geq \text{WDL}\} \quad (26)$$

The cumulative delivered weight at slaughtering of both uninfected and infected fattening pigs were estimated by Formula 27.

$$WD = \sum_{t0-dd} WG_{t,s=uninfected} * Pig_{s=uninfected} + WG_{t,s=infected} * Pig_{s=uninfected} \quad (27)$$

Health care costs were estimated by using Formula 28.

$$Cost_{health} = Pig_{t=dd,s=both} * HC + AB * PAD \quad (28)$$

The costs for the buildings were estimated by Formula 29. The annual costs of the building (depreciated annual replacement value, annual interest paid and annual maintenance) were allocated to the rounds per year and the number of fattening pigs that could be housed within the building.

$$Cost_{buildings} = (RVBI * FS * DPB) + (RVBI * FS * \frac{NIR}{2}) + (RVBI * FS * MB) \quad (29)$$

The average investment in a delivered fattening pig was estimated by Formula 30. This includes the purchase value, meat value and delivery costs.

$$AIP = PP + ((WPD * SLWR * PFP - DC)/2 \quad (30)$$

The costs of interest rate of livestock were estimated by Formula 31.

$$Cost_{irl} = NIRcor * AIB * Pig_{t=dd,s=both} \quad (31)$$

Delivery costs were estimated by Formula 32.

$$Cost_{delivery} = Pig_{t=dd,s=both} * DC \quad (32)$$

Other costs like manure water and electricity were estimated by Formula 33.

$$Cost_{OTC} = Pig_{t=dd,s=both} * OTC \quad (33)$$

The number of delivered fattening pigs was estimated by Formula 34. The number of fattening pigs at *t*=0 were all assumed to be uninfected, from this number of fattening pigs, the fattening pigs that died during the growth period was subtracted.

$$DLpig = Pig_{t=0,s=uninfected} - (MORT_{uninfected} + MORT_{infected}) = Pig_{t=0,s=uninfected} - \quad (34)$$
$$(\sum_{t=0-dd}(Binomial(P_{uninfected}, n = Pig_{t,s=uninfected})) + \sum_{t=0-dd}(Binomial(P_{infected}, n = Pig_{t,s=infected})))$$

The costs of mortality were estimated by Formula 35. The costs of purchase, feed, health care, interest, water heating and electricity, manure and general costs and litter were included.

$$Cost_{mortality} = (MORT_{uninfected} + MORT_{infected}) * PP + \quad (35)$$
$$\frac{Cost_{feed} + Cost_{health} + Cost_{irl} + Cost_{whe} + Cost_{gm} + Cost_{litter}}{Pig_{t=dd,s=both}} \Big/ 2 * (MORT_{uninfected} + MORT_{infected})$$

The labour costs per round were estimated by Formula 36.

$$Cost_{labour} = LP * LH * PL \quad (36)$$

The amount of antibiotics used per round was estimated by Formula 37.

$$AB = \sum_{t=0-dd}(Pig_{t,s=infected} + Pig_{t,s=uninfected}) * Doses * Treatdays \quad (37)$$

In Table 5 the input parameters for the normative simulation models are summarised. Inputs were based on literature, expert opinion (a veterinarian specialised in pigs was consulted) of the expertise of the authors.

Table 5: Input parameters for the fattening pig simulation model, with their respective units and references.

Input parameter	Abbreviation	Value	Unit	Reference
Farm characteristics				
Number of fattening pigs on day t=0 in health class s=uninfected	$Pig_{t=0,s=uninfected}$	4,200	Pigs	Expert opinion
Number of fattening pigs on day t=0 in health class s=uninfected	$Pig_{t=0,s=infected}$	0	Pigs	Authors
Feed conversion ratio	$FCR_{i=uninfected}$	2.58	kg feed/kg growth	(Vermeij, 2014)
	$FCR_{i=infected}$	2.838 (10% higher)	kg feed/kg growth	(Straw et al., 1990)
Slaughter to live weight ratio	SLWR	0.795		Authors
Parameters weight gain function				
Uninfected				Based on the curve (Boehringer-Ingelheim, 2008)
a	$-7.00*10^{-16}$			
b	-0.00744			
c	6.79			
d	107			
Infected				Estimated to result in 10% lower growth.
a	$-7.00*10^{-16}$			
b	-0.00483			
c	5.09			
d	108			
Barn inputs				
Replacement value of buildings and inventory	$RVBI$	440	€ / pig place	(Vermeij, 2014)
Farm size	FS	4,200	Pigs	Authors
Depreciation of buildings	DPB	5	%/year	Authors
Nominal interest rate	NIR	5	%	Authors
Maintenance costs of buildings	MB	1.5	%	Authors
Corrected nominal interest rate	$NIRcor$		% (=NIR/(365/LGP))	Authors

Infection characteristics				
Mortality chance	$P_{Infected}$	4	%	
	$P_{Uninfected}$	2.2		(Vermeij, 2014)
Labour and treatment				
Labour hours	LH	2,300	Hours/year	Authors
Labour	LP	1	Full time equivalent	Authors
Number of doses of antibiotics used	$Doses$	1	Number per treatment day	Authors
Length of treatment	$Treatdays$	5	Days/treatment	Authors
Prices				
Price fattening pig (slaughtered weight)	PFP	1.385	€ / kg	(Vermeij, 2014)
Feed price	PF	25.5	€ / kg	(Vermeij, 2014)
Health care	HC	0.92	€ / delivered pig	Authors
Antibiotics price	PAD	0.05	€ / doses	Authors
Delivery cost	DC	1.82	€ / delivered pig	Authors
Other costs (manure, water, and electricity costs	OTC	8.17	€ / delivered pig	Authors
Purchase price	PP	41	€ / piglet	(Vermeij, 2014)
Labour price	PL	21.63	€ / hour	Authors

2.1.3 Simulation scenarios.

The fattening pig model was used to simulate two types of infectious diseases one gastro-intestinal parasite and a bacterial infection (like *Actinobacillus pleuropneumoniae*). The parasite was assumed to decrease the daily growth curve with 10%, whereas the bacterium was assumed to also increase mortality by 4%. Infections were assumed to first occur in the period between the fifth and seventh week of the growth period, with regard to the period in which fattening pigs are most susceptible for infections. It was assumed that after detection treatment would be started immediately. Incubation effects were assumed for growth impairment, increased mortality and treatment effect. For growth impairment, the effect assumed to be at 50% of the total impairment between day 0-3 after infection and at 100% from day 4 onwards. For increased mortality, the effect was assumed to be at 35% of the total mortality increase between day 3-5 after infection, 55% between day 5-7 and at 100% from day 7 onwards. For treatment, the effect was assumed to be at 0% of the total cure rate between day 0-1 after infection, 10% between day 1-3, 50% between day 3-5 and at 100% from day 5 onwards.

To evaluate the merit of improved diagnosis three moments of diagnosis where defined. Early diagnosis was 7 days after the first pig was infected, intermediate diagnosis and late diagnosis were

14 and 21 days after the first infection, respectively. The type of disease and treatment may influence the effect an improved diagnostic method has. Therefore three transmission rates (β) and cure rates (i.e. probability that an infected animal is cured by the treatment) were evaluated in combination with the moments of diagnosis. In Table 6 the various settings are described. Twenty seven simulations were conducted for both the parasite and the bacterial infection in order to use all possible combinations of settings for moment of diagnosis, transmission factor and cure rate. In general model convergence was reached within 4,000 iteration, to be on the safe side, in each simulation 10,000 iteration were conducted. All simulations were conducted in Microsoft Excell® with the add-in software @Risk® for Excell (Pallisade Decision Tools, 2010).

Table 6: Simulation settings for moment of diagnosis, transmission factor and cure rate of the treatment in the fattening pig simulation model.

	Moment of diagnosis	Transmission factor (β)	Cure rate of treatment
Low	7 days	0.5002	0.25
Intermediate	14 days	0.77	0.5
High	21 days	0.96	0.75

3.2 Results

3.2.1 Parasitic infection

For a parasitic infection in fattening pigs simulations were conducted and the average labour income per round is presented under three transmission rates, slow, medium and fast in Table 7.

Table 7: Mean labour income (€/round) of a fattening pig farm per round with the corresponding 90% confidence interval, for a parasitic infection with slow, medium and fast transmission rates. Labour income was simulated under, late, intermediate and early star

Transmission rate	Time of diagnosis	Cure rate	Mean	5% C.I.	95% C.I.
Slow	Late	Low	8,737	7,710	9,657
Medium	Late	Low	8,575	7,975	9,207
Fast	Late	Low	8,241	7,670	8,875
Slow	Late	Medium	8,367	7,724	9,559
Medium	Late	Medium	8,986	8,353	9,566
Fast	Late	Medium	8,665	8,115	9,212
Slow	Late	High	8,347	7,775	9,088
Medium	Late	High	9,081	8,074	9,643
Fast	Late	High	8,829	8,287	9,365
Slow	Intermediate	Low	8,573	8,238	8,878
Medium	Intermediate	Low	8,345	7,760	9,641
Fast	Intermediate	Low	8,999	7,823	9,809
Slow	Intermediate	Medium	8,701	8,267	9,060
Medium	Intermediate	Medium	8,519	8,055	8,992
Fast	Intermediate	Medium	8,287	7,796	9,508

Slow	Intermediate	High	8,674	8,164	9,093
Medium	Intermediate	High	8,661	8,213	9,099
Fast	Intermediate	High	8,333	7,883	8,812
Slow	Early	Low	8,516	8,110	8,880
Medium	Early	Low	8,931	8,650	9,200
Fast	Early	Low	8,909	8,594	9,197
Slow	Early	Medium	7,809	6,141	8,704
Medium	Early	Medium	9,004	8,563	9,344
Fast	Early	Medium	9,205	8,922	9,463
Slow	Early	High	7,494	6,062	8,612
Medium	Early	High	8,852	8,240	9,330
Fast	Early	High	9,234	8,899	9,516

Under a slow transmission rate, the confidence intervals for the labour income per round overlap for cure rates regardless of the moment on which treatment had started. The differences in labour income ranged from ~0 to 900 € / round. Under a medium transmission rate, for early start of treatment for parasitic infection labour income increased significantly for low and high cure rates. For a high cure rate with an early start of treatment labour income was significantly higher than for low cure rates, when those treatments were started late or intermediate. The differences in labour income ranged from ~180 to 1500 € / round. Under a fast transmission rate, for high cure rates with an early start of treatment labour income increased significantly for low cure rates of treatments that had started later. The differences in labour income ranged from ~230 to ~1200 € / round. This is illustrated graphically in Figure 3.

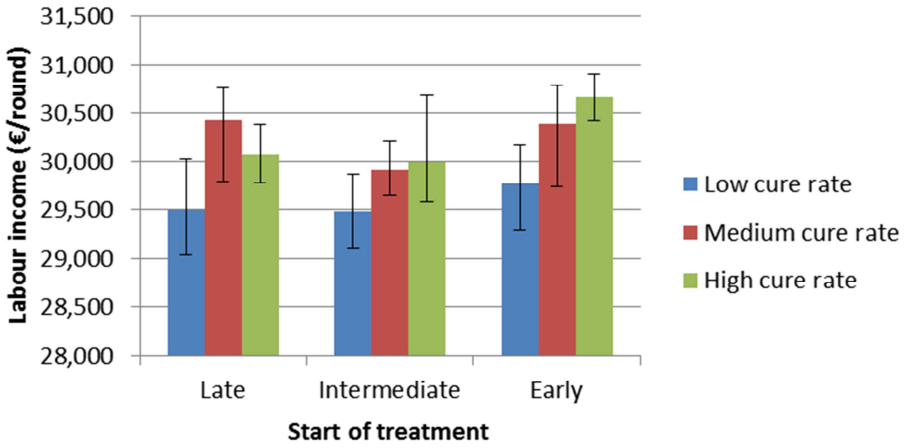

Figure 3: Labour income of a fattening pig farm per round, for a parasitic infection spreading at a fast transmission rate. Labour income was simulated under, late, intermediate and early start of treatment and for low, medium and high cure rates.

A faster transmission rate causes higher losses than slow transmission rate did. Exceptions were noted for medium cure rate and late diagnosis and for a high cure rate with a late or early diagnosis between slow and fast transmission. At a low cure rate and late start of treatment the fast transmission rate caused labour income to decrease ~470 and ~375 €/round, compared to a slow

and medium transmission rate. At a high cure rate and early start of treatment the fast transmission rate caused labour income to decrease ~-170 and ~310 €/round, compared to a slow and medium transmission rate.

3.2.2 Bacterial infection

For a bacterial infection in fattening pigs, simulations were conducted and the average labour income per round is presented under three transmission rates, slow, medium and fast in Table 8. Low cure rates were excluded from the presentation of results, because labour income was always negative at a low cure rate for a bacterial infection, these results and by extension the low cure rates were considered unrealistic.

Table 8: Mean labour income (€/round) of a fattening pig farm per round with the corresponding 90% confidence interval (CI), for a bacterial infection with low, medium and high transmission rates. Labour income was simulated under, late, intermediate and early

Transmission rate	Time of diagnosis	Cure rate	Mean	5% C.I.	95% C.I.
Slow	Late	Medium	-11,849	-23,847	3,199
Medium	Late	Medium	-36,812	-47,894	-22,571
Fast	Late	Medium	-47,962	-57,474	-35,522
Slow	Late	High	-9,394	-21,203	4,510
Medium	Late	High	-33,548	-44,405	-20,128
Fast	Late	High	-44,493	-53,874	-32,173
Slow	Intermediate	Medium	3,489	-1,351	7,190
Medium	Intermediate	Medium	-10,029	-18,242	94
Fast	Intermediate	Medium	-18,739	-26,247	-8,547
Slow	Intermediate	High	4,604	567	7,488
Medium	Intermediate	High	-7,450	-15,263	2,059
Fast	Intermediate	High	-15,842	-23,256	-5,977
Slow	Early	Medium	6,930	5,576	8,097
Medium	Early	Medium	5,018	2,573	7,044
Fast	Early	Medium	2,280	-1,232	5,726
Slow	Early	High	6,941	5,632	8,185
Medium	Early	High	6,162	4,249	7,682
Fast	Early	High	4,036	935	6,911

Under a slow transmission rate, the confidence intervals for the labour income per round overlap for cure rates when the treatment had started on the same moment. For early start of treatment for a bacterial infection labour income increased significantly compared with late or intermediate start of treatment, as did those of intermediate and late start of treatment. The differences in labour income ranged from ~18,000 to ~22,000 € / round. This is illustrated graphically in Figure 4.

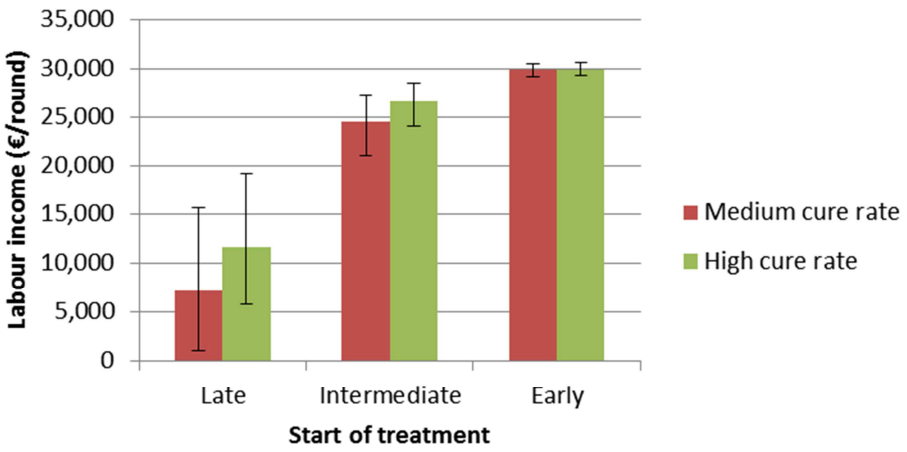

Figure 4: Labour income of a fattening pig farm per round, for a bacterial infection with a slow transmission rate. Labour income was simulated under, late, intermediate and early start of treatment and for medium and high cure rates.

Under a medium transmission rate, for a late start of treatment and for an intermediate start with a medium cure rate the labour income per round was negative. The differences in labour income ranged from ~24,000 to ~65,000 € / round. Under a fast transmission rate, for a late start of treatment and for an intermediate start with a medium cure rate the labour income per round was also negative. The differences in labour income ranged from ~-36,000 to ~130,000 € / round.

A faster transmission rate caused higher losses. At a fast transmission rate only at a high cure rate with an early start of treatment resulted in a positive labour income. At a low cure rate and late start of treatment the fast transmission rate caused labour income to decrease ~150,000 and ~32,000 €/round, compared to a slow and medium transmission rate. At a high cure rate and early start of treatment the fast transmission rate caused labour income to decrease ~7,200 and ~5,000 €/round, compared to a slow and a medium transmission rate.

In each of the simulated scenarios an infection occurred and therefore costs of disease were incurred. So in all scenarios the labour income was below the potential labour income which would be incurred when all pigs would grow along the growth curve of healthy animals and only average mortality would occur. The mortality and feed costs had the highest influence on the labour income per round

3.3 Discussion

At medium and fast transmission rates for parasitic infections treatments with a high cure rate that started early improved labour income per round significantly over treatments with a low cure rate. Increases in labour income per round were observed in the range of 200 to 1500 € / round. For a bacterial infection at a slow transmission late, intermediate and early start of treatment labour income differed significantly. Under medium and fast transmission rates for all treatments labour income differed significantly. The effects of an earlier start of treatment or a higher cure rate were over 10,000 € / round.

The simulations that represent a bacterial infection indicate that mortality is an important factor on fattening pig farms. The increase of mortality for infected animals from 2.2% to 4% caused labour income to be negative in many scenarios of our simulations. This illustrates the importance of early diagnostics and effective treatments for infections that can potentially cause a high mortality disease in fattening pigs. It is likely that farmers are aware of the financial importance of mortality in practice and are therefore keen on detecting and treating infected pigs. Therefore, it would seem reasonable

to assume that farmer notice an infection that increase mortality quickly and that therefore a late diagnosis would seem unrealistic. The simulation results are therefore merely a demonstration of our model and its ability to quantify the financial effects of infections and treatments that influence the mortality rate.

4 General discussion

The simulation scenarios were analysed with the normative simulation models to gain insight in importance of the cure rate, start of treatment and transmission rate. As our approach was general the reported values do not represent any specific disease in practice. Although we did base the inputs and design of the model on *Eimeria* and necrotic enteritis infection in poultry and *Actinobacillus pleuropneumoniae* infections in fattening pigs and discussed the dynamics of these infections with experts. The values indicate potential effect given the assumptions on disease dynamics, treatment and diagnostics we made. We have made these assumptions as realistic as possible.

The normative simulation models used fixed feed conversion rates for healthy and sick animals. In reality these rates will be more variable both over time and between different diseases and farms. Therefore our models cannot estimate feed costs in detail and account for all complex relationships between feed conversion, disease and management. However, our model can give a reasonable approximation, although it is somewhat simplified and feed cost might be over- or underestimated. For the analysis of specific diseases or cases available data or literature might be used to model feed conversion in more detail.

In general our models simulate an average healthy and an average sick animal. This approach ignores the variation amongst animals within a flock or herd. Therefore, the models do not account for instance, for the individual weight of a healthy animal that becomes infected or that of an individual sick animal that is cured. This could over- or underestimate feed cost, weight at delivery and weight at death in our models, however, the average outcome per flock or herd might not be affected too much. The outcomes of the normative simulation models provides an approximation of disease costs and effects on labour income rather than an empirical value for these financial effects on a commercial farm.

The scenarios in our simulations use values for cure rates, start of treatment and transmission rate. In practice these factors cannot be seen as fully independent. For instance, a fast spreading infection with strong effects on growth and mortality is likely to be detected earlier than a slower spreading infection. Therefore our scenarios should be seen as theoretical, which was appropriate for our goal to demonstrate our models and show that they are useful to quantify financial effects of different treatments and diagnostics.

The results of the simulations indicate that earlier diagnosis and hence earlier start of treatment will improve labour income. This increase in labour income can be seen as financial room for the improvement of diagnostics and treatment. On broiler farms it is possible to spent about 100-500 euro's on improved diagnostics and prevention of diseases spreading. For fattening pigs a difference was observed between parasitic infections that only cause growth impairment for which the range is also a couple of hundreds of euros and bacterial infections that also increase mortality for which the financial range is some thousands of euros. Improvement in diagnostics could include more intensive supervision, inspection of a sample of animals (perhaps even slaughter in case of broilers) or precision technology. Precision technology application could include sound sensors that monitor coughing of fattening pigs or sensors that monitor barn temperature and humidity.

Investment in earlier diagnosis will decrease the number of infected animals as our simulations indicated. If an infection is diagnosed early on, treatment of individual animals or containment of infected animals may be possible rather than treating the whole herd or flock, which was what we assumed for our simulations. Furthermore it may be possible to use alternative treatments like phytotherapy or homeopathy more effectively when a disease is detected early as a low number of animals will be infected and/or severely ill. Especcially because such therapies may have a more preventive nature than a curative.

5 Conclusions

The normative simulation models for broilers and fattening pigs can simulate the effects of improved diagnostics in combination with various treatments (with different efficacies) and infections with various transmission rates. The simulation models can produce a broad range of outputs like, labour income, cost of disease, delivered animals, mortality per round, number of infected animals and amount of medicine used. The simulation models can therefore be used to gain insight in the costs of infectious diseases on broiler and fattening pig farms. The financial effects of different treatment strategies and diagnostic procedure can be estimated with the normative simulation models. Furthermore, it is possible to evaluate treatments (based on cure rate but also broader efficacy) and diagnostic procedures (based on time, mortality or growth effects). In addition the number of infected animals and chosen treatment can be used to estimate the amount of medicine used (for instance antibiotics) and evaluate strategies to reduce the use of such medicines.

The simulations conducted illustrate that earlier diagnostics and higher cure rates can increase labour income and therefore farmers have financial possibilities to invest in improved management of animal health.

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