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ENVIRONMENT, WELL-BEING, AND BEHAVIOR

Effects of different broiler production systems on health care costs in the Netherlands

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ABSTRACT This study analyzed the effects of different broiler production systems on health care costs in the Netherlands. In addition to the conventional production system, the analysis also included 5 alternative animal welfare systems representative of the Netherlands. The study was limited to the most prevalent and economically relevant endemic diseases in the broiler farms. Health care costs consisted of losses and expenditures. The study investigated whether higher animal welfare standards increased health care costs, in both absolute and relative terms, and also examined which cost components (losses or expenditures) were affected and, if so, to what extent. The results show that health care costs represent only a small proportion of total production costs in each production system. Losses account for the major part of health care costs, which makes it difficult to detect the actual effect of diseases on total health care costs. We conclude that, although differences in health care costs exist across production systems, health care costs only make a minor contribution to the total production costs relative to other costs, such as feed costs and purchase of 1-d-old chicks.

Key words: animal welfare, animal health, economic analysis, broiler production

INTRODUCTION

In recent years, increasing requirements regarding animal welfare (AW) in broiler production have led to the development of production systems that comply with above-legal AW standards (Blokhuis et al., 2003; Fraser, 2006). Although these standards contribute to improved AW, they also increase production costs (Verspecht et al., 2011). Furthermore, productivity and profitability might be negatively affected if higher production costs do not increase economic returns (McInerney, 2004).

Although livestock diseases occur in broiler farms regardless of which production system is used, the likelihood and the effect of livestock diseases can differ depending on the production system. However, the possible effect of AW-friendly production systems on animal health is not clear. Listers and Van Nijhuis (2012) suggested that the prevalence of coccidiosis or other parasitic infections was higher in systems in which chickens had access to an outdoor area, such as free-range or organic systems. Also, broiler chickens in organic systems showed an increased prevalence of Campylobacter compared with chickens in conventional systems. Cui et al. (2005) found that organic chickens were more frequently contaminated with Campylobacter and Salmonella. In contrast, Van Overbeke et al. (2006) found no significant difference in the prevalence of Salmonella between broiler chickens kept in organic and those kept in conventional systems.

With respect to the possible effect of AW-friendly production systems on animal health, a distinction must be made between prevalence (that is, the likelihood of introduction) and effect. Increased disease prevalence and a greater effect of a disease both result in increased health care costs. Health care costs include all economic effects of a disease and are the sum of 2 components: losses and expenditures (McInerney, 1996). Losses can be caused, for example, by mortality, morbidity, reduced production efficiency, and lower meat yield and quality, which results in reduced returns. Extra expenditures are mainly the costs of veterinary prophylactic and therapeutic treatments to prevent or treat a disease (McInerney et al., 1992; Bennett, 2003; Houe, 2003; Bennett and Ijpelaar, 2005).

The aim of this study was to analyze the effects of different production systems on health care costs. First, we investigated whether higher AW standards increased health care costs in both absolute and relative terms. Second, we examined which cost components (losses or expenditures) were affected and to what extent. This study was restricted to the most important endemic diseases. Epidemic diseases, such as avian influenza,
were not included because they occur only rarely and the differentiation between conventional, free-range, and organic was less relevant.

**MATERIALS AND METHODS**

**Broiler Production in the Netherlands**

Dutch legislation defining standards of broiler production is based on the European Union guidelines (EC, 2007a, b, 2008). In the Netherlands, several so-called AW concepts, such as private labels, have been developed in recent years setting higher requirements for production in terms of AW compared with the minimum standards of conventional broiler production. Table 1 describes the main requirements for conventional production and 5 alternative AW concepts (also referred to as AW systems later in the text) representative for the Netherlands.

A conventional system is defined according to European Union standards. The Better Life hallmark initiated by the Dutch Society for the Protection of Animals (Dierenbescherming) enables a transparent differentiation among animal products in terms of AW. Products that can be produced under different concepts are labeled with a distinctive Better Life logo if they comply with the requirements of this hallmark. Three categories are distinguished within the Better Life hallmark depending on the level of AW: Better Life 1*, Better Life 2*, and Better Life 3*. The number of stars increases as the assumed level of welfare increases. Puur & Eerlijk products fit under the Better Life 1* concept. This concept has the same requirements as in the Volwaard concept, except that a lower stocking density is required (25 kg per m²). The requirements of Better Life 3* concept are the same as the production standards of SKAL (the independent organization that audits organic systems in the Netherlands). The organic standards of SKAL are different from the European Union standards for organic production, but the European Union standards should eventually be implemented in all European Union countries, which means that the European Union standards for organic production are included in the study as well.

**Endemic Diseases Included in the Study**

The study was limited to the most important endemic diseases because it was not possible to include all poultry diseases that can occur on a broiler farm. The selection of diseases was mainly based on Bergevoet et al. (2010), who identified the most important diseases and disorders in a broiler farm in the Netherlands by scoring them on several aspects, such as epidemiology and business economics. In this way, infectious bronchitis (IB), coccidiosis, *Escherichia coli*, and necrotic enteritis (NE) were included in this study, along with infectious bursal disease (IBD), sudden death syndrome (SDS), ascites, and leg problems (European Commission, 2000; De Jong et al., 2012). *Enterococcus*, which had a relatively high score in terms of epidemiological and business economics aspects, had to be excluded because little is known about its spread and pathogens (Bergevoet et al., 2010). Diseases for which vaccinations are obligatory in the Netherlands, such as Newcastle disease, were excluded from the study (GD, 2012). The selected diseases were considered to be the most prevalent diseases in the broiler farms; they were

| Criteria                         | Conventional | Volwaard | Better Life 1*/Puur & Eerlijk | Better Life 2* | Better Life 3*/Skal | Organic |
|----------------------------------|--------------|----------|-------------------------------|---------------|-------------------|---------|
| Breed                            | Fast-growing | Slower-growing | Slower-growing | Slower-growing | Slow-growing | Slow-growing |
| Length of growth period (d)      | 40           | 56       | 56                            | 56            | 81                | 70      |
| Enrichment                       | Litter       | Litter   | Litter Grains and straw       | Litter Grains and straw | Litter | Litter |
| Stocking density (chicken/m²)    | No restriction | No restriction | 12                          | 13            | 7                 | 10      |
| Stocking density (kg/m²)         | 42           | 31       | 25                            | 27.5          | Yes (1 m²/chicken) | Yes (4 m²/chicken) |
| Outdoor access                   | No           | Covered veranda | Covered veranda | Yes (1 m²/chicken) | Natural (minimum 8 h dark period) | Natural (minimum 8 h dark period) |
| Lighting regimen                 | Unnatural (minimum 4 h dark period) | Natural (minimum 6 h dark period) | Natural (minimum 6 h dark period) | Natural (minimum 8 h dark period) | Natural (minimum 8 h dark period) | Natural (minimum 8 h dark period) |
| Flock size                       | No restriction | No restriction | No restriction | No restriction | No restriction | Maximum 4,800 chickens per barn |
| Use of antibiotics               | No restriction | No restriction | No restriction | No restriction | Coccidiostat and preventive drugs are prohibited | Coccidiostat and preventive drugs are prohibited |
economically relevant and could be distinguished between systems (Ruff, 1999; European Commission, 2000; Bennett and Ijpelaar, 2005; Rushton, 2009; Bergevoet et al., 2010; De Jong et al., 2012). Because the prevalence and severity of diseases of a particular organ system can differ depending on housing conditions, the 8 selected diseases were categorized into 5 groups according to organ system: diseases concerning the respiratory system (IB), the organs of immune system (IBD), the gastrointestinal tract (coccidiosis, E. coli, and NE), the locomotion system (leg problems), and the heart and vascular system (ascites and SDS; Table 2). The final selection was discussed with an expert from the Dutch Animal Health Service who specializes in poultry diseases (J. J. de Wit, Dutch Animal Health Service, Deventer, the Netherlands, personal communication).

**Definition of Health Care Costs**

McInerney et al. (1992) defined health care costs \( C \) as the sum of losses \( L \) and expenditures \( E \). A loss implies a foregone benefit, such as lower revenue or lower productivity as a consequence of slower growth (McInerney et al., 1992; McInerney, 1996). Expenditures mainly originate from disease prevention and treatments (McInerney et al., 1992). Evidently, a trade-off exists between \( L \) and \( E \): higher treatment and prevention expenditures result in lower losses, and vice versa; the optimal level of \( L \) and \( E \) is determined by the prices of inputs and outputs (McInerney, 1996). It is possible that a lower output caused by a disease coincides with a lower input such as feed consumption. In this case, the loss can be calculated in such a way that the input saved is deducted from the loss incurred (McInerney et al., 1992).

**Calculation Approach**

To enable calculation of absolute and relative production costs, a baseline situation must first be defined: no endemic disease present on the farm. System requirements, such as breed, enrichment, stocking density, and input variables (mortality, feed conversion, and so on) differ by production systems. These differences have an effect on production costs, which means that baseline situations had to be calculated for each production system. Health care costs are determined by the prevalence and effect of a disease, both of which differ by production systems. The change in production costs due to a disease regarding a particular production system, that is, absolute effect, was calculated as the difference between the production costs in the baseline situation (healthy) and the production costs in the situation with a particular endemic disease. Calculation of absolute effect only partly enables a comparison between production systems. For a more detailed comparison, 2 relative measures were calculated: the relative effect on production costs and the proportion of the health care costs in total production costs. The relative effect on production costs was determined as the ratio of the increase in production costs due to a disease to production costs in the healthy baseline situation. To obtain the proportion of health care costs in total production costs, the absolute effect was divided by the total production costs in the situation with a particular disease.

**Model**

The model described by Gocsik et al. (2013) was adapted to calculate the economic effect of a disease; that is, change in production costs under different production systems. The model was adjusted with some technical, economic, and veterinary inputs, such as disease prevalence and effect on production parameters. Stochastic inputs were replaced by deterministic inputs. Production and health care costs were calculated for each delivered broiler in an Excel (Microsoft Corp., Redmond, WA) model using the partial budgeting approach (Dijkhuizen and Morris, 1997).

The model included 4 factors through which disease occurrence might influence productivity and production costs. The negative effects on productivity (losses) as a consequence of a disease occurrence are increased mortality, decreased daily weight gain, increased feed conversion, and an increased condemnation rate at slaughter.

Increase in mortality due to a disease affects the cost of mortality, which was calculated using equation [1]:

\[
\text{cost of mortality} = \left\{ \left[ \frac{\text{producer price} \times \text{weight at delivery} - \text{price day-old chick}}{2} \right] - \text{cost of delivery} \right\} \times (\text{mortality}).
\]

The chickens were assumed to die in the middle of the production period. The fixed costs per delivered broiler chicken may change due to an increased mortality because fewer chickens are delivered.

Decrease in daily weight gain affects fixed costs. The chickens were assumed to be kept until they reached the required weight to be delivered. Due to a lower daily weight gain, more days are required to reach the delivery weight. A longer production period results in fewer production rounds per year and, eventually, in a decrease in the number of delivered broiler chickens. Thereby, the fixed costs such as cost of housing and labor per delivered broiler chicken increase.

Increase in feed conversion ratio affects feed costs. Extra feed costs were calculated using equation [2]:
| Disease                                      | Cause                          | Effect on efficiency/production | Effect on business economics<sup>1</sup> | Prevention                   | Treatment                      |
|---------------------------------------------|--------------------------------|--------------------------------|------------------------------------------|-------------------------------|--------------------------------|
| **Respiratory**                             |                                |                                |                                          |                               |                                |
| Infections bronchitis<sup>2</sup>           | Coronavirus<sup>2</sup>        | Mortality due to suffocation<sup>2</sup> | ++<sup>3</sup>  -3  -3  | Vaccination, hygiene<sup>2</sup> | Good housing conditions and extra heating<sup>4,5</sup> |
| Immune organs                               |                                |                                |                                          |                               |                                |
| Infections bursal disease<sup>6</sup>      | Virus<sup>6</sup>              | Mortality<sup>7,8,9</sup>      | -7,8 -9 -9 | Good housing conditions and extra heating<sup>4,5</sup> |                                |
| **Gastrointestinal**                        |                                |                                |                                          |                               |                                |
| Coccidiosis<sup>13</sup>                   | *Eimeria acervulina*<sup>14,15</sup> | Weight loss<sup>16</sup>  | +17 -18,19 ++18,19 | Vaccination<sup>20,21,22</sup> | Chemotherapy                    |
| Eimeria maxima<sup>14,15</sup>             |                                | Reduced growth rate            |                                          |                               |                                |
| Eimeria tenella<sup>14,15</sup>            |                                | Mortality                      |                                          |                               |                                |
| Eimeria acervulina<sup>14,15</sup>         | *Eimeria acervulina*<sup>14,15</sup> | Weight loss<sup>16</sup>  | +17 -18,19 ++18,19 | Vaccination<sup>20,21,22</sup> | Chemotherapy                    |
| Escherichia coli<sup>23</sup>             | *E. coli*<sup>23</sup>        | Mortality                      | +24 -25 -26 | Hygiene<sup>23,27</sup>                    | Antibiotics<sup>26</sup>      |
| Necrotic enteritis<sup>28</sup>            |                                | Mortality<sup>19,29</sup>      | + -12 0 | Adjusted feed composition                 | Antibiotics<sup>5</sup>      |
| **Locomotion**                              |                                |                                |                                          |                               |                                |
| Leg problems<sup>30,31,32</sup>            | Genetic predisposition<sup>33</sup> | Skin irritation and blisters, | 0 -34 0 | Various management factors such as limiting feed, meal feeding, and lighting schedule<sup>31,35,36,37</sup> | No                             |
| Metabolic disorders                         |                                | footpad dermatitis and hock burn |                                          |                               |                                |
| Feed composition                            |                                | Reduced feed intake            |                                          |                               |                                |
| Lack of movement                            |                                |                                |                                          |                               |                                |
| **Heart and vascular**                      |                                |                                |                                          |                               |                                |
| Ascites<sup>38</sup>                       | Selection                      | Condemnation<sup>38</sup>     | ++39 0 0 | Slower growth rate<sup>30</sup> | No                             |
| Sudden death syndrome<sup>40</sup>         | Selection                      | Mortality                      | ++41 0 0 | Slower growth rate<sup>12,43,44</sup> | No                             |

<sup>1</sup> = much lower; - = lower; 0 = equal; + = higher; ++ = much higher. Effect is compared with the healthy situation.

<sup>2</sup>Cavanagh, 2003.
<sup>3</sup>Yohannes et al., 2012.
<sup>4</sup>Lopez et al., 2006.
<sup>5</sup>KWIN-V, 2011.
<sup>6</sup>Lasher and Shane, 1994.
<sup>7</sup>Sanchez et al., 2005.
<sup>8</sup>Cavanagh, 1992.
<sup>9</sup>McIlroy et al., 1989.
<sup>10</sup>BCFI, 2012.
<sup>11</sup>McIlroy et al., 1992.
<sup>12</sup>Saif et al., 2003.
<sup>13</sup>Ruff, 1999.
<sup>14</sup>Graat et al., 1996.

Continued
Table 2 (Continued). Diseases and health problems on the broiler farm

| No. | Reference |
|-----|-----------|
| 15  | Haug et al., 2008. |
| 16  | Voeten, 2000. |
| 17  | Williams, 1999. |
| 18  | Williams, 1998. |
| 19  | Voeten et al., 1988. |
| 20  | Wheelhouse et al., 1985. |
| 21  | Vermeulen et al., 2001. |
| 22  | Steenhuisen and Vossen, 2001. |
| 23  | Kabir, 2010. |
| 24  | Rahman et al., 2004. |
| 25  | Tian and Baracos, 1989. |
| 26  | Fernandez et al., 1998. |
| 27  | Dziva and Stevens, 2008. |
| 28  | McDevitt et al., 2006. |
| 29  | Brigden and Kiddell, 1975. |
| 30  | Julian, 2005. |
| 31  | Estévez, 2007. |
| 32  | De Jong et al., 2012. |
| 33  | Manning et al., 2007. |
| 34  | Weeks et al., 2000. |
| 35  | Su et al., 1999. |
| 36  | Fanatico et al., 2005. |
| 37  | Knowles et al., 2008. |
| 38  | Olkowski et al., 1996. |
| 39  | De Smit et al., 2005. |
| 40  | Newberry et al., 1987. |
| 41  | Julian, 1998. |
| 42  | Havenstein et al., 1994. |
| 43  | Van Horne et al., 2003. |
| 44  | Bricket et al., 2007. |
extra feed costs = \left( \frac{\text{weight at delivery}}{1,000} \right) \times \text{feed conversion} \times \text{feed price}. \tag{2}

In the above equation, only the feed conversion rate changed as a consequence of the disease, whereas other variables held constant.

Condemnation rate at slaughter affects revenues. If a broiler chicken at the slaughterhouse is rejected, the production costs are already incurred, but little or no revenue is made. The cost of condemnation rate was calculated using equation [3]:

cost of condemnation at slaughter = \left[ \text{price day-old chick} + \left( \text{producer price} \times \text{weight at delivery} \right) \right] \times \text{condemnation rate}. \tag{3}

The fixed costs per delivered broiler chickens also changed because fewer chickens were delivered. The chickens were assumed to have been rejected as a whole because little or no literature on partial or complete condemnation was available for the diseases concerned (Ellen et al., 2012). Note that birds with leg problems, however, are usually not rejected as a whole. In the Netherlands, the main reasons for rejections are indicated, but rejections are not represented with number per reason of rejection. Carcasses can be rejected for disease and non-disease-related reasons. Due to lack of information on the reasons for rejection, all carcasses are assumed to be rejected for disease-related reasons.

**Model Inputs**

**Technical Inputs.** The criteria and requirements of various production systems presented in Table 1 were converted into model inputs (Table 3). Technical inputs were gathered from the literature and represented the average performance of the farms (Van Horne et al., 2003; Vermeij and Van Horne, 2008; Van Horne, 2009; KWIN-V, 2011; Ellen et al., 2012). All farms were assumed to be managed by one full-time labor equivalent (FTE).

**Veterinary Inputs.** In line with the calculation approach described above, production costs were calculated by production system when diseases were absent and present on the farm. Health care costs were determined in conventional and AW systems by the prevalence and effect of the particular disease. A thorough literature review was conducted to collect data on the prevalence and effect of various diseases. In cases where data on AW systems were not available, an expert was consulted to estimate some of the inputs (J.J. de Wit, Dutch Animal Health Service, Deventer, the Netherlands, personal communication). Estimations regarding the prevalence and effect of various diseases in AW systems were made by relating these inputs to those referring to the conventional system. Although health risk could greatly vary across individual farms, these differences were not taken into account (J.J. de Wit, Dutch Animal Health Service, Deventer, the Netherlands, personal communication). Table 4 presents the prevalence of selected diseases under different production systems.

The requirements of AW concepts may decrease or increase the disease prevalence, but may also affect the effect of the disease on the production parameters. The important production parameters that the disease may affect are mortality, daily weight gain, feed conversion ratio, and condemnation rate at slaughter. Table 5 presents the effect of various diseases.

**Economic Inputs.** Table 6 presents the economic inputs used to calculate the production costs for each production system. Input data were derived from lit-
Sensitivity Analysis

Feed price in the broiler sector is highly volatile, which can have a significant effect on the economic performance of the farm. Moreover, the inputs are based on literature and can vary greatly under farm conditions. Therefore, a sensitivity analysis was conducted to evaluate the robustness of the results. The sensitivity analysis was restricted to diseases with the highest economic effect; that is, coccidiosis, *E. coli*, and NE. Feed costs and purchase of 1-d-old chicks are the main drivers of costs (Castellini et al., 2012). Changes in the purchase price of 1-d-old chicks may influence costs through mortality and condemnation at slaughter. Therefore, the feed price, the feed conversion rate, and the purchase price of 1-d-old chicks were systematically varied one at a time. Feed price was changed by

| Table 4. Prevalence of various diseases and disorders by production systems (%) |
|-------------------------------------------------------------|
| **Disease** | **Conventional** | **Volwaard** | **Better Life 1*/Puur & Eerlijk** | **Better Life 2*/** | **Better Life 3*/Skal** | **Organic** |
| IB* | 0 | 0 | 0 | 0 | 0 | 0 |
| IBD | 0.6 | 0.9 | 0.9 | 0.9 | 0.9 | 0.9 |
| Coccidiosis | 34.4 | 61.6 | 62.1 | 62.1 | 65.5 | 65.5 |
| *E. coli* | 100 | 100 | 100 | 100 | 100 | 100 |
| Necrotic enteritis | 12.3 | 15.7 | 15.7 | 15.7 | 15.7 | 15.7 |
| Leg problems (gait score >3) | 11.3 | 1.7 | 1.7 | 1.7 | 0.1 | 0.1 |
| Ascites | 3.3 | 1.7 | 1.7 | 1.7 | 0.1 | 0.1 |
| SDS | 0.8 | 0.4 | 0.4 | 0.4 | 0.2 | 0.2 |

1No change in disease prevalence across systems due to vaccination of 1-d-old chicks and a lack of research with regard to risk factors (Cook et al., 1999; Lopez et al., 2006). Re-vaccination is assumed to provide a protection level of 100% against the infectious bronchitis (IB) virus. In case of no vaccination, morbidity in the flock is 90% (Cook et al., 1999; Cavanagh, 2003).

2Although Homer et al. (1992) found a prevalence rate of 13.3%, the present study assumed that birds have been vaccinated against infectious bursal disease (IBD), indicating that IBD does not occur on the farm. Cavanagh (2003) suggested that vaccination against IBD provides 100% protection.

3According to Voeten (2000), vaccination is necessary to prevent loss due to IBD. In this study, IBD vaccination is assumed to provide 100% protection.

4No literature has been found indicating an increase in prevalence due to wild birds (Gilchrist, 2005). In the present study, IBD vaccination is assumed to provide 100% protection.

5Infection level >50,000 oocysts (Hang et al., 2008).

6Free-range area and lower stocking density: 59.1% (Williams et al., 1996). Increase due to a longer daylight period (6 h): a small increase in coccidiosis is expected due to a longer daylight period, which results in more activity in this period and, in turn, increases the likelihood of picking up oocysts from the environment (Henken et al., 1992). Therefore, the estimated increase in prevalence is 2.5%.

7Free-range area and lower stocking density: 59.1% (Williams et al., 1996). Increase due to a longer daylight period (8 h): a small increase in coccidiosis is expected due to a longer daylight period, which results in more activity in this period and, in turn, increases the likelihood of picking up oocysts from the environment (Henken et al., 1992). Therefore, the estimated increase in prevalence is 3.0%.

8Free-range area, use of prevention drugs prohibited, and lower stocking density: 62.5% (Williams et al., 1996). Increase due to a longer daylight period (8 h): a small increase in coccidiosis is expected due to a longer daylight period, which results in more activity in this period and, in turn, increases the likelihood of picking up oocysts from the environment (Henken et al., 1992). Therefore, the estimated increase in prevalence is 3.0%.

9*E. coli* is assumed to colonize the intestines of all chickens, among other organ systems. The number of chickens in the flock that suffer from symptoms is unknown.

10No change in prevalence assumed due to a decrease of cfu in the environment, a lower stocking density, and less dust; however, they do result in a lower impact of the disease.

11The number of *E. coli* bacteria increases due to stagnant water in the free-range area, which results in a greater impact of the disease.

12The prevalence in case of slow-growing breed is 0. The prevalence in case of a slower-growing breed is assumed to be between 0 and the value of fast-growing breed used in conventional system (1.7). Effect of free-range access: unknown. Natural day-night regimen: increase of 0.6% (Maxwell and Robertson, 1998).

13Slow-growing breed and outdoor access (Fanatico et al., 2008). Effect of daylight is ignored, because leg problems decrease even further due to a longer dark period (Knowles et al., 2008). The effect of stocking density is ignored because the likelihood of having leg problems decreases even further due to a lower stocking density.

14Free-range and lower stocking density (Van Horne et al., 2003).

15Slow-growing breed: no occurrence of ascites in case of a slow-growing breed (Scheele et al., 2005).

16Maxwell and Robertson (1998).

17The prevalence in case of slow-growing breed is 0. The prevalence in case of a slower-growing breed is assumed to be between 0 and the value of fast-growing breed used in conventional system (1.7). Effect of free-range access: unknown. Natural day-night regimen: increase of 0.6% (Maxwell and Robertson, 1998).

18-ERA, E. coli, and NE. Feed costs and purchase of 1-d-old chicks are the main drivers of costs (Castellini et al., 2012). Changes in the purchase price of 1-d-old chicks may influence costs through mortality and condemnation at slaughter. Therefore, the feed price, the feed conversion rate, and the purchase price of 1-d-old chicks were systematically varied one at a time. Feed price was changed by

- **Hermans and Morgan (2007)**.
- **Fanatico et al. (2008)** and Van Horne et al. (2003).
- **Free-range area: 28% of the wild birds’ feces is infected (Craven et al., 2000). Therefore, the estimated increase compared with the situation without free-range area is 28%.
- **Fanatico et al. (2008) and Van Horne et al. (2003).**
- **Free-range and lower stocking density (Van Horne et al., 2003).**
- **Slow-growing breed and outdoor access (Fanatico et al., 2008). Effect of daylight is ignored, because leg problems decrease even further due to a longer dark period (Knowles et al., 2008). The effect of stocking density is ignored because the likelihood of having leg problems decreases even further due to a lower stocking density.**
- **Maxwell and Robertson (1998).**
- **The prevalence in case of slow-growing breed is 0. The prevalence in case of a slower-growing breed is assumed to be between 0 and the value of fast-growing breed used in conventional system (1.7). Effect of free-range access: unknown. Natural day-night regimen: increase of 0.6% (Maxwell and Robertson, 1998).**
- **Maxwell and Robertson (1998).**
- **Free-range access results in a decrease in mortality due to sudden death syndrome (SDS; Van Horne et al., 2003). The prevalence of SDS is assumed to decrease as well due to the provision of free-range area.**
- **No SDS in case of slow-growing breed. Natural day-night regimen and provision of free-range area reduces the prevalence of SDS even further (Havenstein et al., 1994; Van Horne et al., 2003; Brickett et al., 2007).**

- **Better Life 1*/ Puur & Better Life 2*/Eerlijk**
- **Better Life 3*/Skal**
Table 5. Effect of diseases on production performance under different animal welfare (AW) concepts compared with the healthy baseline situation (bolded data indicate that under particular AW concepts the effect of the disease is changed compared with the conventional system)

| Production system/disease              | Input variable | Mortality (% flock) | Daily weight gain (g/d) | Weight at delivery (g) | Feed conversion ratio (g/g) | Condemnation rate at slaughter (% flock) |
|----------------------------------------|----------------|---------------------|-------------------------|------------------------|-----------------------------|----------------------------------------|
| **Conventional**                        |                |                     |                         |                        |                             |                                        |
| Baseline situation                     |                |                     |                         |                        |                             |                                        |
| **Baseline situation**                 |                |                     |                         |                        |                             |                                        |
| Conventional                           |                |                     |                         |                        |                             |                                        |
| Baseline situation                     |                |                     |                         |                        |                             |                                        |
| Infectious bronchitis (IB)             |                |                     |                         |                        |                             |                                        |
| Infectious bursal disease (IBD)        |                |                     |                         |                        |                             |                                        |
| Coccidiosis                            |                |                     |                         |                        |                             |                                        |
| Coccidiosis with preventive drugs      |                |                     |                         |                        |                             |                                        |
| E. coli                                |                |                     |                         |                        |                             |                                        |
| NE                                     |                |                     |                         |                        |                             |                                        |
| Leg problems                           |                |                     |                         |                        |                             |                                        |
| Ascites                                |                |                     |                         |                        |                             |                                        |
| Sudden death syndrome (SDS)            |                |                     |                         |                        |                             |                                        |
| **Volwaard**                           |                |                     |                         |                        |                             |                                        |
| Baseline situation                     |                |                     |                         |                        |                             |                                        |
| Conventional                           |                |                     |                         |                        |                             |                                        |
| Baseline situation                     |                |                     |                         |                        |                             |                                        |
| Infectious bronchitis (IB)             |                |                     |                         |                        |                             |                                        |
| Infectious bursal disease (IBD)        |                |                     |                         |                        |                             |                                        |
| Coccidiosis                            |                |                     |                         |                        |                             |                                        |
| Coccidiosis with preventive drugs      |                |                     |                         |                        |                             |                                        |
| E. coli                                |                |                     |                         |                        |                             |                                        |
| NE                                     |                |                     |                         |                        |                             |                                        |
| Leg problems                           |                |                     |                         |                        |                             |                                        |
| Ascites                                |                |                     |                         |                        |                             |                                        |
| **Better Life 1*/Puur & Eerlijk**       |                |                     |                         |                        |                             |                                        |
| Baseline situation                     |                |                     |                         |                        |                             |                                        |
| Conventional                           |                |                     |                         |                        |                             |                                        |
| Baseline situation                     |                |                     |                         |                        |                             |                                        |
| Infectious bronchitis (IB)             |                |                     |                         |                        |                             |                                        |
| Infectious bursal disease (IBD)        |                |                     |                         |                        |                             |                                        |
| Coccidiosis                            |                |                     |                         |                        |                             |                                        |
| Coccidiosis with preventive drugs      |                |                     |                         |                        |                             |                                        |
| E. coli                                |                |                     |                         |                        |                             |                                        |
| NE                                     |                |                     |                         |                        |                             |                                        |
| Leg problems                           |                |                     |                         |                        |                             |                                        |
| Ascites                                |                |                     |                         |                        |                             |                                        |
| **Better Life 2*/Skal**                 |                |                     |                         |                        |                             |                                        |
| Baseline situation                     |                |                     |                         |                        |                             |                                        |
| Conventional                           |                |                     |                         |                        |                             |                                        |
| Baseline situation                     |                |                     |                         |                        |                             |                                        |
| Infectious bronchitis (IB)             |                |                     |                         |                        |                             |                                        |
| Infectious bursal disease (IBD)        |                |                     |                         |                        |                             |                                        |
| Coccidiosis                            |                |                     |                         |                        |                             |                                        |
| Coccidiosis with preventive drugs      |                |                     |                         |                        |                             |                                        |
| E. coli                                |                |                     |                         |                        |                             |                                        |
| NE                                     |                |                     |                         |                        |                             |                                        |
| Leg problems                           |                |                     |                         |                        |                             |                                        |
| Ascites                                |                |                     |                         |                        |                             |                                        |
| **Organic**                            |                |                     |                         |                        |                             |                                        |
| Baseline situation                     |                |                     |                         |                        |                             |                                        |
| Conventional                           |                |                     |                         |                        |                             |                                        |
| Baseline situation                     |                |                     |                         |                        |                             |                                        |
| Infectious bronchitis (IB)             |                |                     |                         |                        |                             |                                        |
| Infectious bursal disease (IBD)        |                |                     |                         |                        |                             |                                        |
| Coccidiosis                            |                |                     |                         |                        |                             |                                        |
| Coccidiosis with preventive drugs      |                |                     |                         |                        |                             |                                        |
| E. coli                                |                |                     |                         |                        |                             |                                        |
| NE                                     |                |                     |                         |                        |                             |                                        |
| Leg problems                           |                |                     |                         |                        |                             |                                        |
| Ascites                                |                |                     |                         |                        |                             |                                        |
for these concepts is decreased by 60%. Therefore, the effect of the water may remain there, which could serve as a good reserve for *E. coli*.

Better Life 3* concepts, the free-range area is not covered and restricted to a caged area. The relative decrease in mortality is calculated (80%) according to Van Horne et al. (2003). The effect under the AW concepts is decreased by 40% compared with that under conventional system. However, in case of organic and Better Life 3* concepts, the free-range area is not covered and restricted to a caged area.

**Influence of coccidial infections**

Subclinical coccidiosis is primarily expected in a conventional system. A light infection level is assumed in Volwaard, Better Life 1*, and Better Life 2*. The decrease for conventional systems is assumed to be 10 g/d. The decrease for organic and Better Life 3* is assumed to be 4 g/d. Due to the provision of a free-range area, a slower-growing breed, a lower stocking density, and a natural day-night regimen, the number of birds with GS 4 and 5 decreases.

Mortality due to leg problems is the most severe in the conventional system, which indicates that leg problems have the highest effect on feed conversion in conventional systems. However, in case of organic and Better Life 3* concepts, the free-range area is not covered and restricted to a caged area. A moderate infection level is assumed in Better Life 3* and organic systems because the use of anticoccidial drugs is prohibited (Reid and Johnson, 1970; Voeten et al., 1988).

Increase in mortality due to leg problems is 0.8%; condemnation rate is 0.3% (Verma, 2007).

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RESULTS

**Absolute Effect of Various Diseases on Production Costs**

Table 7 presents the absolute effect of various diseases on production costs. During the calculation of production costs, one disease was considered at a time and no interaction effect between diseases was assumed. Production costs in the baseline situation (no diseases) differed across systems. With regard to production costs, 3 categories emerged. The first category included the conventional system with the lowest production costs. The second category, which included Volwaard, Better Life 1*, and Better Life 2* (also referred to as middle-market systems), produced costs that were higher than the conventional system, but considerably lower than systems in the third category, which included Better Life 3* and organic.

In the conventional system, diseases that affect the gastrointestinal tract (that is, *E. coli* and NE) had the highest absolute effect on production costs. Production costs per delivered broiler increased by €0.144 in case of *E. coli* and by €0.071 in case of NE. The other diseases had a minor effect on production costs. Similarly, in case of the second category, *E. coli* and NE again had the highest effect on production costs, whereas, in the third category, coccidiosis had the highest effect, followed by *E. coli* and NE. The high effect of coccidiosis can be explained by the fact that the use of anticoccidial drugs is prohibited in organic systems. The absolute effect of gastrointestinal problems on production costs remained at the same level or even increased with more welfare-friendly production. However, the absolute effect of leg problems and heart and vascular disease decreased for AW systems because these systems use a more robust breed.

**Relative Effect of Various Diseases on Production Costs**

Table 8 shows the relative effect of various diseases on production costs. Again, the same 3 categories emerged as in the case of absolute effect.

In the conventional system, the highest relative effect was caused by gastrointestinal diseases corresponding to approximately 11.5%, which was the sum of separate effects (i.e., coccidiosis = 1.24%, *E. coli* = 6.8%, NE = 3.39%), followed by leg problems. The dominance of gastrointestinal diseases in terms of relative effect can be recognized in all systems. In the second category (which included Volwaard, Better Life 1*, and Better Life 2*), the relative effect of gastrointestinal diseases

Table 6. Economic inputs by different production systems

| Input variable | Conventional | Volwaard | Better Life 1* | Better Life 2* | Better Life 3* | Organic |
|---------------|--------------|----------|----------------|---------------|---------------|---------|
| Feed price (€/100 kg) | 31.839       | 30.883   | 30.883         | 30.883        | 45.211        | 45.211  |
| Price of 1-d-old chick (€/chick) | 0.302       | 0.320    | 0.320          | 0.320         | 0.438         | 0.438   |
| Litter (€/chicken) | 0.008        | 0.030    | 0.028          | 0.026         | 0.040         | 0.040   |
| Product board levies (€/100 chickens) | 0.290       | 0.290    | 0.290          | 0.290         | 0.290         | 0.290   |
| Carrion collecting service (€/100 chickens) | 0.200       | 0.200    | 0.200          | 0.200         | 0.200         | 0.200   |
| Manure disposal (€/100 chickens) | 2.400        | 2.400    | 2.400          | 2.400         | 2.400         | 2.400   |
| Labor cost (h) | 25.00        | 25.00    | 25.00          | 25.00         | 25.00         | 25.00   |
| Electricity (€/chicken) | 0.023       | 0.023    | 0.023          | 0.023         | 0.012         | 0.012   |
| Heating (€/chicken) | 0.045        | 0.068    | 0.068          | 0.068         | 0.090         | 0.090   |
| Coccidiostat (€/chicken) | 0.007       | 0.007    | 0.007          | 0.007         | 0.007         | 0.007   |
| Vaccination coccidiosis (€/chicken) | 0.120       | 0.120    | 0.120          | 0.120         | 0.120         | 0.120   |
| Vaccination IBD (€/chicken) | 0.010       | 0.010    | 0.010          | 0.010         | 0.020         | 0.020   |
| Re-vaccination IBD (€/chicken) | 0.010       | 0.010    | 0.010          | 0.010         | 0.010         | 0.010   |
| Antibiotic treatment NE and *Escherichia coli* (€/chicken) | 0.027       | 0.027    | 0.027          | 0.027         | 0.027         | 0.027   |
| Fixed costs (%) | | | | | | |
| Depreciation of buildings | 4 | 4 | 4 | 4 | 4 | 4 |
| Depreciation inventory | 8 | 8 | 8 | 8 | 8 | 8 |
| Interest | 5 | 5 | 5 | 5 | 5 | 5 |
| Interest livestock | 6 | 6 | 6 | 6 | 6 | 6 |
| Maintenance of buildings | 1 | 1 | 1 | 1 | 1 | 1 |
| Maintenance inventory | 2 | 2 | 2 | 2 | 2 | 2 |
| Maintenance outdoor access | 2 | 2 | 2 | 2 | 2 | 2 |

1Gocsik et al. (2013).
2KWIN-V (2011).
3Puister (2009). NE = necrotic enteritis.
4Steenhuisen and Vossen (2001).
5Standard tariff for Dutch veterinarians. IBD = infectious bursal disease; IB = infectious bronchitis.
6PVE (2011).
was lower (approximately 8%) than in the conventional system. In the third category, however, their relative effect was almost at the same level as that in the conventional system. The effect of leg problems decreased with increasing AW standards. The relative effect of other diseases remained below 1% in all systems, which meant they were less important in that regard.

### Proportion of Health Care Costs in Total Production Costs

Table 9 lists the health care costs due to gastrointestinal diseases and leg problems as a percentage of total production costs. These diseases were selected because they had the highest relative effect on production costs (as shown in Table 8). Health care costs were split into L and E and presented as percentage shares of the total production costs.

As Table 9 shows, health care costs represent only a small share of total production costs in all systems. In conventional and middle-market systems, the proportion of loss within total health care costs is approximately 3 times greater than the proportion of expenditures. In Better Life 3* and organic systems, the proportion of loss is approximately 90% of the total health care costs. However, in case of coccidiosis, health care costs were solely derived from loss (100%) in these 2 systems, whereas in conventional systems, 73% of health care costs came from loss. This larger loss due to coccidiosis in Better Life 3* and organic systems occurred because the use of anticoccidal drugs was prohibited, which meant that procuring them incurred no expenditures. In general, the proportion of loss in total health care costs is larger than that of expenditures. Because the symptoms of gastrointestinal diseases remain subclinical, these diseases usually remain untreated. For example, a less efficient feed conversion due to a gastrointestinal disease results in a higher feed consumption and, ultimately, in higher feed costs. This implies that it is more difficult to detect the actual effect of these diseases because they are not incurred as direct expenditures. The loss due to leg problems decreased in the middle-market systems due to increasing AW standards. In the organic system, no health care costs occurred due to leg problems.

### Sensitivity Analysis

Because it was of great importance that the ranking of production systems for various diseases is robust to changes in input values, changes in relative effect were studied. Accordingly, we analyzed changes in the sequence from the highest to the lowest relative effect. Table 10 shows that irrespective to changes in the variables included in the analysis, coccidiosis had the highest relative effect in the organic system and the lowest relative effect in the conventional system. *Escherichia coli* had the highest relative effect in the conventional system.
system and the lowest effect in the Better Life 1* system. Similarly, NE had the highest relative effect in the conventional system and the lowest effect in the Better Life 3* system under all of the examined conditions. Overall, the results indicated that changes in feed price, feed conversion, and purchase price of 1-d-old chicks had no effect on the sequence from the highest to the lowest relative effect.

**DISCUSSION**

The aim of the study was to analyze the effect of different broiler production systems on readily quantifiable health care costs, which were calculated per delivered broiler using partial budgeting. A model described by Gocsik et al. (2013) was used and adapted to calculate health care costs in Dutch broiler production systems.

Although the approach used in our study draws heavily on input data that were not available in peer-reviewed scientific literature, all input data were gathered with care and thoroughly checked with an expert in poultry diseases to be able to provide the most accurate results.

The approach used in our study involved certain approximations and assumptions. First, own labor cost was assumed to be fixed. A farm was assumed to have as many animal places as can be managed by one FTE. When diseases occur, the activities on the farm may require more time than the farmer has available and extra personnel may have to be hired, potential causing health care costs to increase. The literature on time spent on treatment and hygiene measures as a consequence of a disease occurrence is scarce. The broiler farmer was assumed to have time available to perform these activities. Second, the default values used in this

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**Table 8. Relative effect of various diseases on production costs per delivered broiler (%)**

| Disease | Conventional | Volwaard | Better Life 1*/Puur & Eerlijk | Better Life 2* | Better Life 3*/Skal | Organic |
|---------|--------------|----------|-------------------------------|----------------|-------------------|--------|
| Baseline situation | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 |
| Respiratory IB | 0.48 | 0.39 | 0.37 | 0.38 | 0.16 | 0.19 |
| Immune organs IBD | 0.48 | 0.39 | 0.37 | 0.77 | 0.33 | 0.38 |
| Gastrointestinal | | | | | | |
| Coccidiosis | 1.24 | 1.70 | 1.68 | 1.48 | 4.03 | 4.38 |
| *Escherichia coli* | 6.86 | 2.89 | 2.80 | 3.28 | 3.54 | 4.37 |
| NE | 3.39 | 3.25 | 3.22 | 3.18 | 2.42 | 2.61 |
| Locomotion | | | | | | |
| Leg problems | 1.19 | 0.35 | 0.33 | 0.31 | 0.00 | 0.00 |
| Heart and vascular | | | | | | |
| Ascites | 0.61 | 0.10 | 0.09 | 0.11 | 0.00 | 0.00 |
| SDS | 0.19 | 0.02 | 0.02 | 0.04 | 0.00 | 0.00 |

1IB = infectious bronchitis; IBD = infectious bursal disease; NE = necrotic enteritis; SDS = sudden death syndrome.

**Table 9. Proportion of health care costs within the total production costs (%) and proportion of loss (L) and expenditures (E) expressed as a percentage in total production costs**

| Disease | Conventional | Volwaard | Better Life 1*/Puur & Eerlijk | Better Life 2* | Better Life 3*/Skal | Organic |
|---------|--------------|----------|-------------------------------|----------------|-------------------|--------|
| Gastrointestinal | | | | | | |
| Coccidiosis | 1.22 | 1.68 | 1.65 | 1.46 | 3.88 | 4.20 |
| L | 0.89 | 1.42 | 1.41 | 1.20 | 3.88 | 4.20 |
| E | 0.33 | 0.26 | 0.24 | 0.26 | — | — |
| *Escherichia coli* | 6.42 | 2.81 | 2.72 | 3.18 | 3.42 | 4.19 |
| L | 5.22 | 1.81 | 1.77 | 2.18 | 2.99 | 3.70 |
| E | 1.21 | 1.00 | 0.96 | 1.00 | 0.43 | 0.49 |
| NE | 3.28 | 3.24 | 3.12 | 3.08 | 2.36 | 2.55 |
| L | 2.04 | 2.24 | 2.17 | 2.08 | 1.93 | 2.05 |
| E | 1.25 | 0.99 | 0.95 | 1.00 | 0.43 | 0.50 |
| Locomotion | | | | | | |
| Leg problems | 1.18 | 0.34 | 0.33 | 0.31 | 0.00 | 0.00 |
| L | 1.18 | 0.34 | 0.33 | 0.31 | — | — |
| E | | | | | | |

1C = L + E. Health care costs (C) consists of loss (L) caused by diseases and the preventive and treatment expenditures (E).
study, such as weight at delivery and feed conversion rate, were averages representing the Netherlands and thus country specific. It is unknown whether and to what extent these values were influenced by diseases. No corrections were made in this respect, which means that these values may differ in practice. However, this assumption is not expected to influence the results considerably because it was valid for all systems. Further, only the direct disease effects were taken into account, in other words the possible immunosuppressive effect of some diseases was not considered. Third, no interactions were assumed between diseases because, for most diseases, it is still unclear whether and to what extent the effect of the diseases changes in case 2 endemic diseases simultaneously occur in the flock (Cavanagh, 2003; Matthijs et al., 2003). Fourth, we assumed that vaccination against IB and IBD would protect the flock 100% and that these diseases would no longer occur on the farm. In case of IBD, however, the hygienic status of the farm is known to influence the effectiveness of the vaccine (Müller et al., 2012). Moreover, little is known about whether the vaccine offers cross-protection against other serotypes. A farm with an outdoor area for chickens is expected to have a lower level of hygiene, which negatively affects the effectiveness of the vaccine. Moreover, chickens in an organic farm have more antibodies against IBD than chickens in conventional farms (Van Overbeke et al., 2006). Hence, in case of farms with Better Life 2*, Better Life 3*, and organic systems, which have an increased risk of IBD, a more expensive vaccination program was assumed to be implemented. Because a vaccine against IB may not provide 100% protection either (Cavanagh, 2003), chickens were assumed to be vaccinated twice. The study investigates the health care costs of the preventive measures, not the economic feasibility. In other words, if vaccination prevented great losses, it was chosen as a preventive measure. Fifth, the chickens were

| Disease | Change in variable | Conventional | Volwaard | Better Life 1*/Puur & Eerlijk | Better Life 2* | Better Life 3*/Skal | Organic |
|---------|--------------------|--------------|----------|-------------------------------|----------------|-------------------|---------|
| Baseline situation | Feed price (%) | -5 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 |
| | | 0 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 |
| | | 5 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 |
| Coccidiosis | -5 | 1.23 | 1.71 | 1.72 | 1.42 | 4.06 | 4.42 |
| | | 0 | 1.24 | 1.70 | 1.70 | 1.45 | 4.03 | 4.37 |
| | | 5 | 1.30 | 1.69 | 1.73 | 1.42 | 3.95 | 4.33 |
| Escherichia coli | -5 | 6.86 | 2.91 | 2.78 | 3.23 | 3.51 | 4.36 |
| | | 0 | 6.86 | 2.90 | 2.81 | 3.25 | 3.56 | 4.37 |
| | | 5 | 6.92 | 2.90 | 2.78 | 3.21 | 3.57 | 4.39 |
| NE | -5 | 3.50 | 3.43 | 3.28 | 3.27 | 2.47 | 2.69 |
| | | 0 | 3.39 | 3.33 | 3.22 | 3.18 | 2.42 | 2.61 |
| | | 5 | 3.39 | 3.27 | 3.14 | 3.09 | 2.35 | 2.55 |
| Feed conversion ratio | Baseline situation | -0.1 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 |
| | | 0 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 |
| | | +0.1 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 |
| Coccidiosis | -0.1 | 1.34 | 1.75 | 1.71 | 1.45 | 4.12 | 4.49 |
| | | 0 | 1.24 | 1.70 | 1.70 | 1.45 | 4.03 | 4.37 |
| | | +0.1 | 1.20 | 1.66 | 1.62 | 1.38 | 3.95 | 4.31 |
| E. coli | -0.1 | 7.17 | 2.98 | 2.85 | 3.33 | 3.61 | 4.49 |
| | | 0 | 6.88 | 2.90 | 2.81 | 3.25 | 3.56 | 4.37 |
| | | +0.1 | 6.60 | 2.79 | 2.71 | 3.13 | 3.47 | 4.29 |
| NE | -0.1 | 3.51 | 3.42 | 3.27 | 3.26 | 2.47 | 2.69 |
| | | 0 | 3.39 | 3.33 | 3.22 | 3.18 | 2.42 | 2.61 |
| | | +0.1 | 3.28 | 3.24 | 3.14 | 3.10 | 2.57 | 2.57 |
| Price of 1-d-old chicks (%) | Baseline situation | -5 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 |
| | | 0 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 |
| | | 5 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 |
| Coccidiosis | -5 | 1.25 | 1.71 | 1.68 | 1.42 | 4.05 | 4.38 |
| | | 0 | 1.24 | 1.70 | 1.70 | 1.45 | 4.03 | 4.37 |
| | | 5 | 1.23 | 1.69 | 1.66 | 1.41 | 4.02 | 4.35 |
| E. coli | -5 | 6.88 | 2.92 | 2.83 | 3.27 | 3.55 | 4.37 |
| | | 0 | 6.88 | 2.90 | 2.81 | 3.25 | 3.56 | 4.37 |
| | | 5 | 6.78 | 2.88 | 2.76 | 3.19 | 3.53 | 4.35 |
| NE | -5 | 3.42 | 3.35 | 3.24 | 3.19 | 2.41 | 2.60 |
| | | 0 | 3.39 | 3.33 | 3.22 | 3.18 | 2.42 | 2.61 |
| | | 5 | 3.36 | 3.31 | 3.20 | 3.15 | 2.41 | 2.60 |

1NE = necrotic enteritis.
assumed to be equally susceptible and sensitive to the diseases throughout the entire growth period. The effect of current breeder health programs is implicitly taken into account, because the prevalence and effect of diseases were determined based on the current production systems and the characteristics of breeds currently used in practice. This model does not take potential resistance against preventive drugs and antibiotics into account. However, coccidiosis is known to be more and more resistant against anticoccidial drugs, which mitigates the negative effects of diseases to a lesser extent (Jenkins et al., 2010). Hence, avoidable costs might be lower than those estimated in the model. Resistance to drugs against NE and E. coli has also been increasing. In each system, the same amount of drugs was assumed to be used. The study did not include the potential effect of a particular disease in previous and subsequent production rounds. Sixth, health care costs may have been overestimated to some extent. A disease has an effect on the production function, and therefore on the optimal production level (McInerney, 1996). An economically rational farmer would minimize the effect of a disease by adjusting the level of input use, which would probably result in health care costs lower than those estimated in this study. Finally, figures for prevalence and effect might not entirely reflect the latest developments in broiler production. For example, in recent years the incidence of ascites has reduced due to including ascites in the selection index; however, recent figures cannot be found in literature. As a consequence, the actual values for prevalence may be lower than those used in our calculation. However, this holds for all systems. Therefore, the differences between systems remain similar. In other words, whereas actual costs due to ascites may be lower, the relative differences between systems remain unchanged. Moreover, due to various assumptions and estimations, production costs may be under- or overestimated. Therefore, it is important that these costs are not used as indicators, but to comprehensively assess the differences between systems. Sensitivity analysis showed that ranking of production systems is robust to changes in feed price, feed conversion, and price of 1-d-old chicks.

To our knowledge, this study is the most extensive attempt to compare AW systems on the basis of their health care costs. The results of the study show that health care costs represent only a small proportion of total production costs, regardless of the production system. Losses account for the majority of health care costs, which makes the actual effect of diseases on total health care costs difficult to detect. Three categories of production systems were distinguished based on health care costs. The first category includes conventional systems, in which diseases affecting the gastrointestinal tract and leg problems had the highest effect on production costs in both absolute and relative terms. Similarly, in the second category, referred to as middle-market systems, gastrointestinal diseases and leg problems had the highest effect on production costs. However, the effect of these diseases was lower than that of diseases in conventional system. The decrease in effect can be explained by the fact that these AW systems use a more robust breed with a slower growth rate. In the third category, gastrointestinal diseases had the highest effect and the overall effect of gastrointestinal diseases was similar to that in the conventional system. However, the effect of coccidiosis increased compared with the conventional system, most likely due to prohibition on the use of anticoccidial drugs and the provision of an outdoor access. Moreover, leg problems and heart and vascular diseases disappeared completely, which is probably the result of the use of a more robust breed with a slower growth rate. Angel (2007) suggested that chickens with slower early growth rate have less problems with skeletal development. Also, research indicated that there was a direct correlation between high growth rate and ascites (European Commission, 2000).

There are only a few studies against which to compare our results. Vermeij (2004) and Vermeij and Van Horne (2008) calculated cost-prices for organic broiler farms in 2004 and in 2008. The total health care costs were estimated at €0.12 per broiler in 2004 and €0.10 per broiler in 2008. These estimates do not agree with the results of this study, in which the absolute health care costs are often higher than €0.10 per delivered broiler in an organic farm. Lovland and Kaldhusdal (2001) found that the profit margin decreased by 33% in case of high levels of NE in the flock compared with low levels of the disease. Moreover, the absolute costs due to NE in the United States were estimated at US$0.05 per broiler chicken (McDevitt et al., 2006). In another American study, the loss ranged between $878.19 and $1,480.52 per flock of 20,000 broilers. This works out to an estimated $0.044 to 0.074 per chicken (Skinner et al., 2010), which, based on exchange rates at the time of writing, equates to approximately €0.03 to 0.06 per broiler. This is in agreement with the results of the conventional system. However, these costs are much higher in Better Life 3* and organic systems. Lund and Algers (2003) supported the findings of this study. Based on a literature study, they concluded that the level of animal health in an organic farm was the same or slightly lower level than in a conventional system, except for (endo-)parasitic infections, which occurred more often in an organic farm. The occurrence of other diseases remained at the same level or decreased compared with a conventional system. This difference can also be found in the results of the present study. In other words, the occurrence of parasitic infections, such as coccidiosis, increases compared with a conventional system, whereas the occurrence of other diseases, such as leg problems, SDS, and ascites, decreases.

Although the study focused on the Dutch situation, the findings are relevant for countries that face similar concerns with respect to AW than the Netherlands (for example, other European Union countries and United
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