

Theses of doctoral dissertation (PhD)

**RISK ANALYSIS METHODS FOR THE EXAMINATION OF THE
LIFE SPAN AND LIFETIME PERFORMANCE OF SOWS**

Angéla Soltész

Advisor:
Dr. Péter Balogh
associate professor



UNIVERSITY OF DEBRECEN

Károly Ihrig Doctoral School of Management and Business

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1. RESEARCH PRELIMINARIES AND OBJECTIVES, RESEARCH HYPOTHESES

I first started to study the methodology of survival analysis in 2008, when I examined the impact of the intensity of husbandry on the life span of a breeding sow population, followed by a comparative examination of breeding sow production farms with survival analysis. The findings obtained with these two examinations had useful information about the risk factors affecting the lifetime performance of sows. Therefore, the objective of my scientific activity was to analyse the impact of risk factors at farms on lifetime performance by involving further populations. I would like my research findings to provide sow production farms with useful information in order to increase the successfulness of their production.

I chose this research topic because the situation of the pig sector in Hungary has become a key issue for today. The drastic decrease of pig population, the change of the national subsidisation system and the changes in fodder and import prices during the last decade had an extreme impact on the sector. In 2012, the Government launched a specific program called the “National Pig Strategy” with the aim to improve this critical situation. The main objective of this strategy was to double the Hungarian pig population and it also contained further strategic measures to work out a breeding, production integration and research and development program. Consequently, it is necessary to examine the production-related risks which can significantly affect the life span of producing sows and, as a result, the efficiency and profitability of production.

Based on the above written points, **I set the following two main objectives** in my doctoral dissertation.

- To provide a quantified evaluation of the risk factors affecting life span and, consequently, their lifetime performance (piglet output). Based on the obtained results, my aim is to come up with practical advices which can contribute to the increase of the useful life span of sows in production; therefore, their productive lifetime performance.
- To prepare a pig farm simulation model which can predict the profitability indexes of rearing pig production farms while considering the various risk factors. My aim is to prepare a

model which can be used for rearing pig production farms that have different characteristics in order to analyse their profitability.

I set the following partial aims in relation to my research:

Aims of secondary research

1. Demonstration of survival analysis and simulation modelling as risk analysis methods.
2. Examination of the factors affecting the lifetime performance and culling of breeding sows based on Hungarian and international technical literature.

Aims of primary research

1. Collecting the lifetime performance data of breeding sows from the North Great Plain region and the compilation of a database which can be used for survival analysis.
2. Evaluation of the life span and lifetime performance of breeding sows from the aspect of risk using survival analysis, with special emphasis on the risks caused by culling reasons, flooring and the intensity of husbandry.
3. Preparing a “model” farm capable of pig farm simulation modelling based on the data of a few breeding pig farms in the North Great Plain region.
4. Evaluation of the production and market-related factors of sow and rearing pig management from the aspect of risk and their ranking based on simulation modelling.

In accordance with the set objectives, as well as technical literature data and practical observations, **I worked out the following five hypotheses.**

- **1st hypothesis:** The survival probability and expected lifetime performance of sows culled due to various reasons are different.
- **2nd hypothesis:** The survival probability and expected lifetime performance of sows reared on the two different flooring types are different.
- **3rd hypothesis:** The expected lifetime performance of sows which have higher than average body weight (forced fattening) is different than pigs reared in optimal conditions.
- **4th hypothesis:** Of the different production risks, the profitability of sow farms is affected by the average farrowing ratio the most.

- **5th hypothesis:** Of the different market risks, the profitability of sow farms is affected by the unit price of fodder of breeding sows the most.

2. DATABASE AND METHODS USED IN THE RESEARCH

I performed the production and economic risk analysis of the lifetime performance of breeding sows. Consequently, the primary data collection based on secondary research and the processing of collected data with quantitative methods constituted an organic part of my work. During data collection, I obtained the production, technological and economic indexes of breeding farms (rearing pig and fattening pig production). Data collection was performed by means of personal inquiries and electronic data provision. The obtained data was processed with survival analysis and simulation model of the various methods recommended in the technical literature. In addition, I performed descriptive statistics and hypothesis analyses as a part of data processing with the aim to compare frequencies and means.

2.1. Material for analysis

During my primary research, I collected the data needed for my analyses from ten sow farms in the North Great Plain region (two gilt production and ten breeding farms). I chose the North Great Plain region as a target for analysis because it is the most significant pig production region in Hungary.

In the course of selecting the farms to be examined, it was a prerequisite for the farms to perform modern production which is in accordance with current regulations. Although the sampling cannot be considered representative, it was not even an objective from the aspect of my dissertation, since risk analysis and simulation modelling does not call for representativity.

In order to perform survival analysis, I obtained the data of 4359 culled breeding pigs from two breeding rearing pig production farms. Furthermore, I obtained the production and constitution details of 1270 culled breeding pigs from a breeding farm. In addition, the technological data of farms were also collected, supplemented by the technological and economic characteristics of seven more breeding farms which constituted the bases of simulation modelling.

2.2. Sources of data collection

During my primary research work, I collected the individual data referring to breeding sows from the electronic breeding registry program (“Röfi”) of the farm and I obtained the on-farm performance

testing details. The technological, production and profitability indexes of different farms were collected on a technological datasheet with the help of the management and economic professionals of each farm.

2.2.1. The “Röfi” program

KW-Röfi is a software developed especially for pig breeders. One of the main tasks of this software is to keep an accurate and up-to-date record of production data, while it also provides its users with decision support information.

The following data were recorded by Röfi for each breeding pig: date of birth, date of first mating, number of farrowings, total number of farrowed piglets, number of piglets born alive, number of piglets born dead, number of weaned pigs, date of cullings, reason for culling.

2.2.2. On-farm performance testing

It is a common practice in Hungary to carry out on-farm performance testing of rearing pigs in farm conditions. According to the Pig Performance Analysis Codex (MGSZH, 2009), on-farm performance testing can be used in the case of boars and gilts which have unique identifiers, their origin and date of birth can be determined in a credible way, the breed or construction they belong to is either acknowledged or the acknowledgement is in process. As a matter of fact, this analysis serves the purpose of preliminary selection with the aim to decide about the suitability for breeding (NOVOZÁNSZKY, 2014).

During my research work, I collected the on-farm performance testing data of breeding sows which contained the following details: age at the time of carrying out the on-farm performance testing (days), body weight (kg), fat depth 1 (mm), fat depth 2 (mm), pork chop thickness (mm), lean meat %. Furthermore, I determined the weight gain (g) per day.

2.2.3. On-farm information datasheet

During my analysis, it was necessary to know the basic technological data and natural efficiency indexes of farms, as well as the sales price and cost items. I collected these data from the eight breeding farms using my custom made “On-farm information datasheet”. The sheets were filled out during personal inquiries. The data referred to 2013.

The questions in the datasheet covered the following topics: breeding, farrowing, piglet management, mortality/culling, specific output, sales prices, fodder prices, specific expenses, other farm costs.

2.3. Methods of data processing and analysis

Following the arrangement of information obtained from the farms, I prepared two databases – one for breeding rearing pig production farms and one for breeding sow production farms – in a way to make it possible to examine the lifetime performance of breeding pigs with survival analysis methods.

The examination of the lifetime performance indexes of sows using survival analysis can be considered frequent in international technical literature (BRANT et al., 1999; JORGENSEN – SORENSEN, 1998; YAZDI et al., 2000; SERENIUS – STALDER, 2004; TARRES et al., 2006; ENGBLOM et al., 2008; FERNÁNDEZ DE SEVILLA et al., 2009; HOVING et al., 2011). Despite this fact, only very few Hungarian researchers have been dealing with survival analysis in pigs (NAGY et al., 2002; BALOGH et al., 2006; NAGY et al., 2010).

Following the examination of the production risk of breeding pigs, I examined the economic risk of farms with simulation modelling. During the simulation procedure, the model is implemented, resulting in representative samples of the performance indexes describing the functions of the system (WINSTON, 1997).

The data needed for modelling were provided by the on-farm information datasheets in relation to the 2013 data of the eight breeding farms.

2.3.1. Survival analysis

During my research, I examined the survival probability of sows using the two non-parametric methods of survival analysis (Kaplan-Meier estimate and Cox relative risk model). The analysed event was the culling of breeding pigs, the duration of which was expressed in days between birth and culling.

Although this method is capable of managing the cases in which the examined event (culling) has not taken place yet (the animal was still in the production process during the analysis or it was transported to a different farm), I did not have to define any censored cases, since all pigs in the database were culled.

I used the survival analysis to evaluate the impact of the following factors: culling reasons, farm type (flooring), body weight.

During the analysis, I prepared the survival and risk functions with the aim to demonstrate my findings. The survival functions provided the probability that the examined sows are not culled 't' time after the beginning of analysis. At the same time, the risk function provided the probability against a unit of time that the examined sows are culled 't' time after the beginning of production (DUCROCQ – SÖLKNER, 1998; NAGY et al., 2002; KOVÁCS, 2006).

During the comparison of each group, the distance between curves demonstrated the differences between each group. In the case of survival functions, the vertical gap showed the extent of survival proportion (the probability of staying in production) at a given age of one of the groups (e.g. one of the farms) in comparison of the other group (the other farm). At the same time, the horizontal distance represents the temporal difference (number of days) between the occurrence of the survival proportion of the two groups (KOVÁCS, 2009).

The Kaplan–Meier analysis determined the median and mean of survival duration (KAPLAN – MEIER, 1958) which made it possible to compare the different groups (culling reasons, farms, body weight categories). I used the log rank test to analyse the significant differences between the examined groups. This test is more sensitive to the differences at the end of the analysis (McGREADY, 2005). For this reason, this test is best used when significant differences can be expected in probability over time.

I examined the risk factors affecting the lifetime performance of sows with the Cox relative risk model. This procedure differed from the Kaplan-Meier estimate in that its main objective was to examine how much staying in production depends on the various risk factors (COX, 1972).

When setting the risk factors (x), I determined the culling reason, farm code and the body weight category as categorical variables, while the various farrowing indexes were the constant variable of the model. In the case of the categorical variables, the base of comparison was the category with the highest survival proportion and the rest of categories

were compared to this one. The time factor (t) was determined as the duration sows spent in production.

The obtained result of the model was the risk rate which showed the risk of the eventuality of culling against each risk factor (KALBFLEISCH – PRENTICE, 1980).

The risk rate was evaluated the following way: in the case of categorical variables, risk rate above 1 meant that the risk of the given category is higher than the risk of the category of comparison, while risk rate below 1 meant that the risk of the given category is lower (KOVÁCS, 2009). In the case of constant variables, the risk rate provided the value of risk of the given variable for one unit of growth.

The significance of each variable was determined using the Wald chi-square test.

Data processing and evaluation was performed with IBM SPSS 22.0 along the same steps for each database.

2.3.2. Simulation modelling

I analysed the profitability of sow and piglet management with the Monte-Carlo simulation, which is a widely used numerical method (OROSZ, 2003; ROHÁCS, 2007; KOVÁCS – CSIPKÉS, 2010; TAKÁCS-GYÖRGY – TAKÁCS, 2011; VIZVÁRI et al., 2011; HUZSVAI et al., 2012). This method is used as an alternative solution of risk analysis and it is based on computerised simulations with randomised values of the system after the modelling of the system (RUSSEL and TAYLOR, 1998). According to this method, values are randomly chosen on the basis of probability distributions attributed to each uncertain factor. These randomly chosen values are then used in the experiments of the simulation analysis (VOSE, 2006).

As a first step, I prepared a model farm in Excel using the data collected on the technological datasheets. This model farm demonstrates the production and profitability of a breeding farm dealing with rearing pig production, considering a given sow population. The model contributes to determining the profitability of the farm on the basis of natural outputs.

As a next step of modelling, I provided the variables to be used in the simulation, along with their possible ranges and probability distributions which I set using @Risk 4.5 running in Excel

(PALISADE, 2005). The assumed distribution of parameters can be selected from various distribution types. Of these, I used the triangle distribution which is recommended if the minimum, maximum and the most probable values are all known (EVANS et al., 2000). I considered the average farm values to be the most probable value.

I set the following input parameters to be the determinant factors of the model:

- Yearly number of farrowings per sow
- Litter size (number per farrowing)
- Suckling pig mortality (%)
- Weaner mortality (%)
- Sow culling (%)
- Rearing pig sales price (HUF per kg)
 - Eurex piglet price (EUR per kg)
 - MNB exchange price (HUF per €)
- Fodder consumption of piglets (kg)
- Fodder consumption of sows (kg)
- Piglet fodder price (HUF per kg)
- Sow fodder price (HUF per kg)

Since producers in the Hungarian pig market increasingly take the tendencies of international piglet prices into consideration, I also examined the tendencies of rearing pig sales prices based on the piglet quotations of the Eurex commodity exchange in Frankfurt. Therefore, I prepared the following two model types based on the method of determining the sales price of rearing pigs:

- Model type 1: calculation on the basis of Hungarian rearing pig sales prices.
- Model type 2: calculation on the basis of the functional correlation between Hungarian rearing pig sales prices and German piglet quotations.

In the first model type, I determined the rearing pig sales prices based on the prices in the technological datasheets. The second model type uses a calculation of the correlation between the rearing pig prices of the Hungarian animal markets (HUF per kg) (HCSO, 2015) and the piglet quotations of the Frankfurt commodity exchange expressed in HUF per kg (An1, 2015; MNB, 2015).

Of the different input data, I set a correlation value of 0.9 between the fodder prices for piglets and sows, thereby indicating the strong positive correlation between fodder prices.

I determined the values of variables in the given range and distribution with a random number generator (SZŐKE et al., 2010).

I provided four economic indexes as output variables of the simulation:

- Total farm revenue (million HUF)
- Total farm cost (million HUF)
- Total farm income (million HUF)
- Prime costs of rearing pig production (HUF per rearing pig)

As a next step, I ran the simulation model with 10000 replications and performed sensitivity analyses for the output variables.

The sensitivity analysis was carried out on the basis of standardised coefficients of regression (β) and Spearman's rank correlation coefficients. The former coefficient is an index expressing the impact of input variables and it is obtained if both the dependent and independent variables are used in a standardised form and not with their original measurement units (MOKSONY, 2006). The significance of this coefficient lies in the fact that it shows the importance rank of independent variables independently of their measurement units (HAJDÚ, 2003). This index made it possible to rank input variables from the aspect of risk. The indication of the coefficient also provided information about the direction of change (SZŐKE et al., 2010); In the case of a positive indication, the increase of the active component results in the increase of the output variable. On the contrary, if the indication is negative, the increase of the input variable results in the decrease of the output variable.

3. MAIN CONCLUSIONS OF THE DISSERTATION

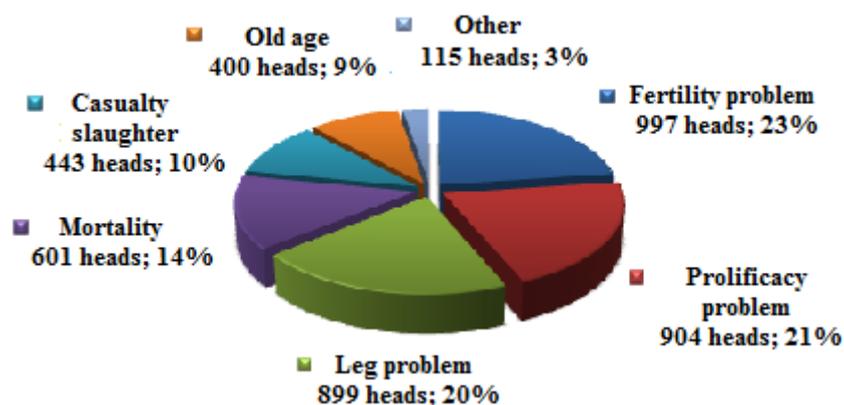
3.1. Examination of the production risk of sow management

3.1.1. *The impact of culling reasons on the lifetime performance of breeding sows*

I set up the following seven culling categories in order to study the culling reasons in breeding populations (Figure 1):

- fertility problem: no oestrus in the case of unmated gilts, no oestrus in the case of sows after the weaning of piglets, recurrent oestrus, unsuccessful insemination, miscarriage, empty sow during pregnancy inspection;
- prolificacy problem: low sow performance, low number of piglets born alive or weaned piglets, teat problems, low milk production;
- leg problem: nail and foot injuries, lameness;
- mortality: pigs found dead (“unintentional culling”);
- casualty slaughter: culling of pigs that cannot be saved;
- old age: old sows
- other reasons: heart problems, problems of the digestive system, vaginal prolapse, unspecified reasons.

Figure 1. Distribution of culling reasons in the breeding populations



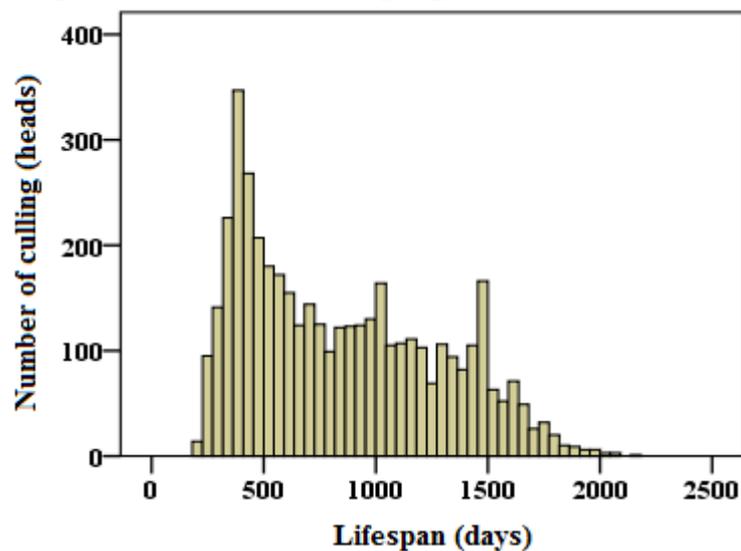
Source: own construction, 2014

In the examined breeding populations, the most frequent problems leading to culling were in connection with fertility, which, together with prolificacy problems, represented 44% of cullings. The high proportion of these two culling categories show that increased

attention is paid to the reproductive performance of young gilts and brood sows at breeding farms. As a result, only pigs that provide a constant high performance are left in production.

The average culling age which characterises the lifetime performance of the population was 845 days (two years and four months), during which sows farrowed 43 weaned piglets on average.

Figure 2. Histogram of the culling age in the case of breeding sows



Source: own construction, 2014

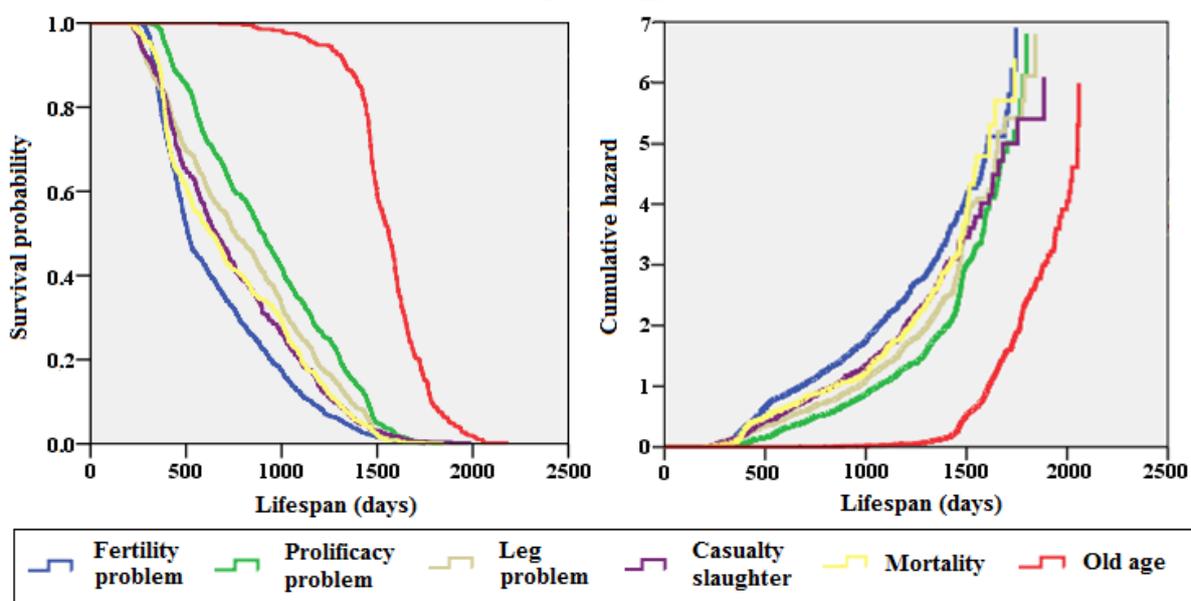
Figure 2 shows the culling age with a histogram. It can be seen that a significant part of cullings is performed even at the initial phase of production which leads one to conclude to a prominent proportion of oestrus and fertility problems in the case of young gilts.

Furthermore, a high proportion of cullings can also be observed at the end of production (around the 1500th day). A possible explanation could be that old sows are culled and replaced by young gilts in order to increase production efficiency.

I examined the duration sows spent in production in each culling category and I observed significant differences between the survival curves of each category (Figure 3).

The log rank test of the survival analyses showed a significant difference between the six examined categories ($\chi^2=1177.890$; $P<0.001$) which means that the survival proportion of the various culling categories significantly differed from each other.

Figure 3. Survival curves of breeding sows broken down to culling reason



Source: own construction, 2014

Pigs culled due to fertility problems had the highest survival probability, since these problems appeared even at the early stage of production. Half of the pigs in this category – nearly 500 pigs – were culled even before 510 days of age. Also, the average culling age was the lowest in this category (650 days).

The curves of dead and casualty slaughtered animals were nearly the same which means that the survival probability of animals in these two categories is the same. The reason for this identity is that casualty slaughter is basically the culling of animals which cannot be saved from dying.

The average culling age of animals culled due to leg problems was 804 days which is a significant difference in comparison with the average age of all other categories ($P < 0.001$).

A similar conclusion can be drawn in the case of pigs culled due to prolificacy problems, where the average culling age was even 922 days.

It can be concluded in each of these five categories that the survival probability decreased to around zero by the 1500th day, indicating a high proportion of culling.

The highest survival proportion was observed in the category of old age, in which the sows in production still had a 20% survival probability on the 1500th day. In the case of the sows culled due to old age, the median of age reached 1560 days, which means that half of the pigs in this category lived for 1560 days before they were culled.

The risk rates of all culling categories (Table 1) showed significant differences ($P < 0.001$) in comparison with the category of old age.

Table 1. Risk rate of each culling reason

Reasons for culling	Regression coefficient	Standard error	Hazard ratio	Sig.
Fertility problem	2.013	0.065	7.487	***
Prolificacy problem	1.343	0.064	3.829	***
Leg problem	1.583	0.064	4.870	***
Mortality	1.770	0.069	5.870	***
Casualty slaughter	1.705	0.072	5.499	***

*** statistically significant at level of $P \leq 0.001$ based on Wald χ^2 test

Source: own calculation, 2014

The risk rate was above 1 in each category which shows that the risk of culling was higher in the case of any category compared to old age. Consequently, when comparing the various culling reasons to culling due to old age, it was found that the culling risk due to fertility problems is 7.5 times higher, culling risk due to prolificacy problems is 3.8 times higher, culling risk due to leg problems is 4.9 higher, while culling risk due to death and casualty slaughter is 5.9 and 5.5 times higher, respectively. These findings support my 1st hypothesis.

Based on this section, it can be concluded that oestrus and insemination problems are the main production risk in the case of breeding populations. Greater attention needs to be paid to satisfying the needs of rearing pigs and more professional rearing pig management in order to increase the efficiency of production. This way, gilts can be prevented from falling out of production too early.

3.1.2. The impact of the difference of flooring on the lifetime performance of breeding sows

I performed the comparative analysis of the lifetime performance of the two breeding sow populations on the basis of the difference between farms, which is the flooring type of the sow barn. This way, I

established two groups of breeding pigs: farm A with straw-covered concrete flooring and farm B with slatted flooring. The 4359 breeding pigs had the following distribution: 1495 pigs from farm A and 2864 pigs from farm B.

The farrowing capacity of the two breeding populations significantly ($P \leq 0.001$) differed from each other. I observed higher average values (number of farrowings, number of piglet born alive, number of weaned piglets) in the case of sows culled on farm A than farm B.

I came to the same conclusion during the examination of the life span of breeding sows: on farm A, breeding pigs lived for 900 (± 10.02) days on average, while the average culling age was much lower (807 (± 8.36) days) on farm B.

I grouped the different culling reasons in accordance with the culling categories shown in the previous section, except that I merged the categories of death and casualty slaughter, since the previously shown findings indicated that there were no differences between the survival values of the two culling reasons.

The distribution of the culling reasons between the two farms showed a statistically significant difference ($\chi^2=15.255$ and $P=0.009$).

On farm A, culling due to leg problems, as well as death and casualty slaughter represented the main reasons for falling out of production. On the contrary, on farm B, fertility problems associated with the initial stage of production were the most frequent culling reasons. At the same time, the number of cullings due to old age was higher – in comparison with farm A – which indicates the high number of old sows kept in production.

I compared the amount of time the breeding sows of the two farms spent in production for each culling reason and I obtained significant differences ($P < 0.001$) in the case of each culling reason, except for death and casualty slaughter.

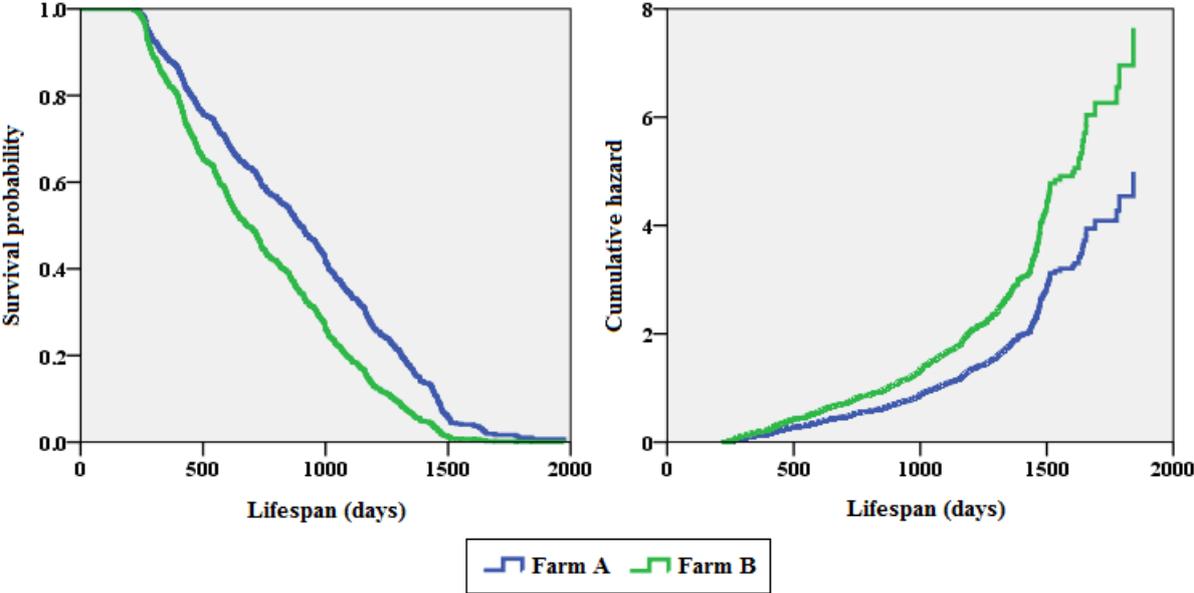
The lowest average age was still observed in the case of pigs culled due to fertility problems; therefore, pigs intended to be reared for breeding purposes fell out of production due to this reason the soonest. Based on the long rank test of survival analysis, breeding pigs on farm A had significantly higher survival proportion ($\chi^2=13.238$ and $P < 0.001$) than pigs on farm B. Consequently, I came to the conclusion

that culled pigs had higher survival proportion in the case of concrete flooring than slatted flooring.

Culling due to prolificacy problems had a more favourable tendency in the case of sows in farm A, as the survival analysis showed significant difference ($\chi^2=13.531$ and $P<0.001$). Therefore, a similar conclusion can be drawn in the case of both culling categories related to reproductive performance. Based on this conclusion, cullings on farm A due to both fertility and prolificacy problems were performed significantly later than on farm B.

One of the biggest differences between the two farms was found in the age of pigs culled due to leg problems. On farm A, sows with leg problems were kept in production for 232 more days on average than similar sows in farm B. The significant difference between the curves symbolising culling probability (Figure 4) also showed that the probabilities of the culling risk of the two breeding populations significantly differ from each other ($\chi^2=38.392$ and $P<0.001$).

Figure 4. Risk curves of leg problems on both breeding farms



Source: own construction, 2014

As regards leg problems, I also concluded that the probability of sows reared on concrete flooring being kept in production is higher than sows reared on slatted flooring. This difference indicates that straw-covered concrete flooring has a definitely better and more preserving influence on the leg of sows.

The average age of pigs removed due to death and casualty slaughter was similar in both populations. Furthermore, the survival analysis did not show any significant difference between the survival and culling proportions of the two farms ($\chi^2=1.481$ and $P=0.224$).

However, culling due to old age that usually occurs at the end of production was different on the two farms. As opposed to the previous tendency, the average age of sows culled due to old age was higher on farm B (1625 days), similarly to the probability of these sows staying in production ($\chi^2=164.563$ and $P<0.001$).

In order to perform the risk-related evaluation of the examined farms, I quantified the risk rate for each culling category which helped me determine how many times the culling risk due to the given reason is higher in comparison with the other farm (farm A was the base of comparison). Table 2 shows the obtained results.

Table 2. The impact of flooring on the lifetime performance of sows in each culling category

Reasons for culling	Regression coefficient	Standard error	Hazard ratio ^a	Sig.
Fertility problem	0.249	0.069	1.283	***
Prolificacy problem	0.260	0.071	1.297	***
Leg problem	0.427	0.069	1.532	***
Mortality	0.079	0.065	1.082	n.s.
Casualty slaughter	-0.427	0.124	0.230	***

n.s. not significant difference, *** statistically significant at level of $P\leq 0.001$ based on Wald χ^2 test

^a reference category is Farm A

Source: own calculation, 2014

I concluded that the culling risk of breeding pigs due to their insufficient reproductive performance (fertility and prolificacy problems) is 1.3 times higher on farm A than on farm B ($P<0.001$).

Culling due to leg problems showed an even higher risk rate as it was 1.5 times higher on farm B than on farm A ($P<0.001$).

At the same time, the culling risk of farm B pigs due to old age was nearly one quarter of that of the breeding pigs on farm A ($P<0.001$).

Based on my results, I came to the quantified conclusion that the culling risk of sows reared on straw-covered concrete flooring due to reproductive and leg problems is significantly lower than that of sows

reared on slatted flooring. Therefore, I accepted my second hypothesis. Furthermore, I established that the lower culling risk of breeding sows reared on concrete flooring results not only in higher survival proportion, but also higher farrowing performance.

3.1.3. The effect of intensive rearing on the lifetime performance of breeding sows

During the examination of the lifetime performance of breeding sows, I evaluated the risk of performance reduction resulting from forced rearing pig management. My analysis was assisted by processing the growth and production data of 1270 culled breeding sows.

I classified rearing pigs into two groups based on their body weight measured during the on-farm performance testing and their optimal body weight ranges: pigs of optimal body weight (85%) and pigs of higher than optimal body weight (15%).

There was a significant difference ($P \leq 0.001$) between the two groups in the average of all parameters measured on the day of the on-farm performance testing (body weight, fat depth I and II, pork chop thickness). Pigs of higher than optimal body weight had higher values.

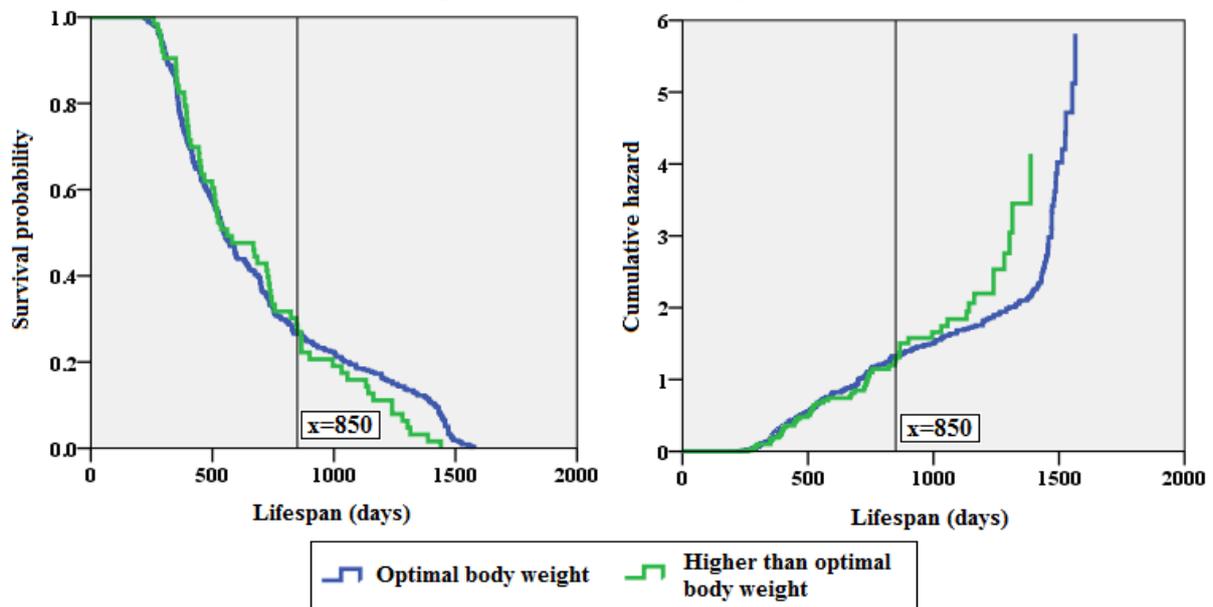
At the same time, there was no significant difference between the two groups ($P > 0.05$) in terms of farrowing indexes related to the whole life span and the average culling age.

As regards the frequency of culling reasons, there was a significant difference between the two groups ($\chi^2 = 29.004$ and $P < 0.001$). In the case of pigs of higher than optimal body weight, culling rate due to leg problems was significantly higher, similarly to the frequency of death and casualty slaughter.

The probability of the two groups staying in production (Figure 5) did not show any significant difference in comparison with the entire lifetime ($\chi^2 = 1.95$; $P = 0.163$). However, it can be observed that the two survival curves intersect each other around the 850th day; therefore, they divide the production period into two sections. I concluded that sows culled before the 850th day farrowed four times at most in both groups. Consequently, I took the number of farrowings during the examination of these two sections of lifetime into consideration; therefore, the first section involved the sows which farrowed four

times at most and the second section involved the ones that farrowed at least five times.

Figure 5. Survival curves of sows of optimal and higher than optimal body weight



Source: own construction, 2014

Following the separate examination of the two sections, I concluded that there is still no significant difference between the survival proportions of the two body weights in the case of sows which farrowed four times at most. This finding could also be assumed on the basis of the curves, since they were close to each other ($\chi^2=0.947$; $P=0.331$). On the contrary, in the case of sows which farrowed at least five times, pigs of higher than optimal body weight had significantly lower survival probability ($\chi^2=24.64$; $P<0.001$). In the second phase of production, half of sows of optimal body weight lived to be 1416 days old, while the ones of higher than optimal body weight lived only for 1239 days; therefore, the difference between the median values of the ages of the two groups was 177 days.

I concluded that the average of the farrowing indexes of sows of higher than optimal body weight is significantly higher in the case of sows which farrowed four times at most in comparison with the average values of sows of optimal body weight. It can be stated that pigs with more intensive growth characteristics had higher litter average index at culling ($P=0.013$) in the first phase of production and also farrowed 3 piglets more on average ($P<0.001$). On the contrary,

the average farrowing indexes of the group of higher than optimal body weight consisting of sows which farrowed at least five times were significantly lower than the reproductive performance of sows of optimal body weight. On average, sows of higher than optimal body weight had less farrowing ($P<0.001$) and 13 piglets less litter ($P<0.001$) during their lifetime.

Based on my findings, I concluded that more intensively growing and, therefore, more developed sows had better reproductive ability in the initial phase of production than sows with optimal growth characteristics. At the same time, higher growth intensity has negative consequences in the subsequent period, resulting in reduced performance of sows of higher than optimal body weight. In addition, these sows are always culled sooner due to their reduced performance, thereby causing the farmer economic loss.

After quantifying the risk rate related to sows falling out of production (Table 3), I concluded that the body weight of sows which farrowed four times at most did not have any significant effect on the culling of sows ($P=0.197$). At the same time, the factors involved in all other examinations significantly increased the likeliness of sows staying in production. Of these factors, it should be pointed out that the risk rate of the farrowing number was 0.3, which means that a single unit increase of the number of farrowings results in 70% decrease in the probability of culling ($P<0.001$). The increase of piglet number also reduced culling risk. It was observed that the largest extent of decrease can be achieved with the increase of the number of weaned piglets ($P<0.001$).

The impact of body weight was significant ($P<0.001$) in the case of sows which farrowed at least five times. The risk rate was 1.5, indicating that the culling risk was 1.5 times higher in the case of sows of higher than optimal body weight. For this reason, it can be concluded that intensive rearing significantly increases the risk of sows falling out of production. At the same time, my 3rd hypothesis can be confirmed only partially, since a significant difference in the lifetime performance of sows was observed only after the 4th farrowing.

In addition, I concluded that the increase of farrowing indexes results in the further decrease of culling risk, although to a lesser extent than in the first phase of production. This phenomenon can be explained by

the fact that sows are constantly getting closer to the stage when they are definitely culled.

Table 3. The effect of body weight and farrowing performance on the lifespan of sows

Traits	Number of farrowing at culling ≤ 4			
	Regression coefficient	Standard error	Hazard ratio	Sig.
Category of body weight ^a	-0.077	0.059	0.926	n.s.
Number of farrowing	-1.205	0.074	0.300	***
Total number of piglets born	-0.028	0.011	0.972	*
Number of piglets born alive	-0.057	0.012	0.945	**
Number of weaned piglets	-0.203	0.008	0.817	***
Traits	Number of farrowing at culling ≥ 5			
	Regression coefficient	Standard error	Hazard ratio	Sig.
Category of body weight ^a	0.375	0.104	1.455	***
Number of farrowing	-0.628	0.142	0.534	***
Total number of piglets born	-0.065	0.011	0.937	***
Number of piglets born alive	-0.082	0.013	0.921	***
Number of weaned piglets	-0.086	0.014	0.917	***

n.s. not significant difference, * statistically significant at level of $P \leq 0.05$ ** statistically significant at level of $P \leq 0.01$ *** statistically significant at level of $P \leq 0.001$ based on Wald χ^2 test

^a reference category is the group with optimal body weight

Source: own calculation, 2014

3.2. Examining the economic risk of sow management

I prepared a so-called model farm in order to analyse the economic risk of sow management. The purpose of this model was to study the operation of a breeding sow farm (Figure 6).

3.2.1. Risk factors of revenue

The extent of revenue was most affected by the variability of the sales price of rearing pigs ($\beta=0.694$). The value of β represents that a single unit increase of standard deviation results in nearly 0.7 increase of the standard deviation of total revenue. The number of piglets born in each farrowing also has a significant effect. One unit change of the standard deviation of this value results in 0.6 unit change in the standard deviation of revenue. In addition, the yearly number of farrowings per sow also has to be emphasised, as it is ranked third among the different risks with a value of $\beta=0.395$. However, if the rearing pig sales price is determined on the basis of the piglet quotations of the Frankfurt commodity exchange, the variability of the average farrowing rate ($\beta=0.785$) is shown to be the most significant risk factor.

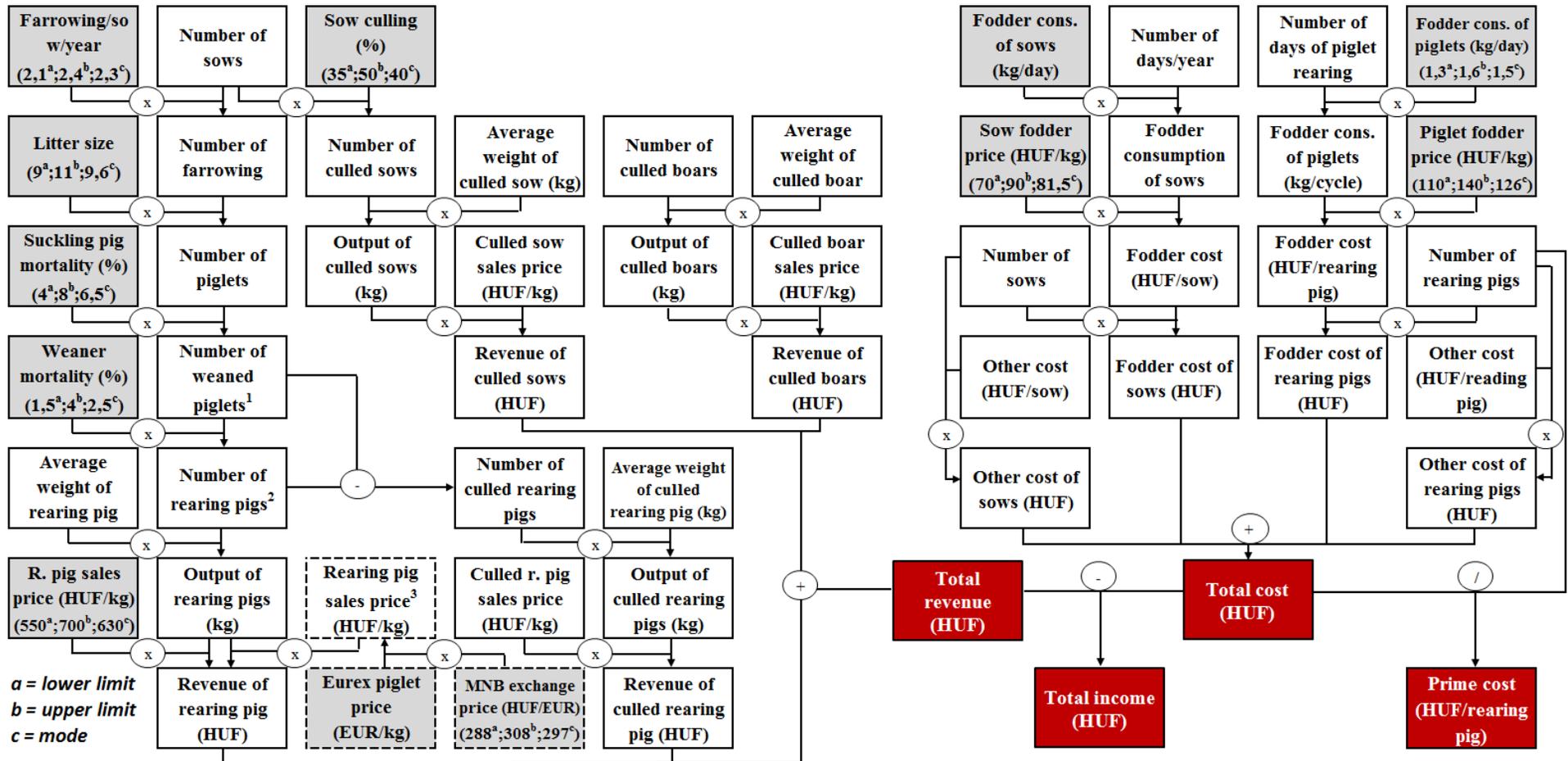
3.2.2. Risk factors of costs

Of all production factors, total farm costs were determined by the number of piglets born per farrowing to the greatest extent, while the most influential market factor was the cost of piglet fodder. In the case of both indexes, I concluded that one unit standard deviation increase results in 0.4 and 0.5 unit standard deviation increase in total.

In addition to fodder price, the fodder consumption of piglets was also a significant risk factor and the β value of the coefficient of regression was also 0.4. Consequently, it can be stated that the greatest farm cost-related risk factor is farrowed piglets and their feeding.

As a matter of course, the feeding of sows also plays an important role, but to a lesser extent than the feeding of piglets.

Figure 6. Structure of the simulation model



Note:

1 Number of weaned piglets = Number of piglets x [(100 - Suckling pig mortality) / 100]

2 Number of rearing pigs = Number of weaned piglets x [(100 - Weaner mortality) / 100]

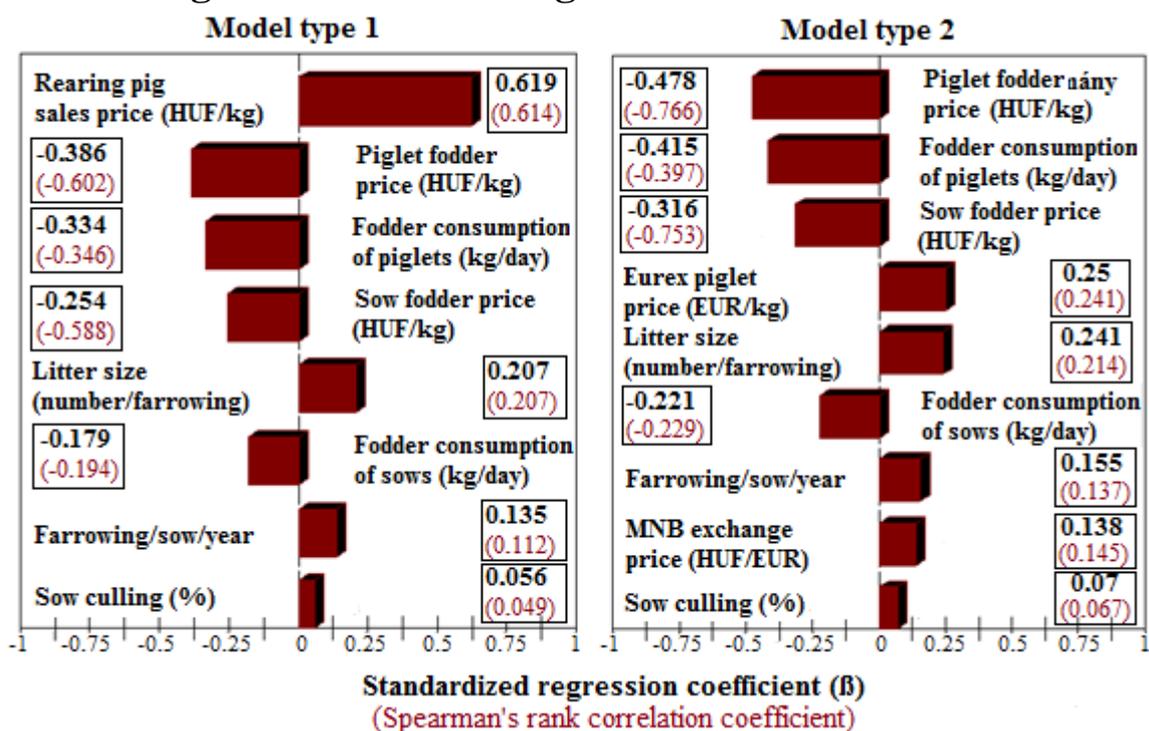
3 Rearing pig sales price = 214,29 + 0,6279 x [Eurex piglet price x MNB exchange price]

Source: own construction, 2015

3.2.3. Risk factors of income

The sensitivity analysis of farm income is shown in Figure 7. When comparing the two model types, it is important to point out that if the model is based on the Hungarian rearing pig sales prices, the fluctuation of this factor has the greatest impact ($\beta=0.619$) on income, although the piglet fodder prices is the second factor in the risk rank with a $|\beta|$ value of 0.386. At the same time, if the simulation is based on the functional correlation of German piglet quotations and Hungarian rearing pig sales prices, total income is most affected by the variability of piglet fodder prices ($|\beta|=0.478$), while the piglet quotation of the Eurex commodity exchange in Frankfurt is the fourth in the risk rank with a β value of 0.25. The rank correlation coefficient shows a weak correlation with income, while one unit of standard deviation change in piglet quotation prices results in only a quarter unit of standard deviation change in income.

Figure 7. Tornado diagram of the total income



Source: own construction, 2015

Furthermore, it can be seen in Figure 7 that while the two different fodder prices and the variability of piglet and sow fodder consumption affect total costs positively, they have an inversely proportional impact on income. In addition, one unit increase of the standard deviation of the average farrowing rate and the yearly number of

farrowings per sow results in the increase of income. The risk rank of the previous six input variables is the same in both model types (the feeding of piglets has the greatest influence ($|\beta|>0.3$ and $|\beta|>0.4$), but there were lower β values in the first model type. The average farrowing rate – which had a significant impact on both revenue and costs – affected income to a lesser extent ($\beta=0.207$ and $\beta=0.241$). The reason for this difference is that higher piglet number results not only in increased income, but it also increases cost.

3.2.4. Risk factors of the rearing pig production cost

Since I prepared the simulation of a farm dealing with rearing pig production, I also considered it to be important to examine the factors affecting the production cost of the main product.

Based on the standardised regression coefficients, a similar conclusion can be drawn as in the case of the risk factors of total costs: the highest risk factor is represented by the variability of piglet fodder price ($\beta=0.5$) and piglet fodder consumption ($\beta=0.4$) in the case of both model types. One unit standard deviation increase of piglet fodder price results in 0.5 unit of standard deviation increase of the production cost of rearing pigs, while one unit of standard deviation increase of daily fodder consumption results in 0.4 unit of standard deviation increase of the production cost of rearing pigs.

Sow fodder price is the third ($\beta=0.33$) item in the risk rank followed by the number of piglets born alive per farrowing and the fodder consumption of sows with the same extent, but different indication of risk ($|\beta|=0.23$). The variability of the average farrowing rate still has a positive impact on total costs, while it affects rearing pig production costs negatively. Consequently, one unit of standard deviation increase of the number of piglets born per farrowing results in 0.4 unit of standard deviation increase in total costs and 0.23 standard deviation decrease in production costs. A similar conclusion can be drawn in the case of the yearly number of farrowings per sow, as its variability increases total costs with 0.26 unit of standard deviation and decreases production costs with 0.15 unit of standard deviation.

Based on the results of the simulation analysis, I concluded that revenue is most affected by the variability of the average farrowing rate ($\beta=0.605$) of all production factors, while total costs are equally as significantly affected by the variability of average farrowing ratio

and the fodder consumption of piglets ($\beta=0.4$). Furthermore, I found the risk factor of the fodder consumption of piglets to be the most significant in terms of the standard deviation of total income ($\beta=-0.334$) and rearing pig production costs ($\beta=0.433$).

Of the various factors affecting the market, the risk value of rearing pig sales price can be considered the most significant in terms of the variability of total revenue ($\beta=0.694$) and total income ($\beta=0.619$) (based on the 2013 prices). Furthermore, I found the risk value of piglet fodder price to be significant in terms of the standard deviation of total costs ($\beta=0.461$) and rearing pig production costs ($\beta=0.499$).

4. NEW AND NOVEL FINDINGS OF THE DISSERTATION

Based on my primary and secondary research, I make the following statements which can be regarded new or novel from the aspect of analyses performed in the topic of my dissertation:

1. I performed survival analysis methods to determine the risk rank of problems leading to the culling of breeding sows in the two examined breeding farms. The culling risk due to prolificacy problems is 3.8 times higher than the culling risk due to old age and the following values were observed in the case of the other culling risks: leg problems – 4.9 times, casualty slaughter – 5.9 times, fertility problems – 7.5 times.
2. Based on the performed survival analytical methods, I concluded that the culling risk due to leg problems is 1.5 higher in the case of breeding sows reared on slatted flooring than those kept on straw-covered concrete flooring, while the culling risk due to reproductive problems is 1.3 higher in the same relation.
3. The performed survival analytical methods also demonstrated that the culling risk of sows of higher than optimal body weight is 1.5 higher than the culling risk of pigs of optimal body weight on the examined breeding farm.
4. I prepared a pig farm simulation model which is capable of predicting the profitability indexes of pig farms with the integration of various risk factors. The significance of the model lies in the optionally modifiable input parameters which enable the model to be used for any pig farm and to perform economic analysis of pig populations with different constitution.

5. PRACTICAL USABILITY OF THE OBTAINED FINDINGS

One of the main objectives of my dissertation was to be able to provide practical advices to farmers based on my research findings which will contribute to prolonging the amount of time sows spend in production; therefore, to increase their lifetime performance.

Based on my findings, it is one of the main recommendations that it is important to perform the population-level analysis of the lifetime performance of sows in order to increase production and to develop the pig sector. In order to achieve these goals, the primary objective could be the reduction of the culling of rearing pigs, since these breeding sows represent a source of costs without any income for farmers.

Since young breeding sows are culled mainly due to their weak reproductive performance and various leg problems, the main emphasis should be placed on the development of characteristics related to prolificacy and constitution in order to achieve improvement in the lifetime performance of sows. Proper management is also necessary in order to provide adequate conditions for production and to achieve these goals. It is recommended to keep sows on straw-covered concrete flooring if it can be integrated into the used technology, as it has a more favourable effect on their foot structure. Furthermore, it is suggested to establish the feeding system of gilts in a way that it regulates the maximum fodder intake and prevents them from obesity (e.g. by a fodder supply equipment which portions fodder individually).

My findings definitely fill a gap in the international and Hungarian technical literature, since there have been very little research in terms of the quantified risk evaluation of flooring and life span.

The significance of my custom developed pig farm simulation model lies in the optionally modifiable input parameters which enable the model to be used for any pig farm and to perform economic analysis of pig populations with different constitution. This feature makes this analytical tool to be easy to use for farmers, too.

6. PUBLICATIONS RELATED TO SUBJECT MATTER OF THE THESIS



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Subject: Ph.D. List of Publications

Candidate: Angéla Soltész
Neptun ID: QSDZ31
Doctoral School: Ihrig Károly Doctoral School of Management and Business Administration
MTMT ID: 10024772

List of publications related to the dissertation

Article(s), studies (12)

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Address: 1 Egyetem tér, Debrecen 4032, Hungary Postal address: Pf. 39, Debrecen 4010, Hungary
Tel.: +36 52 410 443 Fax: +36 52 512 900/63847 E-mail: publikaciok@lib.unideb.hu, Web: www.lib.unideb.hu



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The Candidate's publication data submitted to the iDEa Tudóstér have been validated by DEENK on the basis of Web of Science, Scopus and Journal Citation Report (Impact Factor) databases.

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