The financial feasibility of eubiotics as alternatives for antibiotics in Dutch pig production

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List of abbreviations

AB	Antibiotics
ADG	Average daily growth (gram/day)
AGP	Antibiotics growth promotor
CFU	Colony forming units
FCR	Feed conversion ratio
LAB (mix)	Lactic acid bacteria (mix)
MORT	Mortality (%)
PWD	Post weaning diarrhea
SALM	Salmonella
SD	Swine dysentery
STREP	Streptococcus suis
LAW SC	Lawsonia intracellularis (sub-clinical)
LAW CL	Lawsonia intracellularis (clinical)
Alt. 1	Alternative action 1 – no action
Alt. 2	Alternative action 2 – curative application of antibiotics
Alt. 3	Alternative action 3 – application of eubiotics
Alt. 4	Alternative action 4 – application of eubiotics + curative application of antibiotics

Summary

The main question driving this research was "*What is the financial feasibility of eubiotics as alternatives for antibiotics in Dutch pig production?"*. In the first part of the research, a selection of common diseases in pig production in which eubiotics could play a useful role was made. Next, four alternative actions to deal with these diseases were selected: no action (Alt. 1), use of antibiotics (Alt. 2), use of eubiotics (Alt. 3) and a combination of eubiotics and antibiotics (Alt. 4). Eighteen eubiotics were selected to be modeled in Alt. 3 and 4. Their impact on production parameters was derived from literature. By modeling the impact of the selected diseases in the four different alternative actions, average production parameters in the different situations were calculated. Next, these production parameters were entered in an economic model to obtain results about their impact on the net profit of a pig farm. Of the eighteen selected eubiotics, fourteen led to a lower net profit. The four others, benzoic acid, formic acid, lactic acid and lactobacilli, did lead to a higher net profit than when using antibiotics or any of the other alternative actions. After stochastic simulation, benzoic acid, lactic acid and lactobacilli were left as financially feasible alternatives for antibiotics. They financially outperform antibiotics, mainly due to their growth promoting properties.

1. Introduction

1.1. Background and problem

Pig production in the Netherlands mainly consists of intensive farming systems. To keep pigs healthy in these systems, antibiotics are used to treat and prevent diseases caused by bacteria. Antibiotics are inexpensive and generally effective (Cromwell, 2002).

However, the use of antibiotics has adverse side effects. Bacteria can adapt to antibiotics over time and become resistant to them. More use increases the chances that bacteria become resistant and the antibiotics' effect is reduced. This can cause serious problems, because antibiotics are also used widely to cure bacterial diseases in humans (Casewell et al., 2003). They provide a pivotal role in modern medicine. The European Union poses restrictions on the use of antibiotics in animals to protect human antibiotics from bacterial resistance. Antibiotics have also been used as antibiotic growth promotors (AGP's) in animal husbandry, but this is no longer allowed in the European Union (EU). For pig farmers, these measures restrict their access to effective antibiotics to keep their pigs healthy (Casewell et al., 2003). With the growing number of pigs per farm (CBS, 2018) and the restrictions related to antibiotics use on pigs, the need for alternatives increases.

Possible alternatives for antibiotics for pig farming could be *eubiotics*. Eubiotics are (feed) additives such as *direct acting gut flora modulators, probiotics*, *prebiotics* and *immune modulators* to stimulate a healthy microbiota (Wiemann, 2013). By maintaining a healthy gut in animals, they are less susceptible to certain diseases. A lower chance of an animal getting sick implies a reduction in the required antibiotics to cure diseases caused by bacteria while striving for low feed conversion ratios and low mortality. While eubiotics cannot replace the direct application of antibiotics in these cases, consequent use might reduce the likelihood of certain diseases occurring. Furthermore, if such a disease would occur, it's impact could be reduced. Thus, the need for antibiotic treatment would be reduced as well.

Although eubiotics have been subject to extensive research, it is unclear what the financial value of eubiotics is compared to antibiotics for individual pig farmers. The three crucial parameters here are the efficacy, costs and production effects of eubiotics. A sound understanding of the financial implications on farm level is crucial for farmers to stay competitive in an export-oriented sector, but also for governments as a foundation for policy regarding the reduction of antibiotics usage. Therefore, the goal of this research is to assess the financial feasibility of eubiotics as alternatives for antibiotics in Dutch pig farming.

1.2. Study objective

The overall question underlying this research is "*What is the financial feasibility of eubiotics as alternatives for antibiotics in Dutch pig production?"*. To answer this question, the following research objectives are formulated:

1) Make a qualitative inventory of the most promising applications of eubiotics in pig production and the possible alternative actions to deal with the related animal health issues.
2) Assess the quantitative effects of the different alternative actions on important production parameters such as animal growth, mortality, feed conversion and cost.
3) Estimate the selected combinations of animal health issues and the corresponding alternative actions in a quantitative model to estimate the financial effect per animal and on farm level in a one-year period.

1.3. Research approach

This study will be limited to two specific stages in pig production. The first one (A) is the stage from weaning where piglets weigh 8 kg until they weigh 25 kg. The second production stage considered is the fattening stage (B), from 25 kg to the slaughter weight of around 117 kg. The materials and methods for the individual research objectives are as follows:

1) For the first research objective, the most promising applications of eubiotics that could be alternatives for antibiotics will be selected from state-of-the-art literature on eubiotics, including the thesis of Breunesse (2019) and more traditional literature on pig farming, such as the *Handboek Varkenshouderij* ("pig farming manual") by Vermeij (2010). Also, experts on eubiotics will be consulted. The health issues the eubiotics might help prevent will be listed with relevant possible actions such as no treatment, treatment with antibiotics and application of eubiotics to create all possible scenarios. In the scenarios with the application of eubiotics, a second decision occurs: treat with antibiotics if needed or not.

2) For the second objective, literature results about the impact of eubiotics on animal growth, mortality, feed conversion, cost and other important parameters will be selected and quantified with the aid of literature and expert opinions.

3) The outcomes of the first and second research objective will provide input for the third research objective: these will be the inputs in a model in Microsoft Excel to assess the financial consequences for the farmer for each alternative action, showing the financial feasibility of the eubiotics and what their value is compared to other options, such as more use of antibiotics. The model used will be an adaptation of the model described in Gocsik et al. (2015). The outcome of this model is the annual change in gross margin on farm level for all combinations of animal health issues and corresponding actions identified in the first and second objective. The model will also be used to run what-if and break-even analyses on the scenarios with the 'application of eubiotics' action, to assess which parameters should be changed to improve its feasibility. Next, the model inputs will be adjusted to account for uncertainty. The Excel plugin @Risk by Palisade will be used for this model modification. Uncertain input variables will be replaced with mathematical distributions. This will also result in distributions as outcomes. These outcomes will be more useful for decision makers because they not only state the change in net profit caused by a specific action, but also the associated risk.

1.4. Setup of the report

The remainder of the report is organized in the following way: After this introduction, the qualitative inventory is set up in chapter 2. A selection and description of relevant diseases, possible alternative actions and eubiotics is given here. Next, the quantitative impacts of these diseases and eubiotics are addressed in chapter 3. The outcome of this section are production parameters which can be entered in the economic model. This is done in chapter 4. The production parameters are entered in the model to determine the change in net profit for each alternative action and the different eubiotics. The outcomes are presented in the same chapter. Next, the results are discussed in chapter 5 and finally conclusions are drawn in chapter 6.

2. Qualitative Inventory

2.1. Introduction

The first research objective is to make a qualitative inventory of the most promising applications of eubiotics in pig production and the possible alternative actions to deal with the related animal health issues. Three main stages can be distinguished in pig production. The first one is the suckling stage: this is from birth until the suckling piglets are separated from the sow. The sucklings drink the sow's colostrum in this stage. The second stage is the piglet stage. The piglets are no longer drinking milk but weaned to feed. The third stage is the fattening stage in which the pigs are fattened to slaughter weight. Because eubiotics are usually feed additives, the second and third stage will be considered in this research. These are referred to as stage A for piglets and stage B for fatteners.

The application of eubiotics has two main uses: the first one is prevention of diseases and reducing their impact, the second one is growth promotion. Although both applications work in a similar way, they will be considered separately to be able to use existing research on their efficacy. Literature studies are usually either framed towards reducing disease impact or growth promotion, but not both. First, eubiotics targeted at diseases will be considered. Secondly, eubiotics targeted at growth promotion will be reviewed.

2.2. Method – selection of pig diseases

Several common pig diseases are described in existing literature (Bergevoet, 2010; Breunesse, 2019; Zimmerman et al., 2012). Most of these are the result of an infection. Most of these infectious diseases are caused by caused by viruses or bacteria. A small part is caused by other types of agents, such as nematodes. Non-infectious diseases make up a small part of the diseases found in Dutch pig production.

The selection of pig diseases initially started with the selection made by Breunesse (2019) displayed in Table 1. Also, the section on bacterial diseases in the book *Diseases of Swine* by Zimmerman et al. (2012) was consulted to review all important diseases.

Table 1: Pig diseases selected by Breunesse (2019)

Disease (abbreviation)
Actinobacillus pleuropneumoniae (APP)
Mycoplasma hyopneumoniae (MYC)
Porcine reproductive and respiratory syndrome virus (PRRS)
Swine influenza (SIV)
Porcine Circovirus 2 (PCV2)
Post-weaning Diarrhoea (PWD)
Ileitis (Lawsonia intracellularis)(LAW)
Streptococcosus suis (STREP)
Salmonellosis (Salmonellosis typhimurium) (SALM)

In this qualitative inventory, diseases caused by bacterial infection were be selected because these can be treated with antibiotics, as opposed to diseases with another cause (Karaman, 2015). Eubiotics can possibly reduce the likelihood of a disease caused by bacterial infection, and if it occurs, reduce its impact. This naturally leads to a reduction in antibiotics required for treatment. Because eubiotics are feed additives which can be effective in the gastrointestinal tract, gastrointestinal diseases were considered. To select the most promising applications of eubiotics in Dutch pig production, the following selection criteria have been formulated:

- The disease is caused by a bacterial infection;
- The disease occurs in the gastrointestinal tract;
- The disease is common in Dutch pig production;
- The disease can occur during the piglet (post weaning) stage (A, 8-25 kg) OR
  Fattening stage (B, 25-120 kg) OR
  Both these stages (A and B);
- The disease is economically relevant;
- The disease can be treated with antibiotics (ABs)

2.3. Selected pig diseases and alternative actions

The selection criteria resulted in the following diseases and alternative actions. For each disease, a short description is given. Also, three alternatives actions are briefly discussed. These are not taking any action, application of antibiotics and application of eubiotics. In a later part of the research, a fourth alternative action was added, which is a combination of antibiotics (Alt. 2) and eubiotics (Alt. 3).

2.3.1. Post-weaning diarrhea (*E. coli*)

Escherichia coli is the main cause of post-weaning diarrhea (PWD) in pigs (Fairbrother et al., 2005). *E. coli* is present in every pig, but in adverse conditions the bacteria can multiply too fast and cause a gastrointestinal infection. Animals are affected by the toxins produced by the bacteria. Especially weaned piglets are vulnerable. The combination of stress, switching feed and differences in circumstances when piglets are separated from the sow makes post-weaning diarrhea (PWD) very common. The piglets suffer from diarrhea, lose weight or die. During the infection, growth is usually depressed. Infected pigs can be treated with antibiotics (Geudeke & Franssen, 2015).

2.3.1.1. No action

If no action is taken, post-weaning diarrhea is likely to result in a growth reduction in post weaning piglets. Mortality can increase to up to 25% (Fairbrother & Carlton, 2012), but in the current Dutch production system a mortality of 13.4% is average without antibiotic treatment (Breunesse, 2019). Untreated animals that survive are expected to fully recover.

2.3.1.2. Antibiotics only

Post-weaning diarrhea can be treated with antibiotics. Although it is relatively effective, the economic impact is not fully neutralized because animals can only be treated after being diagnosed. At that time, the animal is already sick, and stopped growing or is even losing weight. When treated with antibiotics, mortality can be limited to 1,5-2% (Fairbrother & Carlton, 2012).

2.3.1.3. Eubiotics

PWD slows piglet's growth temporarily and increases mortality. Eliminating this growth lag and mortality would imply economic gains. Research on the impact of several feed additives on PWD has been done, assessing their impact on growth performance and impact on the disease. Positive results have been obtained with benzoic acid (Silveira et al., 2018), formic acid, propionic acid (Tsiloyiannis et al., 2001), lactobacilli (Wang et al., 2009) and a carvacrol-based mix of essential oils (Pu et al., 2018).

2.3.2. Salmonellosis (*Salmonella typhimurium*)

Salmonella (SALM) is commonly carried by pigs without causing clinical signs. However, excessive growth of some serotypes might cause pigs to develop a gastrointestinal infection. *Salmonella typhimurium* is the most commonly found serotype in pigs. This can lead to diarrhea, fever, fatigue and death (Bonardi, 2017). Weaned piglets are most susceptible to outbreaks, but fattener pigs can also get sick. Many serotypes exist, several of which are of serious concern for pig health. Furthermore, some serotypes of Salmonella carried by pigs can pose a risk to human health (Carlson et al., 2012). Treatment is difficult due to the different serotypes and bacterial resistance to antimicrobials.

2.3.2.1. No action

Infection with Salmonella can, but does not necessarily cause clinical disease in pigs. When it does lead to disease, diarrhea and dehydration cause growth depression and in few instances, death.

2.3.2.2. Antibiotics only

The effect of antibiotic treatment of Salmonella infection is limited when the animal is already diseased (Carlson et al., 2012). The bacteria grow in places that cannot be reached properly by antibiotic agents. Preventive use of antibiotics -altough not allowed- is more effective because the bacteria are exposed to the antibiotics before being able to harm the pig. Because Salmonella is somewhat more difficult to treat and it is an endemic disease, the time that an animal is diseased is relatively long.

2.3.2.3. Eubiotics

A literature review on the efficacy of eubiotics on Salmonella in weaned piglets and fattener pigs indicated limited possibilities. Several studies where conduced, but trials with different probiotics and organic acids did not result in improvement (Walsh et al., 2012). Another study focusing on phytogenic feed additives (essential oils) showed similar results (Bruno et al., 2013). However, a formic acid-based feed additive did result in reduced fecal shedding, reducing infection rates (Allaart et al., 2017). In very specific cases, positive effects were measured with the use of citric acid (Tsiloyiannis et al., 2001) and probiotics (Kreuzer et al., 2012). However, the timespan and setting of the experiments with successful results make a questionable representation of a realistic production setting.

2.3.3. Swine Dysentery (*Brachyspira hyodysenteriae*)

Swine dysentery (SD) is an endemic disease that originates in the gastrointestinal tract. Grower and finisher pigs are most susceptible to Swine dysentery, caused by *Brachyspira hyodysenteriae* (Hampson, 2012). Infected pigs express several symptoms including (bloody) diarrhea and loss of appetite. The disease can last for several weeks. It is notable that the disease has been practically eradicated in the United States for several years but re-emerged in 2007 (Burrough, 2016). Meanwhile, it has been common in other parts of the world, including Europe.

2.3.3.1. No action

Animals suffering from swine dysentery express severe growth lag. Mortality can be as high as 30-50% of the herd if no treatment takes place. In the current, local production system, 10% is assumed (Anonymous, 2014; Houben, 2019). Pigs that do recover take several weeks. However, even when pigs are no longer diseased, the growth is slower than before the infection (Hampson, 2012).

2.3.3.2. *Antibiotics only*

Due to increasing antimicrobial resistance, only few effective antibiotics are left available to treat swine dysentery (Hampson, 2012). In severe cases, animals should get antibiotics injected; in other cases, mixing antibiotics with water or feed can be an effective way to treat the disease.

2.3.3.1. *Eubiotics*

Only one relevant feed additive targeting on the impact and occurrence of Swine Dysentery was found: a mix of phytogenic feed additives. The feed additive, sold as “Patente Herba (Plus)” showed an improvement in growth performance and reduction of diarrhea in piglets (Nikola et al., 2018). The manufacturer of the product claims reduced infection rates and mortality in its own communication ("Patent Herba Brochure," 2017). However, the safety and effectiveness of Patente Herba should be questioned. It does not seem to be available for purchasing anymore and it is not approved by the European Food Safety Authority (EFSA). For these reasons, it is not considered further in this research.

2.3.4. Ileitis (*Lawsonia intracellularis*)

Ileitis (LAW), also known as Proliferative enteropathy (PE), is an infectious disease that originates in the gastrointestinal tract. It is caused by *Lawsonia intracellularis* which is commonly carried by pigs (Vannucci & Gebhart, 2014). Various manifestations exist in many different animals, although two are common in pigs. One is common in post-weaned pigs (PIA, acute) and one is common in older fattening pigs (PHE, chronic). The most important symptom is diarrhea, which results in reduced feed update, depressed growth and -in very few cases- death. Treatment requires antibiotics, but prevention by vaccination is also an effective approach (Gebhart, 2012)

2.3.4.1. *No action*

When untreated, growth is slowed down, and feed conversion rate increases significantly. However, pigs can recover within 4-10 weeks (Gebhart, 2012).

2.3.4.2. *Antibiotics only*

Antibiotic treatment is an effective way to cure pigs of Ileitis (Gebhart, 2012). Several antibiotics are available to cure the diseased pigs. These can be mixed in feed or drinking water. With this treatment, animals recover in several days.

2.3.4.3. *Eubiotics*

An study on the impact of zinc amino acid complex did not prove any change in growth parameters, but did show a dramatic reduction in lesions (Leite et al., 2018). This could lead to a reduction of clinical occurrence of Ileitis. Patent Herba Plus, a eubiotic to reduce the incidence and impact of swine dysentery, also claims be effective to reduce the morbidity caused by Ileitis (Draskovic et al., 2018). Also, feed conversion ratio was improved during this trail. However, it is excluded in this research for reasons stated in the previous paragraph about swine dysentery.

2.3.5. *Streptococcus*

Streptococcus suis (type II, STREP) is an infection that mainly affects piglets which are 4 to 12 weeks old (Staats et al., 1997). Although at a lower chance, older pigs can also be affected. Infection can lead various symptoms including fever, meningitis, pneumonia and death. *S. suis* can be treated with antibiotics and is the cause of a considerable share of the total antibiotics use in pig production. The bacteria are carried in pigs’ tonsils, causing presence on most farms. However, the infection can also occur in the gastrointestinal tract (Gottschalk, 2012).

2.3.5.1. No action

Without treatment, pigs suffer from various symptoms as stated above. Most of these diminish growth. Mortality caused by *S. suis* can rise up to 20% in extreme cases (Gottschalk, 2012), but a 5% increase is assumed for the local production system (Breunesse, 2019).

2.3.5.2. Antibiotics only

Antibiotics are used to treat *S. suis*, but antimicrobial resistance is increasing (Gottschalk, 2012). The type of antibiotic used should be selected based on the local resistance pattern. Timely administration of antibiotics are crucial to limit the impact of the disease.

2.3.5.3. Eubiotics

Because *S. suis* can occur in the gut but is mainly a respiratory disease, the effect of eubiotics can be questioned. No evidence was found in literature that eubiotics have a positive impact related to *S. suis*.

2.3.6. Excluded diseases

Of the initial selection of pig diseases as displayed in Table 1, several were excluded. Actinobacillus pleuropneumoniae (APP) and Mycoplasma hyopneumoniae (MYC) are both bacterial diseases but are not relevant in this research as they are respiratory diseases. Porcine reproductive and respiratory syndrome virus (PRRS) and swine influenza (SIV) are also respiratory and furthermore, caused by a virus. Porcine circovirus 2 (PCV2) is a gastrointestinal disease, but also caused by a virus. Due to these properties, it is highly unlikely that eubiotics have any impact on these diseases.

2.4. Eubiotics and Growth promotion

Since the ban on AGP's, eubiotics have gained interest to replace these as growth promotors. Many studies have been conducted to test the effect of feed additives on growth performance in pigs. In this chapter, the most promising growth promoting applications of eubiotics will be reviewed. The aim of eubiotics in this context is to promote growth by influencing and modifying the microbiota of the gut tract (Broz, 2018). While not targeting a specific microorganism causing a clinical disease, the general approach and the way they work are the same as in the studies where a specific microorganism is investigated.

2.5. Method - Selection of eubiotics

Literature research was conducted to find experimental results on the efficacy of different eubiotics regarding the selected pig diseases and growth promotion. Names of commercially available eubiotics produced by Delacon, DSM, Pancosma and Trouw Nutrition (Nutreco) were used as search keywords. Furthermore, the active compound in the products were used as search keywords. For instance, VevoVitall is a feed additive produced by DSM. The active compound in VevoVitall is benzoic acid. Also, the organic acids reviewed by Roth and Kirchgessner (1998), "probiotic", "prebiotic", "feed additive" were used as search keywords. These were combined with "pigs" OR "swine". The selection of the most relevant diseases made in research objective one was used in the search to find results on the combination of these diseases and eubtiotics. Furthermore, the database of relevant eubiotics was controlled and extended by A. Mary (Animal Nutrition & Health EMEA – Applied Animal Nutrition Scientist). All studies referred to are in-vivo studies on their efficacy on weaning piglets and/or fattener pigs. In all cases, a (negative) control group of animals was kept under the same conditions as the experimental group.

2.6. Selection of eubiotics

2.6.1. Overview

The literature review resulted in the selection displayed in Table 2. The items categorized as probiotics and essential oils are aggregated classifications: e.g., many probiotics based on various lactic acid bacteria (LAB) exist. For reasons of simplicity, they are simplified as *lactobacilli*. In the case of products based on more than one strain of lactobacilli, they are considered *LAB mix*. Products based on essential oils are usually a mix of several oils. Hence, they are classified based on their main ingredient.

Table 2: Selection of eubiotics

Eubiotic	Category	Natural origin (oils)
Benzoic Acid	Organic acid	
Formic Acid	Organic acid	
Lactic Acid	Organic acid	
Propionic Acid	Organic acid	
Citric Acid	Organic acid	
Fumaric Acid	Organic acid	
Butyric Acid	Organic acid	
Lactobacilli	Probiotic	
Bacilli	Probiotic	
Enterococci	Probiotic	
Yeast	Probiotic	
LAB mix	Probiotic	
Thymol base	Essential oil	Thyme
Carvacrol base	Essential oil	Oregano
Cinnamaldehyde base	Essential oil	Cinnamon
Di/Triallyl base	Essential oil	Garlic
Eugenol base	Essential oil	Clove
P-Cymene base	Essential oil	Rosemary

2.6.2. Eubiotics as products and brand names

Eubiotics are usually sold under a brand name instead of the name of the compound. The products can have a single active compound, or several, as usually the case with essential oil mixes. In the following section, a selection of commercially available eubiotics is described and classified according to their main ingredient in Table 2. This selection is far from complete. However, the purpose is only to provide an indication of how the selected eubiotics in Table 2 relate to actual commercially available products.

2.6.2.1. Benzioc acid/Vevovitall

VevoVitall is a brand name of DSM. The product is benzoic acid, which can be applied as feed additive for growth promotion in piglets (Diao et al., 2016). The study of Diao et al. showed promising results in piglets with an initial weight of 18.75 kg over a 14-day period.

2.6.2.2. *Bacilli/Calsporin*

Orffa sells their probiotic with *Bacillus subtilis* spores under the name Calsporin. Calsporin was demonstrated an effective growth promoting feed additive in both fatteners (Rychen et al., 2018) and weaned piglets (EFSA Panel on Additives & Products or Substances used in Animal Feed, 2010).

2.6.2.3. *Enterococi/Cylactin*

Cylactin is a probiotic feed additive sold by DSM. It contains *Enterococcus faecium* and can be used for sows, suckling piglets, weaned piglets and fatteners (EFSA Panel on Additives & Products or Substances used in Animal Feed, 2015). Efficacy as growth promotor was demonstrated when used for sows, suckling piglets and weaning piglets. The effect on the latter are quantified in the next chapter.

2.6.2.4. *Lactic Acid Bacteria*

Lactic acid bacteria (LAB) are bacteria that produce lactic acid. Positive results were achieved with live lactic acid bacteria (Giang et al., 2010). Live bacteria were isolated from the gut tract of fattener pigs, multiplied and used as probiotic feed additive for weaned piglets. Growth was significantly increased in the experimental groups. Also, the incidence and severity of diarrhea was significantly reduced. Three different experiments with three respective LAB complexes were performed. The first complex consisted of *Enterococcus faecium* 6H2 (3 × 10^8 CFU/g); *Lactobacillus acidophilus* C3 (4 × 10^6 CFU/g) and *Pediococcus pentosaceus* D7 (3 × 10^6 CFU/g). The second tested complex consisted of *E. faecium* 6H2 (3 × 10^8 CFU/g); *L. acidophilus* C3 (4 × 10^6 CFU/g) and *L. plantarum* 1K8 (2 × 10^6 CFU/g). The third complex was a combination of *L. acidophilus* C3 (4 × 10^6 CFU/g); *L. plantarum* 1K8 (2 × 10^6 CFU/g) and *L. plantarum* 3K2 (7 × 10^6 CFU/g). In another study, positive effects with LAB were demonstrated with *lactobacillus plantarum* ZJ316 (Suo et al., 2012). Diarrhea incidence and mortality were reduced, and growth increased. Positive results with lactic acid bacteria were also demonstrated with fattener pigs (Giang et al., 2011). This was achieved with a combination of *Bacillus subtilis* H4, *Saccharomyces boulardi* Sb, *Enterococcus faecium* 6H2, *Lactobacillus acidophilus* C3, *Pediococcus pentosaceus* D7, and *Lactobacillus fermentum* NC1. Lactic Acid bacteria all produce lactic acid, but the vast number of different strains gives manufacturers of eubiotics the opportunity to create their own, unique product.

2.6.2.5. *Aromex ME plus*

Aromex ME Plus Aromex is is a phytogenic feed additive (PFA): a mixture of essential oils. It is based on essential oils of rosemary, thyme and quillaja saponins (Bartoš et al., 2016). Aromex ME Plus showed significant growth improvement in pigs between 68 and 115 kg, but not in the previous growth stage (45-68 kg) of pigs in the same study by Bartoš et al. (2016).

2.6.2.6. *Crina*

DSM produces and sells a mix of essential oils (thymol, eugenol and piperine) as the product Crina Piglets. Efficacy of Crina as a growth promotor did not prove significant (van Krimpen et al., 2003). However, experiments with different combinations of feed additives did result in significant improvement. In particular the combination of Crina Piglets and VevoVitall demonstrated significant growth improvement in weaned piglets. (Zhang et al., 2016).

2.6.2.7. *Fresta F Plus*

Fresta F Plus is another PFA produced by Delacon Biotechnik Ges.m.b.H. It is produced by Delacon Biotechnik Ges.m.b.H. The main ingredients are caraway oil and lemon oil. Just like with Aromex ME plus, fattener pigs demonstrated increased growth performance with Fresta F Plus in the stage between 68 and 115 kg; between 45 and 68 kg, no significant difference occurred in the same trial (Bartoš et al., 2016).

3. Quantification

3.1. Introduction

The possible alternative actions determined at the first research objective are quantified into production parameters and monetary values. The first alternative action considered is that where no action is taken. The second alternative is the application of antibiotics to treat diseases. The third alternative action is the use of eubiotics only. The fourth alternative action is the use of eubiotics with antibiotics. In the alternative actions 2 and 4, antibiotics are applied if an animal gets sick. Input data on the first and second alternative will be supplied by the thesis by Breunesse (2019). The data for the third alternative will be collected from in-vivo studies on piglets and fattener pigs. A combination of these two is used for the fourth alternative.

3.2. Method

The impact of the diseases was quantified by Breunesse (2019). These will serve as inputs for the economic model. In the scenario's involving eubiotics or antibiotics, they will be the anchor points from which the production parameters are impacted by diseases, eubiotics and antibiotics.

3.2.1. Default values

Default growth parameters for unaffected, healthy animals are displayed in Table 3. For both production stages A and B, the average daily growth (ADG) is indicated in grams. Also, the feed conversion ratio (FCR), or the amount of feed required for growth, is displayed. Finally, the average mortality over the herd, or group of animals is listed in per cent. The default growth stages are described in Table 4. The start and end of each stage are defined by the total age of the animal in days and the corresponding weight.

Table 3: Default production parameters in stage A and B (adapted from Breunesse (2019))

Production stage	ADG (g/day)	FCR	Mortality (%)
A	447	1,42	2,4%
B	795	2,61	2,4%

Table 4: Default growth in stage A and B (adapted form Breunesse (2019))

	Days	Kg
A start	28	8
A end	66	25
B start	66	25
B end	182	116,9

3.2.2. Disease impact

The onset and duration of the diseases are displayed in Table 5. In case an animal gets diseased by one of the selected diseases, it is assumed to follow the course displayed in this table. The upper section is the expected course without antibiotic treatment; the lower section is with antibiotic treatment. The effects on production parameters are displayed in Table 6. When an animal is sick, these are the changes in production parameters. These occur during the timeframes specified in Table 5. The clinical impact on ADG, FCR and MORT is listed for all diseases. Additionally, data is included for the subclinical impact of LAW because LAW has a relatively high subclinical occurrence. Little or no clinical symptoms can be noticed, but production parameters deteriorate. Finally, the fraction of animals affected, or epidemiological impact, is displayed in Table 7. The average distribution of healthy, subclinical diseased and clinically diseased animals is indicated for each disease.

Table 5: Start, end and duration of diseases without and with antibiotic treatment (Adapted from Breunesse (2019))

AB treatment		Start age (days)	End age (days)	Days affected
No	PWD	42	66	24
	SALM	42	182	140
	STREP	56	182	126
	LAW	91	182	91
	SD	66	182	116
Yes	PWD	42	49	7
	SALM	42	54	12
	STREP	56	63	7
	LAW	91	98	7
	SD	66	75	9

Table 6: Relative effect of diseases on production parameters (adapted from Breunesse (2019))

	Effect on ADG		Effect on FCR		Mortality stage A+B	
	Subclinical	Clinical	Subclinical	Clinical	No AB	AB
PWD	0,0%	-27,5%	0,0%	12,6%	11,0%	2,0%
SALM	0,0%	-16,2%	0,0%	15,3%	0,0%	0,0%
STREP	0,0%	-51,8%	0,0%	0,0%	5,0%	1,6%
LAW	-12,7%	-20,0%	6,0%	25,0%	3,0%	1,0%
SD	0,0%	-29,4%	0,0%	22,1%	7,6%	2,6%

Table 7: Epidemiological impact – (adapted from Breunesse (2019))

	Healthy	Subclinical	Clinical
PWD	76,5%	0,0%	23,5%
SALM	95,1%	0,0%	4,9%
STREP	87,1%	0,0%	12,9%
LAW	33,4%	53,3%	13,3%
SD	90,0%	0,0%	10,0%

3.2.3. Treatment costs

In case of application of antibiotics to treat diseases, the treatment incurs costs. The costs of antibiotic treatment are listed in Table 8 in euros per animal. Note that LAW SC (subclinical) incurs no costs because no treatment takes place; the disease is subclinical and therefore ‘unknown’ to the farmer.

Table 8: Antibiotic treatment cost per animal (adapted from Breunesse (2019))

Disease	AB treatment cost/animal	
PWD	€	0,13
SALM	€	0,15
STREP	€	0,10
LAW SC	€	-
LAW CL	€	0,22
SD	€	0,22

From the in-vivo results on eubiotics performance in literature, the relative change in performance is used for further calculations. The inputs from literature are transformed into values that can be inputs in the model by Gocsik et al. (2015). This is done by a series of calculations stated below. Calculations are ran separately for both stages A and B. Changes in stage A are expressed in a change in the piglet price: an input of the model. Changes in stage B are expressed in ADG, FCR and mortality: also inputs for the model. Costs of eubiotics and antibiotic treatment are added as variable costs in the model.

3.2.4. Alternative 1 – No action

The first action considered is 'no action'. In this case, no eubtiotics or antibiotics are used to diminish disease impact or promote growth. Changes in production parameters as described by Breunesse (2019) are assumed to be deviations from the baseline production parameters. For ADG and FCR, the relative change is added or deducted to the baseline value for an affected animal during the time it is affected with equation (1) and equation (2).

$$ADG_{Affected,no\ treatment} = ADG_{Default} * (1 + Change\ (\%)\ in\ parameter_{Disease}) \quad (1)$$

$$FCR_{Affected,no\ treatment} = FCR_{Default} * (1 + Change\ (\%)\ in\ parameter_{Disease}) \quad (2)$$

Mortality is the relative number of animals that die before reaching their slaughter weight. The change in mortality from Table 6 is added or deducted to the baseline from Table 3 mortality with equation (3). The mortality is added or deducted in an absolute way, so if the default mortality is 2,4% and the change in mortality caused by the disease is 10%, the total mortality is 2,4% + 10% = 12,4% of the group of animals.

$$Mortality\ (\%)_{Affected,no\ treatmen} = Mortality\ (\%)_{default} + Change\ in\ mortality\ (\%)_{Disease} \quad (3)$$

When animals are affected by a disease, the onset of the disease is assumed to be as described in Table 5. This means the affected animals only express $ADG_{Affected}$ and $FCR_{Affected}$ for the days they are affected. However, reduced $ADG_{Affected}$ causes growth retardation and thus it takes longer for an animal to reach a certain weight. In the case of 'no action', an occurring disease is assumed to last until the animals reaches slaughter weight, except for PWD, which ends at the end of stage A. To calculate the actual number of days an animal is affected in a stage, equation (4) is applied.

$$Days_{Affected,no\ treatment} = \frac{Growth\ in\ stage\ (kg) - (Days_{NotAffected} *\ ADG_{Default})}{ADG_{Affected,no\ treatment}} \quad (4)$$

The total time required to complete growth in a stage then consist of the days an animal is healthy and the days an animal is affected. The total time required for an affected animal in a stage is described by equation (5).

$$Days\ in\ stage_{Affected,no\ treatment} = Days_{NotAffected} + Days_{Affected,no\ treatment} \quad (5)$$

To be able to use the existing model by Gocsik et al. (2015), the production parameters are converted to averages for the entire group of animals. First, production parameters are corrected for the limited time animals are affected. The average ADG and FCR are calculated for affected animals throughout the whole production stage using equation (6) and (7).

$$ADG_{AvAffected\ no\ treat} = \frac{Growth\ in\ stake\ (kg)}{Days\ in\ stage_{Affected,no\ treatment}} \quad (6)$$

$$FCR_{AvAffected,no\ treatment} = \frac{FCR_{Affected,no\ treatment} * Days_{Affected,no\ treatment} + FCR_{Default} * Days_{NotAffected}}{Days\ in\ stage_{Affected,no\ treatment}} \quad (7)$$

Secondly, the production parameters are corrected for the limited fraction of the group of animals that is affected. Table 7 describes the fraction of animals affected by a certain condition. The average production parameters are calculated with equation (8) and (9).

$$ADG_{AvHerd} = ADG_{AvAffected,no\ treatment} * Group_{Affected,no\ treatment}(\%) + ADG_{Default} * (1 - Group_{Affected,no\ treatment}(\%)) \quad (8)$$

$$FCR_{AvHerd} = FCR_{AvAffecte\ ,no\ treatment} * Group_{Affected,no\ treatment}(\%) + FCR_{Default} * (1 - Group_{Affected,no\ treatment}(\%)) \quad (9)$$

To calculate the average time animals need to grow in each stage, $Days\ in\ stage_{Affected}$, the output of equation (5), is corrected for the animals affected in the group using equation (10).

$$Days\ in\ stage_{Av,Group} = Days\ in\ stage_{Affected,no\ treatment} * Group_{Affected}(\%) + Days\ in\ stage_{Default} * (1 - Group_{Affected}(\%)) \quad (10)$$

3.2.4.1. Piglet price

Because the model by Gocsik et al. (2015) only adjusts production parameters for stage B, stage A will be included by adjusting the price of a piglet. The piglet price is determined by adding the additional feed cost, mortality cost and other costs to the default piglet price. Equation (11), (12), (13) and (14) are only applicable to stage A. The additional piglet feed cost is equal to the additional feed required multiplied with the feed price and corrected for the fraction of the group that is affected. It is displayed in equation (11).

$$Additional\ piglet\ feed\ cost = \Big(\big(ADG_{Affected,no\ treatment} * FCR_{Affected,no\ treatment} * Days\ in\ stage_{Affected,no\ treatment}\big) - \big(ADG_{Default} * FCR_{Default} * Days\ in\ stage_{Default}\big)\Big) * Piglet\ feed\ price * Group_{Affected}(\%) \tag{11}$$

Other relevant costs include housing of piglets. These costs are derived from Vermeij (2010). The sum of these costs is divided by the default days in stage A, to estimate the other costs per day per animal as displayed in equation (12). These include housing and utilities.

$$Other\ costs\ per\ day\ per\ animal = \frac{Total\ housing\ cost\ stage\ A}{Days\ in\ stage\ A_{Default}} \tag{12}$$

The other costs per day per animal are used to determine the increase in other costs as part of the piglet price in equation (13).

$$Other\ cost = Other\ cost\ per\ day\ per\ animal * \big(Days\ in\ stage_{Affected,no\ treatment} - Days\ in\ stage_{Default}\big) * Group_{Affected}(\%) \tag{13}$$

To determine the cost of mortality, death halfway the stage is assumed as in equation (14).

$$Mortality\ cost = Piglet\ price_{8\ kg} + Other\ cost + \left(\frac{Piglet\ price_{25\ kg} - Piglet\ price_{8\ kg}}{2}\right) * Mortality\ (\%)_{Affected,no\ treatment} \tag{14}$$

The sum of equation (11), (13) and (14) then gives the increase in piglet price in a certain condition. The total piglet price is corrected in equation (15).

$$Piglet\ price = Piglet\ price_{Default} + Additional\ piglet\ feed\ cost + Other\ costs + Mortality\ cost \tag{15}$$

The equations (3), (8), (9) and (15) provide inputs for the model by Gocsik et al. (2015).

3.2.5. Alternative 2 - Antibiotics

The second alternative action is to use antibiotics to treat the diseases. Calculation for this alternative are the same as in Alternative 1 – No action, with two exceptions: adjustments are made for the growth period and treatment costs. Calculations for this alternative are labeled with *Affected, AB treatment* instead of *Affected, no treatment*. In this scenario, animals are affected for a shorter period because the disease is assumed to be fully cured after treatment. The $Days_{Affected,AB\ treatment}$ are given by Table 5. Equation (5) is replaced to calculate the days required to compensate growth retardation during the affected period. To do this, the (slower) growth during the disease is multiplied with the number of days the animal is affected. This is subtracted from the total growth required in the stage. The remainder is divided with the $ADG_{Default}$ and leaves the number of $Days_{NotAffected}$ as displayed in equation (16).

$$Days_{NotAffected} = \frac{Total\ growth\ in\ stage - \ (Days_{Affected\ AB,treatment} * ADG_{Affected,AB\ treatment})}{ADG_{Default}} \tag{16}$$

The cost of antibiotic treatment is the sum of the *antibiotic treatment* and *farm visit veterinarian* by Breunesse (2019) and is displayed in Table 8. These represent the cost of the antibiotic material and the cost of the veterinarian. The cost of treatment is assigned depending on the production stage where the disease occurs. For conditions in stage A, the cost of antibiotic treatment is included in the piglet price: it is added to the sum in equation (15). For conditions occurring in stage B, the cost of antibiotic treatment is deducted from the net return to management.

3.2.6. Alternative 3 – Eubiotics

In the third alternative, eubiotics are mixed with the animal feed to reduce the chance animals get diseased, reduce disease impact, improve growth and/or decrease feed conversion ratio. For each eubiotics (category) in Table 2 the average impact of the eubiotics on ADG and FCR was calculated for both production stages.

The papers selected in previous chapter's literature study all feature quantitative data on production parameters and involved in-vivo experiments. The results and relevant parameters were included in the database to assess the expected impact on growth parameters, so these can be entered in the economic model later. The database includes the following parameters, when available: eubiotics name/active compound; concentration in feed; animals inoculated with infection during experiments (Y/N); type of disease/infection introduced; rate of (sub)clinical symptoms (%); growth stage (A/B); change in ADG (%); change in FCR (%); mortality (%); source; additional comments.

Outliers and duplicates where removed with the help of A. Mary. The full list of studies including the details listed above can be found in the file "eubiotics database.xlsx". To be able to use the results, they were grouped. For each eubiotic (category), the literature results in the database where divided in four categories. The categories distinguish results in stage A or B and if an infection/disease was tested for in the experiment. If case of no results in a category, it was excluded. Within each category, the results were averaged to determine the expected impact on growth parameters. The impact on production parameters of each eubiotic (category) is displayed in Table 9. The categories are indicated by the different columns.

Table 9: Impact of eubiotics on production parameters in stage A and B in healthy or diseased condition

	Stage A				Stage B				
	Not infected		Infected		Not infected		Infected		Infection
Eubiotic	ADG	FCR	ADG	FCR	ADG	FCR	ADG	FCR	
Benzoic Acid	13,7%	-5,1%	11,5%	-3,6%	4,4%	-2,1%			PWD
Formic Acid	12,7%	-1,7%	14,6%	-6,9%	5,9%	0,3%			PWD
Lactic Acid	6,7%	-0,8%			9,0%	-4,9%			
-Propionic Acid	13,8%	-6,0%	8,5%	-4,8%					PWD
Citric Acid	0,4%	-5,5%							
Fumaric Acid	3,1%	5,0%							
Butyric Acid	1,6%	-3,0%			7,2%	-0,5%			
Lactobacilli	8,3%	-4,9%	19,2%	-7,4%	16,2%				PWD
Bacilli	4,2%	-2,7%			2,8%	-2,3%			
Enterococci	5,9%	-4,3%	7,3%	0,0%	3,7%	-2,3%			SALM
Yeast	8,3%	-0,3%			5,8%	11,5%			
LAB mix	7,7%	-5,0%			3,8%	-2,4%			
Thymol base	9,0%	-3,9%			2,0%	-2,8%			
Carvacrol base	-1,0%	0,3%	-0,1%		0,2%	-0,2%			PWD
Cinnamaldehyd e base	1,6%	-1,7%			3,2%	1,0%			
Di/Triallyl base	5,2%	-4,3%			4,8%	-6,2%			
Eugenol base	0,9%	-2,4%			0,9%	-2,0%			
P-Cymene base					-0,1%	0,5%			

The effect on production parameters was calculated for all combinations of selected diseases as selected in Table 5, eubiotics selected in Table 2 and -when relevant- for each production stage. All calculations are the same as in Alternative 1 – No action, but with different production parameters. Because all animals are fed the same (feed with eubiotics), two changes occur in production parameters: healthy animals express better growth because of eubiotics, and disease likelihood and impact is reduced.

The default production parameters for healthy animals in the previous formulas were replaced by improved production parameters due to eubiotics. The improved production parameters are the default production parameters plus the changes indicated columns 'Not infected' for stage A and B in Table 9. The production parameters ADG and FCR for healthy animals are described by equation (17) and (18). Change in mortality is not considered for healthy animals.

$$ADG_{Healthy,eubiotic} = ADG_{Default} * (1 + Change\ in\ parameter_{Eubiotic}(\%)) \quad (17)$$

$$FCR_{Healt\quad,eubiotic} = FCR_{Default} * (1 + Change\ in\ parameter_{Eubiotic}(\%)) \quad (18)$$

The production parameters for diseased animals were based on the diminished production parameters as displayed in Table 6. Next, these were corrected for the impact reduction caused by each eubiotic as displayed in Table 9. The production parameters for diseased animals are described by equation (19), (20) and (21). The $ADG_{Affected,no\ treatment}$, $FCR_{Affected,no\ treatment}$ and $Mortality_{Affected,no\ treatment}(\%)$ are respectively derived from equation (1), (2) and (3).

$$ADG_{Affected,eubiotic} = ADG_{Affected,no\ treatment} * (1 + Change\ in\ parameter_{Eubiotic}\ (\%)) \quad (19)$$

$$FCR_{Affected,eubiotic} = FCR_{Affected,no\ treatment} * (1 + Change\ in\ parameter_{Eubiotic}\ (\%)) \quad (20)$$

$$Mortality\ (\%)_{Affected,eubiotic} = Mortality_{Affected,no\ treatment}(\%) + Change\ in\ parameter_{Eubiotic}\ (\%) \quad (21)$$

Later, the two sets of production parameters -for healthy and diseased animals- were combined. This is required because the application of eubiotics is assumed to be for the whole group of animals, and the likelihood of disease should be weighed in to determine average production parameters for the whole group.

3.2.7. Alternative 4 – Eubiotics + Antibiotics

The fourth alternative is a combination of eubiotics and antibiotics. The beneficial effects of eubiotics are combined with the possibility to cure a disease with antibiotics if it occurs. Calculations were a combination of those in alternative 2 and alternative 3. The main assumption is that eubiotics enhance production parameters and reduce the likelihood and impact of disease. However, if a disease does occur, it can be treated with antibiotics and the animal will be healthy after treatment.

Here, the $Days_{NotAffected,AB,eubiotic}$ was calculated in the same way as Alternative 2 because the disease is assumed to last a given time. The days an animal is not affected during a production stage is given by equation (22).

$$Days_{NotAffected,AB,eubiotic} = \frac{Total\ growth\ in\ stage - (Days_{Affected,AB\ treatment} * ADG_{Affected,AB\ treatment})}{ADG_{Healthy,eubiotic}}$$

(22)

3.2.8. Disease incidence

The above calculations regarding the alternative actions will provide average production parameters in case a disease occurs. However, eubiotics are either mixed with feed or not: they do not provide treatment but a combination of growth promotion and reduction of disease likelihood and impact. Because of these properties, it is especially important to weigh in the expected incidence of diseases. This way, the benefit of improved growth for healthy animals and reduced disease likelihood and impact is proportionated. The weight of different conditions was assigned according to Table 10. The chance of an outbreak in a given production round was multiplied with the production parameter in case of a disease occurring in the group. Next, this product was divided by the total of a weight, which is 100 % in this case. The calculation is displayed in equation (23).

$$Average\ production\ parameter_{\ i} = \sum_{i=1}^{N} \frac{weight_i * production\ parameter_i}{\sum_{i=1}^{N}(weight_i)}$$

(23)

Table 10: Expected disease incidence (adapted from GD (2017))

Disease	Chance of outbreak/round
Post-weaning diarrhea	3,9%
Salmonellosis	0,4%
Swine Dysentery	0,9%
Ileitis (subclinical)	8,7%
Ileitis (clinical)	4,7%
Streptococcus	0,7%
None	80,6%

3.3. Assumptions

Several assumptions were done due to a lack of available data or for the sake of the model. These assumptions are described below.

1) Average production parameters for healthy, unaffected animals are as described in Table 3.
2) Days indicate the age of the animal. The piglets are born at t=0 and begin stage A at t=28. Stages A and B are assumed to progress as listed in Table 4. The weight of the animal determines in what stage the animal is.
3) Linear growth is assumed over a production stage.
4) When animal growth is slowed down, the ADG is used as a basis to calculate the growth period length of a stage in days. ADG was chosen because the farmer's goal is to get the animal to slaughter weight, and this assumption is aimed at that.
5) The onset and duration of a disease are as described by Breunesse (2019) in Table 5. This implies an animal can be either diseased or healthy. In case an animal gets diseased, the disease will last for the specified time.
6) In the case of STREP without AB treatment, MORT is equally divided across both production stages A and B. The disease on average occurs in stage A as can be seen in Table 5. Without treatment, most of the time an animal is diseased is in stage B. However, animals in stage A are assumed to be more likely to die from this type of infection. Taking both effects into account, mortality is divided equally. This estimation was necessary because the in-vivo results found in literature featured too small samples to provide proper foundation for further calculations.
7) In the case of sub-clinical Ileitis in alternative 2 and 4, no antibiotic treatment occurs. Because the disease is sub-clinical, it is not noted by the farmer. The animals are therefore not treated as opposed to a situation with a clinical disease.
8) Eubiotics with a significant effect on growth parameters and/or infection rate reduce the mortality caused by the disease by an average 50%, normally distributed with a standard deviation of 40%. These estimations were determined with the help of expert A. Mary. The standard deviation was applied in the sensitivity analysis, which is discussed later in this report. These estimations were necessary because the in-vivo results found in literature featured too small samples to provide proper foundation for further calculations.
9) Eubiotics with a significant effect on growth parameters reduce the chance of infection by an average of 33.3%, normally distributed with a standard deviation of 30%. This assumption was determined in the same way and for the same reason as assumption 8).
10) Eubiotics are added to feed, so the amount of feed stays the same. If a eubiotic is added as 1% of the feed, the total amount is 100% feed + 1% eubiotic = 101%.

3.4. Outcome quantification

The full outputs of the calculations to obtain values for the model are not included in this report due to the large amount and size of the tables, but a brief summary is given. The complete output is available in Appendix I: production parameters

First, the effect of eubiotics on production parameters was calculated. The impact of eubiotics on production parameters was assessed according to paragraph 3.2.6. The quantified impact of the selected eubiotics is displayed in Table 9. In this table, the first column indicated the type of eubiotic. Impact of the different eubiotics on production parameters are given for production stage A and B and for each stage impact on healthy or diseased animals are distinguished. Empty spaces are due to the absence of literature results and are considered zero. The data in this table is the first step in establishing the production parameters of the whole group of animals.

Secondly, all calculations to determine production parameters in case of a disease were ran. This was done for each alternative action, resulting in *4 alternative actions * 7 conditions/diseases* = 28 sets of outcomes. In the scenario's involving eubiotics, the production parameters are given for each type of eubiotic. An example of these results is given in Table 11. In this table, the production parameters are given for the scenario where PWD occurs and eubiotics are used. The full selection is available in Appendix I: production parameters.

Third, the outcomes in the previous paragraph were combined to provide an expected value. For each alternative, seven diseases/conditions are weighed according to their chance of occurrence as given in Table 10. This resulted in a set of expected outcomes for each of the four alternative actions. An example is given in Table 12. In this table, the average production parameters for the whole group of animals with the use of eubiotics (Alt. 3) is displayed. The columns indicate the applied eubiotic, production parameters ADG, FCR and MORT and the piglet price. The latter four parameters will serve as inputs for the financial model. In the parameters generated in this step, the impact and incidence of the discussed diseases are taken into account, as well as growth promotion. In total, 4 averaged tables were produced: one for each alternative action. These are available in Appendix I: production parameters. The outcomes of alternative action one and two, *no action* and *antibiotic treatment* have only one line of data because these alternative actions only have one outcome each. The tables with alternative action three and four include a row for each eubiotic (category).

Table 11: Average production parameters in the case of PWD occurence with use of eubiotics

Alt 3. – Eubiotics only	PWD			
Eubiotic	ADG	FCR	MORT	Piglet price
None	795	2,61	2,40%	€ 38,11
Benzoic Acid	830	2,55	2,40%	€ 35,82
Formic Acid	842	2,62	2,40%	€ 35,99
Lactic Acid	866	2,48	2,40%	€ 36,36
Propionic Acid	795	2,61	2,40%	€ 36,46
Citric Acid	795	2,61	2,40%	€ 36,38
Fumaric Acid	795	2,61	2,40%	€ 37,32
Butyric Acid	853	2,60	2,40%	€ 36,48
Lactobacilli	924	2,61	2,40%	€ 36,07
Bacilli	817	2,55	2,40%	€ 36,41
Enterococci	824	2,55	2,40%	€ 36,27
Yeast	841	2,91	2,40%	€ 36,46
LAB mix	826	2,55	2,40%	€ 36,19
Thymol base	811	2,54	2,40%	€ 37,06
Carvacrol base	796	2,60	2,40%	€ 37,58
Cinnamaldehyde base	821	2,64	2,40%	€ 36,77
Di/Triallyl base	833	2,45	2,40%	€ 36,53
Eugenol base	802	2,56	2,40%	€ 36,75
P-Cymene base	795	2,62	2,40%	€ 42,43

Table 12: Average production parameters with use of eubiotics after taking the disease likelihood into account

Alt 3. – Eubiotics only	Average production parameters for entire group			
Eubiotic	ADG	FCR	MORT	Piglet price
None	790	2,62	2,63%	€ 34,57
Benzoic Acid	825	2,56	2,52%	€ 34,06
Formic Acid	837	2,62	2,52%	€ 34,26
Lactic Acid	860	2,49	2,52%	€ 34,52
Propionic Acid	792	2,62	2,52%	€ 34,59
Citric Acid	792	2,62	2,52%	€ 34,50
Fumaric Acid	792	2,62	2,52%	€ 35,40
Butyric Acid	847	2,60	2,52%	€ 34,61
Lactobacilli	916	2,62	2,52%	€ 34,32
Bacilli	813	2,56	2,52%	€ 34,55
Enterococci	820	2,56	2,52%	€ 34,41
Yeast	836	2,91	2,52%	€ 34,60
LAB mix	821	2,56	2,52%	€ 34,33
Thymol base	807	2,55	2,52%	€ 35,07
Carvacrol base	793	2,61	2,52%	€ 35,57
Cinnamaldehyde base	816	2,64	2,52%	€ 34,87
Di/Triallyl base	829	2,46	2,52%	€ 34,62
Eugenol base	798	2,57	2,52%	€ 34,84
P-Cymene base	791	2,63	2,52%	€ 39,67

4. Monetary output & sensitivity

The results of the second research objective, in which the effects of disease and alternative actions where quantified, serve as input for the model used in the third research objective, in which the financial impact was determined. The calculated production parameters ADG, FCR, piglet price, mortality, additional medical costs and costs of eubiotics were entered in the model by Gocsik et al. (2015). This model was originally designed to compare the economic feasibly of different production systems in pig production over a five-year period. The different production systems represent different standards of animal welfare. In this research, the standard production system was used a baseline and the other production systems such as higher animal welfare systems, were excluded. All input variables except for the ones listed above were kept the same. In this research, the *net return to management per animal*, which was an intermediate outcome in the original model, is the final output. For more information about the model and the research it was used for, please refer to Gocsik et al. (2015).

4.1. Method – deterministic modeling

The adjusted ADG, FCR and MORT and piglet price calculated for the different alternative action and different eubiotics were entered in the model. The price of antibiotic treatment as displayed in Table 8 was deducted from the *net return to management per animal*. The cost of eubiotics per animal was calculated according to feed quantity and deducted in the same way. Eubiotics are generally mixed in feed at a concentration of 0.05 – 1.5 %. In the model, the eubiotics were added to the required amount of feed, resulting a total quantity of more than 100%. This was chosen because reducing the amount of nutritional feed and replacing it with a eubiotic would not be realistic. The costs of eubiotics were calculated by multiplying the feed quantity per animal with the concentration and the price of the eubiotic. The feed concentrations and prices of the eubiotics are displayed in Table 13. Calculating the costs of eubiotics was done for both stages A and B. In stage A, the costs of eubiotics were included in the piglet price. In stage B, the costs were deducted from the net return per animal.

The difference between alternative 1 (no action) and the other alternative actions in net return to management per animal is calculated for each situation. This outcome gives a monetary value of using eubiotics, antibiotics or both.

Table 13: Eubiotic feed concentration and price

#	Eubiotic	feed %	€/kg
1	Benzoic Acid	0,50%	€ 1,50
2	Formic Acid	0,75%	€ 0,90
3	Lactic Acid	1,20%	€ 0,90
4	Propionic Acid	1,00%	€ 3,75
5	Citric Acid	1,50%	€ 1,10
6	Fumaric Acid	2,00%	€ 1,60
7	Butyric Acid	0,40%	€ 4,00
8	Lactobacilli	0,05%	€ 30,00
9	Bacilli	0,05%	€ 30,00
10	Enterococci	0,05%	€ 30,00
11	Yeast	0,05%	€ 30,00
12	LAB mix	0,05%	€ 30,00
13	Thymol base	0,20%	€ 25,00
14	Carvacrol base	0,20%	€ 25,00
15	Cinnamaldehyde base	0,10%	€ 25,00
16	Di/Triallyl base	0,10%	€ 25,00
17	Eugenol base	0,10%	€ 25,00
18	P-Cymene base	1,00%	€ 25,00

#	Price source
1	A. Kies
2	A. Kies
3	https://www.alibaba.com/product-detail/Best-Sale-Food-grade-lactic-acid_60763860137.html?spm=a2700.7724838.2017115.1.5a8d6d68Ukgalh&s=p
4	https://www.alibaba.com/product-detail/Propionic-acid-food-grade-C3H6O2_60319305284.html?spm=a2700.7724838.2017115.32.252b593bAYhSQA
5	A. Kies
6	A. Kies
7	A. Kies
8	estimation
9	estimation
10	estimation
11	estimation
12	estimation
13	Crina, A. Kies
14	https://www.alibaba.com/product-detail/Essential-oil-bulk-pure-oregano-essential_60667378263.html?spm=a2700.7724857.normalList.18.5eb3457d3RytDX&s=p
15	https://www.alibaba.com/product-detail/Cinnamon-Bark-Essential-Oil-100-Pure_60788699187.html?spm=a2700.7724857.normalList.248.472a2f8fIhrcOf
16	https://www.alibaba.com/product-detail/Bulk-Natural-and-Synthetic-Garlic-Oil_60746940140.html?spm=a2700.7724857.normalList.78.61927d17cOikSp
17	https://www.alibaba.com/product-detail/Bulk-Natural-and-Synthetic-Garlic-Oil_60746940140.html?spm=a2700.7724857.normalList.78.61927d17cOikSp
18	https://www.alibaba.com/product-detail/China-factory-100-Pure-and-Natural_60814969446.html?spm=a2700.7724838.2017115.1.40966532vDPLVr

4.2. Outcome financial model (deterministic)

The difference in net return per animal from the baseline situation (Alt.1) for the other alternative actions is displayed in Table 14. Using antibiotics resulted in an average increase in net return per animal of €0,35. Using eubiotics (Alt. 3) resulted in an increase in net return per animal when using benzoic acid, formic acid, lactic acid and lactobacilli. The expected benefits were respectively €1,24, 0,39, €2,55 and 0,86 per animal. The other eubiotics resulted in a deterioration of the net profit per animal of 0,86 to 65,87. As expected, results improved when combining eubiotics and antibiotics. However, benzoic acid, formic acid, lactic acid and lactobacilli were still the only eubiotics resulting in a higher profit. The expected benefits were respectively €1,51, 0,63, €2,75 and 1,09 per animal. Note that these values are lower than the sum of the individual values of antibiotics and eubiotics. In Table 15 the changes in net profit per year all given for all the same options. The change in net profit per animal was multiplied by the annually produced number of animals to present results on an annual basis. The expected change in annual net profit was in the range of €4 900 – €36 000 per year for the profitable eubiotics. All these values were higher than that of Alt. 2 – antibiotics, which resulted in a change in annual net profit of €4 166, 50.

Table 14: Difference in net return per animal for different alternative actions

	Δ net return per animal			
Eubiotic	Alt. 1 – No action	Alt. 2 – Antibiotics	Alt. 3 – Eubiotics	Alt. 4 – Eub + AB
None	€ -	€ 0,35	€ -	€ 0,35
Benzoic Acid			€ 1,24	€ 1,51
Formic Acid			€ 0,39	€ 0,63
Lactic Acid			€ 2,55	€ 2,75
Propionic Acid			€ -8,85	€ -8,65
Citric Acid			€ -3,71	€ -3,50
Fumaric Acid			€ -8,37	€ -8,32
Butyric Acid			€ -1,44	€ -1,25
Lactobacilli			€ 0,86	€ 1,09
Bacilli			€ -1,36	€ -1,16
Enterococci			€ -1,01	€ -0,78
Yeast			€ -8,07	€ -7,89
LAB mix			€ -0,83	€ -0,60
Thymol base			€ -10,05	€ -9,94
Carvacrol base			€ -12,69	€ -12,66
Cinnamaldehyde base			€ -5,72	€ -5,57
Di/Triallyl base			€ -1,06	€ -0,87
Eugenol base			€ -4,74	€ -4,59
P-Cymene base			€ -65,87	€ -66,50

Table 15: Annual changes in net return of each alternative on farm level

	Annual result			
Eubiotic	Alt. 1	Alt. 2	Alt. 3	Alt. 4
None	€ -	€ 4.166,50	€ -	€ 4.166,50
Benzoic Acid			€ 15.490,55	€ 18.990,48
Formic Acid			€ 4.902,48	€ 7.953,93
Lactic Acid			€ 33.297,45	€ 35.939,75
Propionic Acid			€ -106.402,90	€ -104.180,32
Citric Acid			€ -44.559,92	€ -42.109,72
Fumaric Acid			€ -100.679,17	€ -100.136,55
Butyric Acid			€ -18.490,56	€ -16.128,62
Lactobacilli			€ 11.902,59	€ 15.064,87
Bacilli			€ -16.765,05	€ -14.336,61
Enterococci			€ -12.509,87	€ -9.768,62
Yeast			€ -102.362,20	€ -100.136,22
LAB mix			€ -10.352,93	€ -7.429,89
Thymol base			€ -123.153,35	€ -121.862,52
Carvacrol base			€ -152.841,05	€ -152.662,77
Cinnamaldehyde base			€ -70.859,46	€ -69.158,81
Di/Triallyl base			€ -13.290,68	€ -10.951,78
Eugenol base			€ -57.460,38	€ -55.697,69
P-Cymene base			€ -791.687,62	€ -800.199,76

4.3. Method - stochastic analysis

The inputs used to determine the production parameters were based on experimental results, but also partially on estimations and assumptions. They were selected in such a way to find the right balance between reliability, validity, practical possibilities, and the accessibility of data. In other words, they are subject to uncertainty. In such a situation, it is important to check the sensitivity of the model. By varying the input parameters, the robustness of the results can be checked. This was done by varying input parameters with the Palisade @Risk plugin for Excel. 500 Iterations were done, resulting in 500 results for each outcome. For several parameters, their deterministic value was replaced by a stochastic distribution. Below is an explanation of the altered parameters.

The production parameters MORT and the epidemiological impact (part of the group that is affected by a disease) were set as triangular distributions. The expected value was kept the same, and the minimum values where set according to the 'best' and the maximum value to the 'worst' results as determined by Breunesse (2019). Furthermore, the chance that an animal dies from a disease was varied in the situations where eubiotics were applied. It was distributed normally with a mean of 50% and a standard deviation of 40% (as described in assumption 8). E.g., a disease resulting in an MORT increase of 10% now has a mean value of 5%. Also, the chance of that an animal is affected by disease was varied in the situations where eubiotics were applied. It was distributed normally with a mean of 33.3% and a standard deviation of 30% (as described in assumption 9). The stochastic input parameters are summarized in Appendix II: Stochastic inputs.

The results on alternative 3 and 4 are changes in net profit per animal. The anchor point for this change, or baseline, is alternative 1: no action. By using alternative 1 as baseline, the value of different options can be easily compared. However, curative antibiotic treatment as modeled in alternative 2 is standard practice in the Netherlands. For this reason, the value of eubiotics compared to antibiotics was checked. The financially most attractive eubiotics were compared to the outcome of alternative 2 by deducting the value of alternative 2. For this simulation, 5000 iterations were done.

4.4. Outcome financial model (stochastic)

The model was ran with the stochastic input parameters described in the previous paragraph. This resulted in a range of outcomes for each combination of eubiotic and alternative action 3 and 4. For each range, the minimal, mean and maximum values are displayed in Table 16 (Alt. 3) and

Table 17 (Alt. 4), both raw output of the @Risk tool. In the tables, the first column indicates which eubiotic was used. The graph column gives a graphical representation of the 500 outcomes and how they are distributed. Next, the lowest (Min) average, (Mean) and highest (Max) values of the simulation are given. @Risk automatically gives the 5% and 95% percentiles in the next columns. Finally, the error rate of 0 confirms the correct execution of the simulation. These results give a good overview of which eubiotics are likely to be interesting to farmers and which are not. By looking at the outer limits of each range, one can quickly see that the eubiotics with a minimum (min) value of more than 0 can be considered more profitable than the baseline situation (alt. 1). Eubiotics with a maximum value lower than 0 were never more profitable than the baseline situation (alt. 1).

The eubiotics with a minimum value higher than 0 when only using eubiotics (Alt. 3) were Benzoic acid, lactic acid and lactobacilli. In combination with antibiotics (Alt. 4), these three and formic acid had a minimum value of more than 0. This means that these options result in a higher net profit than taking no action in any of the 500 iterations.

In alternative 3, the results for formic acid spanned from €-0.10 to €0.90. This means that -taking uncertainty into account- the change in net profit per animal can be either positive or negative.

All other eubiotics had negative upper limits for change in net profit. The negative upper limit indicates that a negative change in net profit per animal occurred in every of the 500 iterations.

The change in net profits per animal with the use of benzoic acid, formic acid, lactic acid and lactobacilli (Alt. 3, without antibiotic treatment) were compared to the outcome of alternative 2, antibiotic treatment only. By comparing the change in net profit per animal of these eubiotics and deducting the result of alternative 2, positive mean results still occur for these eubiotics occur. This indicates that on average, the monetary value of using these eubiotics is higher than of antibiotics. In Figure 1 and Figure 2, probability density graphs of the net return per animal with the use of formic acid and lactobacilli compared to antibiotics are displayed. In the simulation, the added net return of using formic acid was higher than the added return of using antibiotics in 50,7% of 5000 iterations. For lactobacilli, this was 99,7%. Probability density graphs for benzoic acid and lactic acid are not included, because 100% of their outcomes were positive in this situation.

Table 16: Stochastic results Alt 3. - Eubiotics only.

Output is change in net profit per animal. Columns min, mean, max represent lowest, average and highest values.

Inputs | Outputs | Statistic Functions — Inputs= 14; Outputs= 42; Statistic Functions= 0; Iterations= 500; Runtime= 00:00:06

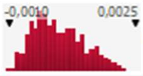
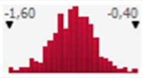
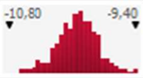
Name	Worksheet	Cell	Graph	Min	Mean	Max	5%	95%	Errors
Range: Alt. 3									
None / Alt. 3	Output	N33		€0,00	€0,00	€0,00	€0,00	€0,00	0
Benzoic Acid / Alt. 3	Output	N34		€0,70	€1,26	€1,82	€0,94	€1,54	0
Formic Acid / Alt. 3	Output	N35		-€0,10	€0,40	€0,90	€0,12	€0,66	0
Lactic Acid / Alt. 3	Output	N36		€1,92	€2,58	€3,26	€2,22	€2,94	0
Propionic Acid / Alt. 3	Output	N37		-€9,33	-€8,84	-€8,35	-€9,12	-€8,59	0
Citric Acid / Alt. 3	Output	N38		-€4,17	-€3,70	-€3,22	-€3,96	-€3,46	0
Fumaric Acid / Alt. 3	Output	N39		-€8,85	-€8,36	-€7,88	-€8,63	-€8,12	0
Butyric Acid / Alt. 3	Output	N40		-€1,97	-€1,42	-€0,87	-€1,73	-€1,14	0
Lactobacilli / Alt. 3	Output	N41		€0,30	€0,88	€1,47	€0,56	€1,18	0
Bacilli / Alt. 3	Output	N42		-€1,89	-€1,34	-€0,78	-€1,65	-€1,05	0
Enterococci / Alt. 3	Output	N43		-€1,55	-€0,99	-€0,41	-€1,31	-€0,69	0
Yeast / Alt. 3	Output	N44		-€8,33	-€8,09	-€7,85	-€8,21	-€7,96	0
LAB mix / Alt. 3	Output	N45		-€1,38	-€0,81	-€0,23	-€1,13	-€0,52	0
Thymol base / Alt. 3	Output	N46		-€10,64	-€10,04	-€9,42	-€10,38	-€9,72	0
Carvacrol base / Alt. 3	Output	N47		-€13,19	-€12,68	-€12,17	-€12,97	-€12,42	0
Cinnamaldehyde base / Alt. 3	Output	N48		-€6,29	-€5,71	-€5,23	-€5,99	-€5,47	0
DiTriallyl base / Alt. 3	Output	N49		-€1,73	-€1,03	-€0,32	-€1,41	-€0,66	0
Eugenol base / Alt. 3	Output	N50		-€5,26	-€4,72	-€4,18	-€5,03	-€4,44	0
P-Cymene base / Alt. 3	Output	N51		-€66,55	-€65,86	-€65,20	-€66,25	-€65,52	0

Table 17: Stochastic results Alt 4. - Eubiotics + Antibiotics

Output is change in net profit per animal. Columns min, mean, max represent lowest, average and highest values.

Inputs | Outputs | Statistic Functions — Inputs= 14; Outputs= 42; Statistic Functions= 0; Iterations= 500; Runtime= 00:00:06

Name	Worksheet	Cell	Graph	Min	Mean	Max	5%	95%	Errors
Range: Alt. 4									
None / Alt. 4	Output	O33	0,15 – 0,65	€0,20	€0,40	€0,63	€0,26	€0,53	0
Benzoic Acid / Alt. 4	Output	O34	1,10 – 2,00	€1,12	€1,58	€1,99	€1,37	€1,78	0
Formic Acid / Alt. 4	Output	O35	0,20 – 1,10	€0,28	€0,68	€1,05	€0,51	€0,87	0
Lactic Acid / Alt. 4	Output	O36	2,20 – 3,40	€2,28	€2,83	€3,34	€2,57	€3,08	0
Propionic Acid / Alt. 4	Output	O37	-9,00 – -8,20	-€8,97	-€8,60	-€8,26	-€8,77	-€8,42	0
Citric Acid / Alt. 4	Output	O38	-3,90 – -3,10	-€3,80	-€3,45	-€3,12	-€3,60	-€3,27	0
Fumaric Acid / Alt. 4	Output	O39	-8,70 – -7,90	-€8,61	-€8,26	-€7,94	-€8,42	-€8,09	0
Butyric Acid / Alt. 4	Output	O40	-1,70 – -0,70	-€1,63	-€1,19	-€0,79	-€1,39	-€0,99	0
Lactobacilli / Alt. 4	Output	O41	0,60 – 1,60	€0,67	€1,15	€1,60	€0,93	€1,37	0
Bacilli / Alt. 4	Output	O42	-1,60 – -0,60	-€1,54	-€1,10	-€0,69	-€1,30	-€0,89	0
Enterococci / Alt. 4	Output	O43	-1,20 – -0,30	-€1,17	-€0,72	-€0,30	-€0,93	-€0,52	0
Yeast / Alt. 4	Output	O44	-8,10 – -7,55	-€8,08	-€7,86	-€7,58	-€8,00	-€7,73	0
LAB mix / Alt. 4	Output	O45	-1,00 – -0,10	-€0,99	-€0,53	-€0,11	-€0,74	-€0,32	0
Thymol base / Alt. 4	Output	O46	-10,40 – -9,40	-€10,35	-€9,87	-€9,43	-€10,09	-€9,66	0
Carvacrol base / Alt. 4	Output	O47	-13,00 – -12,20	-€12,98	-€12,60	-€12,26	-€12,77	-€12,42	0
Cinnamaldehyde base / Alt. 4	Output	O48	-6,00 – -5,10	-€5,93	-€5,52	-€5,19	-€5,68	-€5,34	0
DiTriallyl base / Alt. 4	Output	O49	-1,40 – -0,20	-€1,37	-€0,79	-€0,26	-€1,07	-€0,54	0
Eugenol base / Alt. 4	Output	O50	-5,00 – -4,10	-€4,95	-€4,53	-€4,14	-€4,71	-€4,33	0
P-Cymene base / Alt. 4	Output	O51	-66,90 – -66,00	-€66,87	-€66,43	-€66,04	-€66,63	-€66,23	0

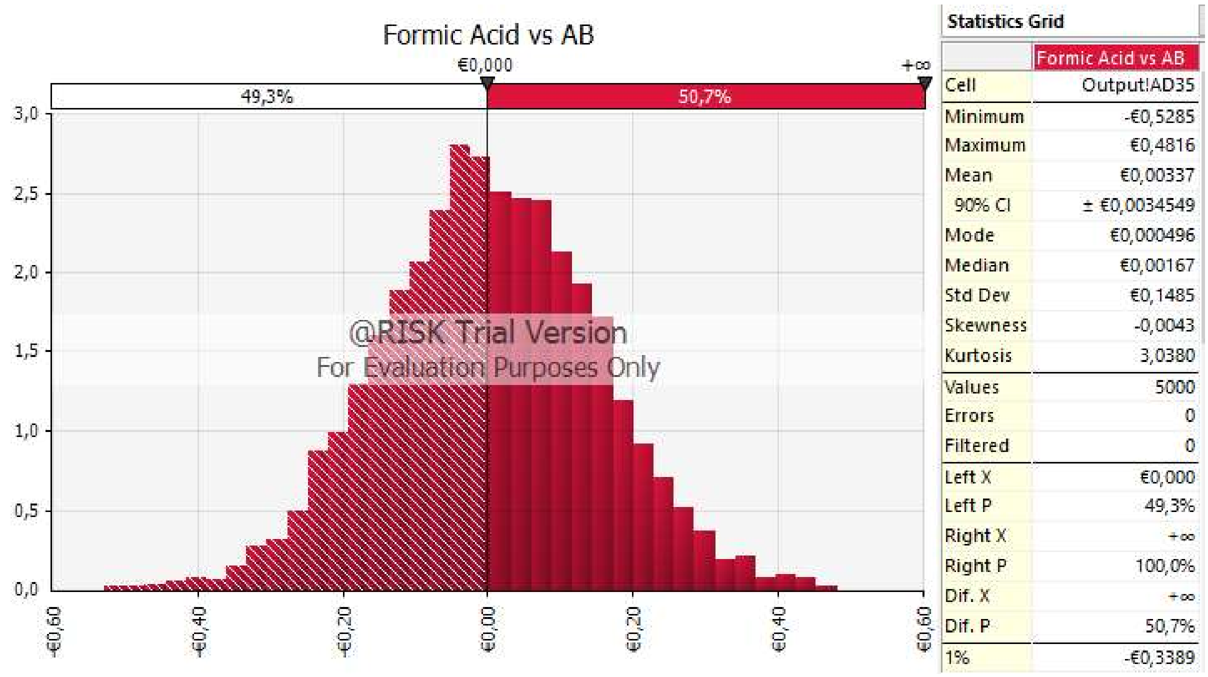


Figure 1: Probability density graph of the change in net profit per animal of formic acid versus antibiotics

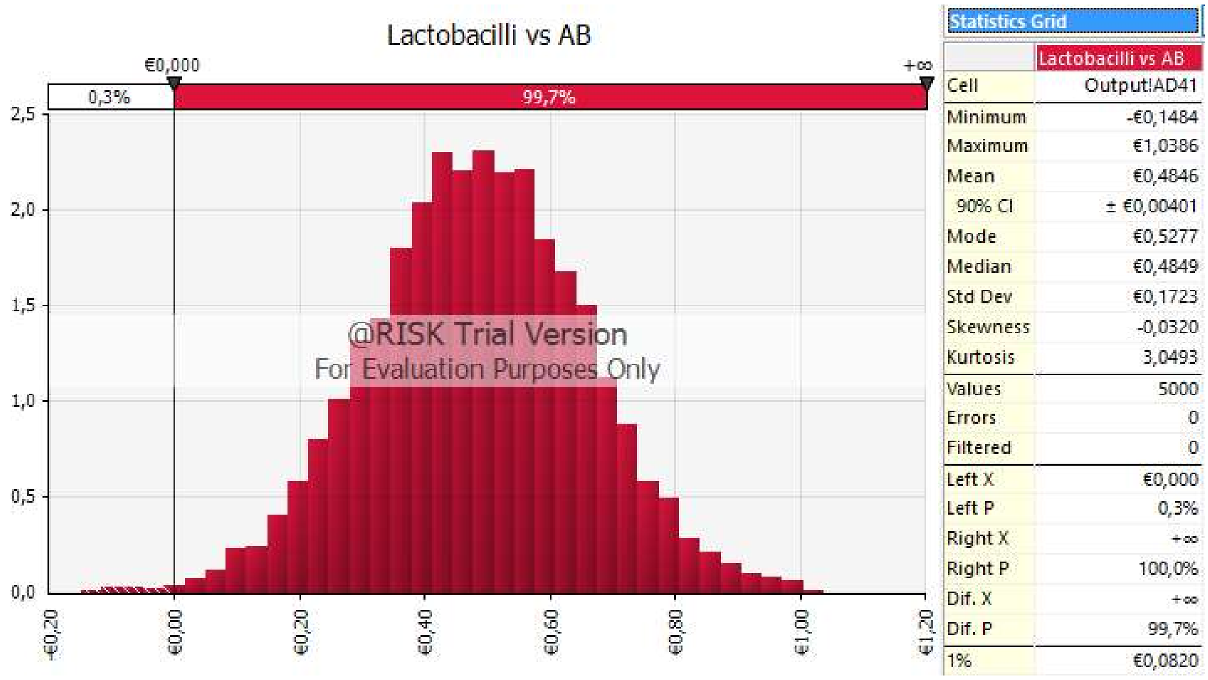


Figure 2: Probability density graph of the change in net proft per animal of lactobacilli versus antibiotics

4.5. What-if analysis

Several eubiotics resulted in a negative change in net return per animal, as could be seen in Table 14. For the eubiotics with a change in net return per animal between 0 and -5 euro, a what-if analysis was done using Excel's Solver. The goal of this analysis was to determine what the maximum price of these eubiotics would be without the availability of antibiotics and with the availability of antibiotics. This will be referred to as the break-even price. This implies that the goal for the situation without availability of antibiotics was a change in net return per animal of €0. With the availability of antibiotics, the goal was changed to a net return per animal of €0,35 (the value of antibiotics, alt 2 - Table 14). All other variables were kept constant in the what-if analysis. The outcomes are displayed in Table 18. Given the required concentration and their effects, these eubiotics would be financially feasible for pig farmers at or below these prices. Of course, the prices are all lower than the original prices in Table 13.

Table 18: Maximum prices for unfeasible eubiotics with and without the availability of antibiotics

Eubiotic	Break-even price/kg no AB (Δ net profit/animal = 0)	Break-even price/kg with AB (Δ net profit/animal = 0,35)
Citric Acid	€ 0.15	€ 0.06
Butyric Acid	€ 2.62	€ 2.28
Bacilli	€ 19.40	€ 16.66
Enterococci	€ 22.14	€ 19.40
LAB mix	€ 23.50	€ 20.76
DiTriallyl base	€ 20.72	€ 19.30
Eugenol base	€ 6.57	€ 5.21

5. Discussion

5.1. Results

The results presented in Table 14, indicating the difference in net result per animal, show large differences for different eubiotics. Taking alternative 1 – no action as baseline, lactic acid leads to an improvement of €2,25 while P-cymene based essential oil mix leads to a loss of €-65,87. Several factors lead to these outcomes. First, there are growth promoting effects to make animals grow faster and improve feed conversion ratio. Second, the chances and (negative) impact of disease is reduced. Third, the price of eubiotics plays a role. Taking these factors into account, only four eubiotics lead to a financial improvement: benzoic acid, formic acid, lactic acid and lactobacilli. However, the current situation is that antibiotics are used in pig production. When taking uncertainty into account and zooming in the on results in the sensitivity analysis, benzoic acid and lactic acid financially outperform antibiotics. Formic acid and lactobacilli outperform antibiotics on average, but the probability density functions in Figure 1 and Figure 2 show that there are situations where this is not the case. For formic acid, the chance of outperforming is only just more than half: 50.7%. For lactobacilli, a more assuring result of 99.7% chance of financially outperforming antibiotics was calculated. The mediocre improvement from using formic acid is not likely to convince farmers. Given these outcomes, benzoic acid, lactic acid and lactobacilli could be taken into consideration as alternatives for antibiotics.

5.1.1. Impact on production parameters

Most eubiotics had a positive impact on production parameters. Benzoic acid, lactic acid, propionic acid, citric acid, butyric acid, lactobacilli, bacilli, enterococci, LAB mix, thymol-based oil, di/triallyl based oil and eugenol-based oil led to a higher ADG and lower FCR. Formic acid, fumaric acid, yeast and cinnamaldehyde based oil improved ADG, but resulted in a higher FCR thus having both positive and negative impact. Carvacrol based oil and P-cymene based oil led to a lower ADG and higher FCR: these eubiotics only led to worse production parameters. The first group, with a positive impact on production parameters, have the most potential of providing a financially feasible alternative for antibiotics compared to the latter two groups.

5.1.2. Eubiotics cost

Most eubiotics that did not lead to a higher net profit per animal, did lead to better production parameters. Higher ADG and lower FCR did provide positive effects, but these were mainly offset by the price of the eubiotics themselves. For eubiotics that do lead to considerably better production parameters, such as butyric acid, a lower price or a lower required concentration might make them financially feasible. If the price or required concentration in the feed can be lowered enough, these eubiotics could also be financially feasible. For eubiotics with a negative change in net return per animal between €-5,- and €0,-, the maximum prices of the eubiotics were determined. These break-even prices were considerably lower than the currently assumed prices, especially when the eubiotic has to financially outperform antibiotics. It will be up to the producers of these products to assess if they can offer them at or below this price point.

5.2. Literature

Performing experiments with live animal to assess the impact of eubiotics is costly. The available literature was limited and not always consistent. Several experimental results were rejected from the database because they were not credible. The reason for the outcomes was not always clear, but in many cases, the experimental groups vastly outperformed the control group simply because the control group had poor growth performance. This is not a good comparison to Dutch pig production: pigs already have very good growth performance. Although it was possible to filter out these results and deal with the literature that reported successful outcomes, this was more difficult for the other side: experiments with poor results. It is likely that poor experimental outcomes are not published, because they did not lead to the results desired by the commissioner. This might lead to a selection bias which could skew the results to a more optimistic picture. However, the total amount of experimental data used to base this research on is of such quantity that results of multiple (independent) experiments were used for most eubiotics. This avoided too much influence of single experiments on this research' results.

To create a better understanding of the financial feasibility of eubiotics, there should first be more insight on the effect of eubiotics in a bio-industrial setting. Trials with more animals will give more accurate results and the impact of eubiotics can be checked in combination with different feed patterns.

Due to the lack of sufficient data about the impact of eubiotics on pig diseases, several assumptions of this impact were done. These assumptions were done with the help of field experts, but they are still not based on experimental outcomes. The assumptions were varied in the stochastic simulation to compensate for the fact that they are not completely accurate. With more knowledge about the effect of eubiotics on pig diseases, these assumptions could be more accurate or replaced by experimental data in the future.

5.3. Disease impact

Even though several eubiotics seem financially feasible, it is not very clear how well they lower the likelihood of disease and disease impact. Few studies include the (artificial) introduction of infections and these did not cover all diseases selected in this research. Table 9 only shows results for PWD and SALM, because no literature that met the selection criteria was found on other diseases. This means that of all the diseases common in pig production -viral, bacterial and other- only for two diseases any direct effect by eubiotics was found. On the other hand, a considerable part of the financial benefit of eubiotics is caused by growth promotion. For the moment, this might suggest eubiotics to be more of an alternative for banned AGP's then for actual curative use of antibiotics. More research is needed to assess the effects of eubiotics, but still, their use will be limited to gastrointestinal issues. It is unlikely they have significant effects on respiratory conditions, which make up a large part of pig diseases and economic impact of pig diseases.

5.4. Presentation of results

The results in this research where not bottom-line profits, but the changes in net profit per animal and per year. This was done because absolute numbers are much less stable. This is due to several factors that all have one common feature: they fluctuate. The market around pig farming is always changing. Prices of feed, piglets, fattened pigs change all the time due to market circumstances. Changes in net profit will only be affected by these fluctuations in the second degree. For example, an eubiotic which improves FCR will be perform better in the model with high feed prices, and one that increases ADG will perform good when the interest is high (so stables are more expensive). However, these effects are much smaller than the fluctuations that would happen if the outcomes where presented as total net profit per animal. The final representation of the results as change in net profit shows the isolated effect of the different alternative actions.

5.5. Further research

In this research, it became clear that there is little information available about the impact of eubiotics on pig diseases, both in terms of (reduced) likelihood and (reduced) impact. Further research is required to be able to assess the effect of eubiotics. Furthermore, the relation to other measures to keep animals healthy -such as farm hygiene, housing etc.- should be researched. With more available data and more accurate data, further research about the financial impact of eubiotics in pig production can be done. This could lead to more accurate outcomes, and more important, model the results under different farm conditions. With these outcomes, individual farmers can make a more informed decision to benefit their farm, producers of eubiotics can market their products to the right segments and antibiotics use might be reduced without causing difficulties for the pig sector.

6. Conclusion

The main question in this research was "*What is the financial feasibility of eubiotics as alternatives for antibiotics in Dutch pig production?"*. After reviewing the results, benzoic acid, lactic acid and lactobacilli can be considered financially feasible. Using these as feed additives resulted in an increase of net profit per animal of respectively €1,24, €2,55 and €0,86 per animal compared to taking no action: considerably higher than the €0.35 for curative application of antibiotics. Stochastic simulation confirmed that these eubiotics financially outperform curative application of antibiotics under uncertainty. Formic acid is also financially feasible, but stochastic simulation indicated mediocre results compared to antibiotics. Only half the cases indicated formic acid performing better.

However, fourteen of the eighteen selected eubiotics can be considered infeasible with the current performance, price and feed concentration required. Eleven of the eighteen eubiotics do lead to better production parameters, but their benefits are outweighed by their costs. If their benefits on production parameters can be improved and/or their prices and required feed concentration can be reduced, these eubiotics could become feasible in the future. This group of eubiotics include propionic acid, citric acid, fumaric acid, butyric acid, bacilli, enterococci, Lactobacilli mixes, thymol-, caravel-, di/Triallyl- and eugenol based essential oil mixes.

Some financially infeasible eubiotics even resulted in deteriorating production parameters. Yeast, cinnamaldehyde based essential oil mixes and p-cymene based essential oil mixes led to higher FCR – requiring more feed for the same amount of meat. Given their current impact on production parameters, they are not financially feasible, and it is unlikely they will be soon.

Returning to the main research question - *What is the financial feasibility of eubiotics as alternatives for antibiotics in Dutch pig production?* – this research offers an answer, but with an important side note. Several eubiotics are financially feasible in Dutch pig production. Some of them are even financial alternatives for antibiotics. However, little data was found on the reduction of impact and likelihood of eubiotics on pig diseases. The beneficial (financial) effects of eubiotics were due to growth promotion for a considerable part, and the reduced impact of diseases was limited impact on the results. For now, eubiotics should be primarily considered as growth promotors. Using them as growth promotors in practice can hopefully contribute to gaining more insight about their impact on the occurrence and severity of pig diseases.

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9. Appendix I: production parameters

The production parameters for each of the four alternative action are presented in the following tables. For each alternative action, several sets of production parameters are given. First, those in the situation where no disease occurs (disease: none). Next, the production parameters in case of each disease and are listed. Finally, the average production parameters are calculated by taking the likelihood of a disease into account. These are presented at the end of each alternative action. These average production parameters serve as inputs for the economic model.

Alt. 1	No action			
Disease	ADG	FCR	MORT	Piglet price
None	795	2,61	2,40%	€ 34,41
PWD	795	2,61	2,40%	€ 38,11
SALM	789	2,63	2,40%	€ 34,46
SD	772	2,67	10,00%	€ 34,41
LAW SC	752	2,68	2,40%	€ 34,41
LAW CL	778	2,68	5,40%	€ 34,41
STEP	742	2,61	4,90%	€ 35,24
Average	790	2,62	2,63%	€ 34,56

Alt. 2	Antibiotics only				
Disease	ADG	FCR	MORT	Piglet price	AB cost
None	795	2,61	2,40%	€ 34,41	€ 0,00
PWD	795	2,61	2,40%	€ 35,10	€ 0,13
SALM	795	2,61	2,40%	€ 34,44	€ 0,15
SD	793	2,61	5,00%	€ 34,41	€ 0,22
LAW SC	752	2,68	2,40%	€ 34,41	€ 0,00
LAW CL	794	2,62	3,40%	€ 34,41	€ 0,22
STEP	795	2,61	2,40%	€ 34,71	€ 0,10
Average	791	2,62	2,47%	€ 34,44	€ 0,02

Alt. 3	Eubiotics only			
Disease:	None			
Eubiotic	ADG	FCR	MORT	Piglet price
None	795	2,61	2,40%	€ 34,41
Benzoic Acid	830	2,55	2,40%	€ 33,90
Formic Acid	842	2,62	2,40%	€ 34,14
Lactic Acid	866	2,48	2,40%	€ 34,44
Propionic Acid	795	2,61	2,40%	€ 34,52
Citric Acid	795	2,61	2,40%	€ 34,42
Fumaric Acid	795	2,61	2,40%	€ 35,47
Butyric Acid	853	2,60	2,40%	€ 34,55
Lactobacilli	924	2,61	2,40%	€ 34,21
Bacilli	817	2,55	2,40%	€ 34,47
Enterococci	824	2,55	2,40%	€ 34,31
Yeast	841	2,91	2,40%	€ 34,54
LAB mix	826	2,55	2,40%	€ 34,22
Thymol base	811	2,54	2,40%	€ 35,08
Carvacrol base	796	2,60	2,40%	€ 35,67
Cinnamaldehyde base	821	2,64	2,40%	€ 34,85
DiTriallyl base	833	2,45	2,40%	€ 34,56
Eugenol base	802	2,56	2,40%	€ 34,81
P-Cymene base	795	2,62	2,40%	€ 40,45

Disease:	PWD			
Eubiotic	ADG	FCR	MORT	Piglet price
None	795	2,61	2,40%	€ 38,11
Benzoic Acid	830	2,55	2,40%	€ 35,82
Formic Acid	842	2,62	2,40%	€ 35,99
Lactic Acid	866	2,48	2,40%	€ 36,36
Propionic Acid	795	2,61	2,40%	€ 36,46
Citric Acid	795	2,61	2,40%	€ 36,38
Fumaric Acid	795	2,61	2,40%	€ 37,32
Butyric Acid	853	2,60	2,40%	€ 36,48
Lactobacilli	924	2,61	2,40%	€ 36,07
Bacilli	817	2,55	2,40%	€ 36,41
Enterococci	824	2,55	2,40%	€ 36,27
Yeast	841	2,91	2,40%	€ 36,46
LAB mix	826	2,55	2,40%	€ 36,19
Thymol base	811	2,54	2,40%	€ 37,06
Carvacrol base	796	2,60	2,40%	€ 37,58
Cinnamaldehyde base	821	2,64	2,40%	€ 36,77
DiTriallyl base	833	2,45	2,40%	€ 36,53
Eugenol base	802	2,56	2,40%	€ 36,75
P-Cymene base	795	2,62	2,40%	€ 42,43

Disease:	SALM			
Eubiotic	ADG	FCR	MORT	Piglet price
None	789	2,63	2,40%	€ 34,46
Benzoic Acid	825	2,57	2,40%	€ 33,95
Formic Acid	836	2,63	2,40%	€ 34,19
Lactic Acid	860	2,50	2,40%	€ 34,48
Propionic Acid	791	2,62	2,40%	€ 34,58
Citric Acid	791	2,62	2,40%	€ 34,46
Fumaric Acid	791	2,62	2,40%	€ 35,50
Butyric Acid	846	2,61	2,40%	€ 34,59
Lactobacilli	915	2,62	2,40%	€ 34,26
Bacilli	812	2,56	2,40%	€ 34,52
Enterococci	819	2,57	2,40%	€ 34,36
Yeast	835	2,91	2,40%	€ 34,58
LAB mix	820	2,56	2,40%	€ 34,27
Thymol base	806	2,55	2,40%	€ 35,13
Carvacrol base	792	2,62	2,40%	€ 35,71
Cinnamaldehyde base	816	2,65	2,40%	€ 34,89
DiTriallyl base	828	2,47	2,40%	€ 34,61
Eugenol base	798	2,57	2,40%	€ 34,86
P-Cymene base	790	2,64	2,40%	€ 40,50

Disease:	SD			
Eubiotic	ADG	FCR	MORT	Piglet price
None	772	2,67	10,00%	€ 34,41
Benzoic Acid	812	2,60	6,20%	€ 34,41
Formic Acid	823	2,66	6,20%	€ 34,41
Lactic Acid	846	2,53	6,20%	€ 34,41
Propionic Acid	779	2,65	6,20%	€ 34,41
Citric Acid	779	2,65	6,20%	€ 34,41
Fumaric Acid	779	2,65	6,20%	€ 34,41
Butyric Acid	833	2,64	6,20%	€ 34,41
Lactobacilli	899	2,65	6,20%	€ 34,41
Bacilli	800	2,59	6,20%	€ 34,41
Enterococci	807	2,59	6,20%	€ 34,41
Yeast	822	2,93	6,20%	€ 34,41
LAB mix	808	2,59	6,20%	€ 34,41
Thymol base	794	2,58	6,20%	€ 34,41
Carvacrol base	781	2,64	6,20%	€ 34,41
Cinnamaldehyde base	803	2,67	6,20%	€ 34,41
DiTriallyl base	815	2,50	6,20%	€ 34,41
Eugenol base	786	2,60	6,20%	€ 34,41
P-Cymene base	779	2,66	6,20%	€ 34,41

Disease:	LAW SC			
Eubiotic	ADG	FCR	MORT	Piglet price
None	752	2,68	2,40%	€ 34,41
Benzoic Acid	789	2,62	2,40%	€ 34,41
Formic Acid	796	2,66	2,40%	€ 34,41
Lactic Acid	812	2,57	2,40%	€ 34,41
Propionic Acid	766	2,66	2,40%	€ 34,41
Citric Acid	766	2,66	2,40%	€ 34,41
Fumaric Acid	766	2,66	2,40%	€ 34,41
Butyric Acid	803	2,65	2,40%	€ 34,41
Lactobacilli	849	2,66	2,40%	€ 34,41
Bacilli	780	2,62	2,40%	€ 34,41
Enterococci	785	2,62	2,40%	€ 34,41
Yeast	796	2,85	2,40%	€ 34,41
LAB mix	786	2,61	2,40%	€ 34,41
Thymol base	776	2,61	2,40%	€ 34,41
Carvacrol base	767	2,65	2,40%	€ 34,41
Cinnamaldehyde base	783	2,67	2,40%	€ 34,41
DiTriallyl base	791	2,55	2,40%	€ 34,41
Eugenol base	771	2,62	2,40%	€ 34,41
P-Cymene base	766	2,66	2,40%	€ 34,41

Disease:	LAW CL			
Eubiotic	ADG	FCR	MORT	Piglet price
None	778	2,68	5,40%	€ 34,41
Benzoic Acid	815	2,61	3,90%	€ 34,41
Formic Acid	826	2,67	3,90%	€ 34,41
Lactic Acid	848	2,54	3,90%	€ 34,41
Propionic Acid	783	2,66	3,90%	€ 34,41
Citric Acid	783	2,66	3,90%	€ 34,41
Fumaric Acid	783	2,66	3,90%	€ 34,41
Butyric Acid	836	2,65	3,90%	€ 34,41
Lactobacilli	901	2,66	3,90%	€ 34,41
Bacilli	804	2,60	3,90%	€ 34,41
Enterococci	810	2,60	3,90%	€ 34,41
Yeast	825	2,93	3,90%	€ 34,41
LAB mix	811	2,60	3,90%	€ 34,41
Thymol base	798	2,59	3,90%	€ 34,41
Carvacrol base	785	2,65	3,90%	€ 34,41
Cinnamaldehyde base	807	2,68	3,90%	€ 34,41
DiTriallyl base	818	2,51	3,90%	€ 34,41
Eugenol base	790	2,61	3,90%	€ 34,41
P-Cymene base	783	2,67	3,90%	€ 34,41

Disease:	STREP			
Eubiotic	ADG	FCR	MORT	Piglet price
None	742	2,61	4,90%	€ 35,28
Benzoic Acid	792	2,56	4,90%	€ 34,78
Formic Acid	802	2,62	4,90%	€ 35,00
Lactic Acid	824	2,49	4,90%	€ 35,29
Propionic Acid	759	2,61	4,90%	€ 35,41
Citric Acid	759	2,61	4,90%	€ 35,28
Fumaric Acid	759	2,61	4,90%	€ 36,28
Butyric Acid	812	2,60	4,90%	€ 35,40
Lactobacilli	877	2,61	4,90%	€ 35,09
Bacilli	780	2,55	4,90%	€ 35,33
Enterococci	786	2,56	4,90%	€ 35,18
Yeast	801	2,88	4,90%	€ 35,38
LAB mix	787	2,55	4,90%	€ 35,09
Thymol base	774	2,54	4,90%	€ 35,95
Carvacrol base	761	2,60	4,90%	€ 36,50
Cinnamaldehyde base	783	2,63	4,90%	€ 35,70
DiTriallyl base	795	2,46	4,90%	€ 35,43
Eugenol base	766	2,56	4,90%	€ 35,66
P-Cymene base	759	2,62	4,90%	€ 41,28

Average				
Eubiotic	ADG	FCR	MORT	Piglet price
None	790	2,62	2,63%	€ 34,57
Benzoic Acid	825	2,56	2,52%	€ 34,06
Formic Acid	837	2,62	2,52%	€ 34,26
Lactic Acid	860	2,49	2,52%	€ 34,52
Propionic Acid	792	2,62	2,52%	€ 34,59
Citric Acid	792	2,62	2,52%	€ 34,50
Fumaric Acid	792	2,62	2,52%	€ 35,40
Butyric Acid	847	2,60	2,52%	€ 34,61
Lactobacilli	916	2,62	2,52%	€ 34,32
Bacilli	813	2,56	2,52%	€ 34,55
Enterococci	820	2,56	2,52%	€ 34,41
Yeast	836	2,91	2,52%	€ 34,60
LAB mix	821	2,56	2,52%	€ 34,33
Thymol base	807	2,55	2,52%	€ 35,07
Carvacrol base	793	2,61	2,52%	€ 35,57
Cinnamaldehyde base	816	2,64	2,52%	€ 34,87
DiTriallyl base	829	2,46	2,52%	€ 34,62
Eugenol base	798	2,57	2,52%	€ 34,84
P-Cymene base	791	2,63	2,52%	€ 39,67

Alt. 4	Eubiotics + antibiotics			
Disease:	None			
Eubiotic	ADG	FCR	MORT	Piglet price
None	795	2,61	2,40%	€ 34,41
Benzoic Acid	830	2,55	2,40%	€ 33,90
Formic Acid	842	2,62	2,40%	€ 34,14
Lactic Acid	866	2,48	2,40%	€ 34,44
Propionic Acid	795	2,61	2,40%	€ 34,52
Citric Acid	795	2,61	2,40%	€ 34,42
Fumaric Acid	795	2,61	2,40%	€ 35,47
Butyric Acid	853	2,60	2,40%	€ 34,55
Lactobacilli	924	2,61	2,40%	€ 34,21
Bacilli	817	2,55	2,40%	€ 34,47
Enterococci	824	2,55	2,40%	€ 34,31
Yeast	841	2,91	2,40%	€ 34,54
LAB mix	826	2,55	2,40%	€ 34,22
Thymol base	811	2,54	2,40%	€ 35,08
Carvacrol base	796	2,60	2,40%	€ 35,67
Cinnamaldehyde base	821	2,64	2,40%	€ 34,85
DiTriallyl base	833	2,45	2,40%	€ 34,56
Eugenol base	802	2,56	2,40%	€ 34,81
P-Cymene base	795	2,62	2,40%	€ 40,45

Disease:	PWD				
Eubiotic	ADG	FCR	MORT	Piglet price	AB cost
None	795	2,61	2,40%	€ 35,10	€ 0,13
Benzoic Acid	830	2,55	2,40%	€ 34,34	€ 0,13
Formic Acid	842	2,62	2,40%	€ 34,54	€ 0,13
Lactic Acid	866	2,48	2,40%	€ 34,83	€ 0,13
Propionic Acid	795	2,61	2,40%	€ 34,98	€ 0,13
Citric Acid	795	2,61	2,40%	€ 34,84	€ 0,13
Fumaric Acid	795	2,61	2,40%	€ 35,78	€ 0,13
Butyric Acid	853	2,60	2,40%	€ 34,94	€ 0,13
Lactobacilli	924	2,61	2,40%	€ 34,63	€ 0,13
Bacilli	817	2,55	2,40%	€ 34,88	€ 0,13
Enterococci	824	2,55	2,40%	€ 34,74	€ 0,13
Yeast	841	2,91	2,40%	€ 34,93	€ 0,13
LAB mix	826	2,55	2,40%	€ 34,66	€ 0,13
Thymol base	811	2,54	2,40%	€ 35,52	€ 0,13
Carvacrol base	796	2,60	2,40%	€ 36,02	€ 0,13
Cinnamaldehyde base	821	2,64	2,40%	€ 35,23	€ 0,13
DiTriallyl base	833	2,45	2,40%	€ 34,99	€ 0,13
Eugenol base	802	2,56	2,40%	€ 35,20	€ 0,13
P-Cymene base	795	2,62	2,40%	€ 40,83	€ 0,13

Disease:	SALM				
Eubiotic	ADG	FCR	MORT	Piglet price	AB cost
None	795	2,61	2,40%	€ 34,44	€ 0,15
Benzoic Acid	830	2,55	2,40%	€ 33,94	€ 0,15
Formic Acid	842	2,62	2,40%	€ 34,17	€ 0,15
Lactic Acid	866	2,48	2,40%	€ 34,46	€ 0,15
Propionic Acid	795	2,61	2,40%	€ 34,56	€ 0,15
Citric Acid	795	2,61	2,40%	€ 34,44	€ 0,15
Fumaric Acid	795	2,61	2,40%	€ 35,48	€ 0,15
Butyric Acid	853	2,60	2,40%	€ 34,57	€ 0,15
Lactobacilli	924	2,61	2,40%	€ 34,25	€ 0,15
Bacilli	817	2,55	2,40%	€ 34,50	€ 0,15
Enterococci	824	2,55	2,40%	€ 34,34	€ 0,15
Yeast	841	2,91	2,40%	€ 34,56	€ 0,15
LAB mix	826	2,55	2,40%	€ 34,25	€ 0,15
Thymol base	811	2,54	2,40%	€ 35,11	€ 0,15
Carvacrol base	796	2,60	2,40%	€ 35,69	€ 0,15
Cinnamaldehyde base	821	2,64	2,40%	€ 34,87	€ 0,15
DiTriallyl base	833	2,45	2,40%	€ 34,59	€ 0,15
Eugenol base	802	2,56	2,40%	€ 34,84	€ 0,15
P-Cymene base	795	2,62	2,40%	€ 40,47	€ 0,15

Disease:	SD				
Eubiotic	ADG	FCR	MORT	Piglet price	AB cost
None	793	2,61	5,00%	€ 34,41	€ 0,22
Benzoic Acid	827	2,56	3,70%	€ 33,90	€ 0,22
Formic Acid	838	2,62	3,70%	€ 34,14	€ 0,22
Lactic Acid	860	2,49	3,70%	€ 34,44	€ 0,22
Propionic Acid	794	2,61	3,70%	€ 34,52	€ 0,22
Citric Acid	794	2,61	3,70%	€ 34,42	€ 0,22
Fumaric Acid	794	2,61	3,70%	€ 35,47	€ 0,22
Butyric Acid	848	2,60	3,70%	€ 34,55	€ 0,22
Lactobacilli	914	2,61	3,70%	€ 34,21	€ 0,22
Bacilli	815	2,56	3,70%	€ 34,47	€ 0,22
Enterococci	821	2,56	3,70%	€ 34,31	€ 0,22
Yeast	837	2,89	3,70%	€ 34,54	€ 0,22
LAB mix	822	2,55	3,70%	€ 34,22	€ 0,22
Thymol base	808	2,54	3,70%	€ 35,08	€ 0,22
Carvacrol base	795	2,61	3,70%	€ 35,67	€ 0,22
Cinnamaldehyde base	818	2,64	3,70%	€ 34,85	€ 0,22
DiTriallyl base	830	2,46	3,70%	€ 34,56	€ 0,22
Eugenol base	801	2,57	3,70%	€ 34,81	€ 0,22
P-Cymene base	793	2,63	3,70%	€ 40,45	€ 0,22

Disease:	LAW SC				
Eubiotic	ADG	FCR	MORT	Piglet price	AB cost
None	752	2,68	2,40%	€ 34,41	€ 0,00
Benzoic Acid	789	2,62	2,40%	€ 33,90	€ 0,00
Formic Acid	796	2,66	2,40%	€ 34,14	€ 0,00
Lactic Acid	812	2,57	2,40%	€ 34,44	€ 0,00
Propionic Acid	766	2,66	2,40%	€ 34,52	€ 0,00
Citric Acid	766	2,66	2,40%	€ 34,42	€ 0,00
Fumaric Acid	766	2,66	2,40%	€ 35,47	€ 0,00
Butyric Acid	803	2,65	2,40%	€ 34,55	€ 0,00
Lactobacilli	849	2,66	2,40%	€ 34,21	€ 0,00
Bacilli	780	2,62	2,40%	€ 34,47	€ 0,00
Enterococci	785	2,62	2,40%	€ 34,31	€ 0,00
Yeast	796	2,85	2,40%	€ 34,54	€ 0,00
LAB mix	786	2,61	2,40%	€ 34,22	€ 0,00
Thymol base	776	2,61	2,40%	€ 35,08	€ 0,00
Carvacrol base	767	2,65	2,40%	€ 35,67	€ 0,00
Cinnamaldehyde base	783	2,67	2,40%	€ 34,85	€ 0,00
DiTriallyl base	791	2,55	2,40%	€ 34,56	€ 0,00
Eugenol base	771	2,62	2,40%	€ 34,81	€ 0,00
P-Cymene base	766	2,66	2,40%	€ 40,45	€ 0,00

Disease:	LAW CL				
Eubiotic	ADG	FCR	MORT	Piglet price	AB cost
None	794	2,62	3,40%	€ 34,41	€ 0,22
Benzoic Acid	826	2,56	2,90%	€ 33,90	€ 0,22
Formic Acid	837	2,62	2,90%	€ 34,14	€ 0,22
Lactic Acid	859	2,50	2,90%	€ 34,44	€ 0,22
Propionic Acid	794	2,61	2,90%	€ 34,52	€ 0,22
Citric Acid	794	2,61	2,90%	€ 34,42	€ 0,22
Fumaric Acid	794	2,61	2,90%	€ 35,47	€ 0,22
Butyric Acid	847	2,60	2,90%	€ 34,55	€ 0,22
Lactobacilli	911	2,61	2,90%	€ 34,21	€ 0,22
Bacilli	815	2,56	2,90%	€ 34,47	€ 0,22
Enterococci	821	2,56	2,90%	€ 34,31	€ 0,22
Yeast	836	2,89	2,90%	€ 34,54	€ 0,22
LAB mix	822	2,56	2,90%	€ 34,22	€ 0,22
Thymol base	808	2,55	2,90%	€ 35,08	€ 0,22
Carvacrol base	795	2,61	2,90%	€ 35,67	€ 0,22
Cinnamaldehyde base	818	2,64	2,90%	€ 34,85	€ 0,22
DiTriallyl base	829	2,47	2,90%	€ 34,56	€ 0,22
Eugenol base	801	2,57	2,90%	€ 34,81	€ 0,22
P-Cymene base	794	2,63	2,90%	€ 40,45	€ 0,22

Disease:	STREP				
Eubiotic	ADG	FCR	MORT	Piglet price	AB cost
None	795	2,61	2,40%	€ 34,71	€ 0,10
Benzoic Acid	830	2,55	2,40%	€ 34,11	€ 0,10
Formic Acid	842	2,62	2,40%	€ 34,33	€ 0,10
Lactic Acid	866	2,48	2,40%	€ 34,61	€ 0,10
Propionic Acid	795	2,61	2,40%	€ 34,73	€ 0,10
Citric Acid	795	2,61	2,40%	€ 34,60	€ 0,10
Fumaric Acid	795	2,61	2,40%	€ 35,60	€ 0,10
Butyric Acid	853	2,60	2,40%	€ 34,72	€ 0,10
Lactobacilli	924	2,61	2,40%	€ 34,41	€ 0,10
Bacilli	817	2,55	2,40%	€ 34,65	€ 0,10
Enterococci	824	2,55	2,40%	€ 34,50	€ 0,10
Yeast	841	2,91	2,40%	€ 34,71	€ 0,10
LAB mix	826	2,55	2,40%	€ 34,42	€ 0,10
Thymol base	811	2,54	2,40%	€ 35,28	€ 0,10
Carvacrol base	796	2,60	2,40%	€ 35,82	€ 0,10
Cinnamaldehyde base	821	2,64	2,40%	€ 35,02	€ 0,10
DiTriallyl base	833	2,45	2,40%	€ 34,75	€ 0,10
Eugenol base	802	2,56	2,40%	€ 34,99	€ 0,10
P-Cymene base	795	2,62	2,40%	€ 40,60	€ 0,10

Average					
Eubiotic	ADG	FCR	MORT	Piglet price	AB cost
None	791	2,62	2,47%	€ 34,44	€ 0,02
Benzoic Acid	826	2,56	2,44%	€ 33,92	€ 0,02
Formic Acid	838	2,62	2,44%	€ 34,16	€ 0,02
Lactic Acid	861	2,49	2,44%	€ 34,46	€ 0,02
Propionic Acid	792	2,61	2,44%	€ 34,54	€ 0,02
Citric Acid	792	2,61	2,44%	€ 34,43	€ 0,02
Fumaric Acid	792	2,61	2,44%	€ 35,48	€ 0,02
Butyric Acid	848	2,60	2,44%	€ 34,56	€ 0,02
Lactobacilli	917	2,61	2,44%	€ 34,23	€ 0,02
Bacilli	814	2,56	2,44%	€ 34,49	€ 0,02
Enterococci	821	2,56	2,44%	€ 34,33	€ 0,02
Yeast	837	2,90	2,44%	€ 34,55	€ 0,02
LAB mix	822	2,55	2,44%	€ 34,24	€ 0,02
Thymol base	807	2,54	2,44%	€ 35,10	€ 0,02
Carvacrol base	794	2,61	2,44%	€ 35,69	€ 0,02
Cinnamaldehyde base	817	2,64	2,44%	€ 34,87	€ 0,02
DiTriallyl base	829	2,46	2,44%	€ 34,58	€ 0,02
Eugenol base	799	2,56	2,44%	€ 34,83	€ 0,02
P-Cymene base	792	2,63	2,44%	€ 40,47	€ 0,02

10. Appendix II: Stochastic inputs

A summary of the way stochastic inputs were entered in @Risk as described in paragraph 4.3 Method - stochastic analysis. The function RiskNormal represents a normal distribution, the function RiskTriang a triangular distribution. The min, mean and max values indicate the lowest, mean and highest values.

Name	Worksheet	Cell	Graph	Function	Min	Mean	Max
Category: Effective eubiotics reduce mortality by							
Effective eubiotics reduce mortality by / Mean	Baseline	L21	-60% 160%	RiskNormal(0,5;M21;RiskStatic(0,5))	-∞	50,0000%	+∞
Category: Effective eubiotics reduce the chance of disease by							
Effective eubiotics reduce the chance of disease by / Mean	Baseline	L20	-40% 120%	RiskNormal(0,33;M20;RiskStatic(0,33))	-∞	33,0000%	+∞
Category: LAW							
LAW / Subclinical	Onset	D33	15% 55%	RiskTriang(0,18;0,533;0,534;RiskStatic(0,533))	18,0000%	41,5667%	53,4000%
LAW / Clinical	Onset	E33	12% 32%	RiskTriang(0,133;0,133;0,3;RiskStatic(0,133))	13,3000%	18,8667%	30,0000%
Category: LAW CL							
LAW CL / Δ Mortality % no AB	Baseline	J39	0% 7%	RiskTriang(0,01;0,03;0,06;RiskStatic(0,03))	1,0000%	3,3333%	6,0000%
LAW CL / Δ Mortality % AB	Baseline	K39	-0,5% 3,5%	RiskTriang(0;0,01;0,03;RiskStatic(0,01))	0,0000%	1,3333%	3,0000%
Category: PWD							
PWD / Clinical	Onset	E30	15% 55%	RiskTriang(0,192;0,235;0,515;RiskStatic(0,235))	19,2000%	31,4000%	51,5000%
PWD / Δ Mortality % no AB	Baseline	J35	0% 30%	RiskTriang(0,02;0,11;0,25;RiskStatic(0,11))	2,0000%	12,6667%	25,0000%
PWD / Δ Mortality % AB	Baseline	K35	-2% 12%	RiskTriang(0;0,02;0,11;RiskStatic(0,02))	0,0000%	4,3333%	11,0000%
Category: SALM							
SALM / Clinical	Onset	E31	4% 18%	RiskTriang(0,047;0,049;0,161;RiskStatic(0,049))	4,7000%	8,5667%	16,1000%
SALM / Δ Mortality % no AB	Baseline	J36	-0,5% 2,5%	RiskTriang(0;0;0,02;RiskStatic(0))	0,0000%	0,6667%	2,0000%
Category: STREP							
STREP / Clinical	Onset	E32	0% 55%	RiskTriang(0,01;0,129;0,5;RiskStatic(0,129))	1,0000%	21,3000%	50,0000%
STREP / Δ Mortality % no AB	Baseline	J40	0% 22%	RiskTriang(0,016;0,05;0,2;RiskStatic(0,05))	1,6000%	8,8667%	20,0000%
STREP / Δ Mortality % AB	Baseline	K40	-1% 6%	RiskTriang(0;0,016;0,05;RiskStatic(0,016))	0,0000%	2,2000%	5,0000%