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DEVELOPMENT OF BREEDING GOALS AND ECONOMIC EVALUATION OF BREEDING PROGRAM DESIGNS FOR INDIGENOUS PIG BREEDS LOCATED IN PRODUCTION SYSTEMS IN NORTHWEST VIETNAM

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LIST OF ABBREVIATIONS

ADG	Average daily gain
BCR	Benefit-cost ratio
BIC	Bayesian information criterion
CatPCA	Categorical principal components analyses
CBBP	Community-based breeding program
CSF	Classical swine fever
CVM	Contingent valuation method
EBW	Empty body weight
FC	Fix cost
FCR	Feed conversion ratio
FMD	Foot and mount disease
GM	Gross margin
GR	Gross ratio
GSD	Genetic standard deviation
ME	Metabolizable energy
NR	Net revenue
PC	Principal components
PEDv	Porcine epidemic diarrhea virus
PRRS	Porcine reproductive and respiratory syndrome
Ps	Pseudorabies
RR	Rate of returns
TC	Total cost
TE	Technical efficiency
TR	Total revenue
VC	Variable cost
VND	Vietnam dong
WTP	Willingness to pay

SUMMARY

Pig production systems using indigenous breeds have a substantial impact on diversity in Vietnamese pig populations and also contribute to the income of small-scale farms in the northwest of Vietnam. The objective of the present study was an in-depth evaluation of current breeding practices, breeding goals, and favourable traits for different indigenous pig production systems. The research was performed using a wide range of methods. Single person interviews with a semi-structured questionnaire were undertaken across 171 households in three provinces in northwest Vietnam (Son La, Hoa Binh, and Yen Bai) to attain information regarding production and management practices, disease prevalence, veterinary health-care services as well as willingness to pay (WTP) of producers for a vaccination programme. The different aspects of the objective are divided into four scientific studies (**chapters 2, 3, 4,** and **5**), which address the previously mentioned research areas: 1) Characterization of Ban pig production systems, based on management practices, productivity, and reproductive performances; 2) Derivation of economic efficiency of farmers in Ban pig production systems; 3) Investigating the farmers' willingness to pay for a vaccination programme and the factors affecting WTP; 4) Derivation of the economic importance of functional, production, and survival traits for the indigenous breed.

The first study (**chapter 2**) provides vital information on the socio-economic and pig management practices in indigenous pig production systems in northwest Vietnam. The indigenous pig production systems were characterized using i) a two-step clustering approach and ii) K-means clustering combined with categorical principal components analyses (CatPCA). Two-step clustering allocated the farms into three clusters. The first cluster was called "Nursery farms with low disease incidences" because 96% of these farms sold piglets to the slaughterhouse after the nursery with a live weight between 10 to 25 kg. A large percentage of farms in cluster 1 had high healthy piglets and sows (41% and 51% of farms, respectively). Cluster 2 was named "Fattening and mixed farms with high investment and high disease incidences" because these farms had large pigpen sizes (20.03 m^2), modern pigsty constructions, but a high rate of disease incidences. Similar to cluster 1, farms in cluster 3 also focused on the nursery phase, but the pigpen and herd size was smaller (12.13 m^2 and 7.61 piglets respectively). Hence, cluster 3 was defined as "Nursery farms with low investment". The K-means cluster after CatPCA classified farms into cluster A "Farms incorporating male and female farmers in farm management", cluster B "Nursery farms with low efficiency", or cluster

C “Farms with long suckling interval”. Correspondingly, husband and wife were herd managers in 64% of farms in cluster A. Average weaning age for farms in cluster C was 70.25 days. We compared the farm allocations from both clustering approaches, and we identified substantial differences. In the last step, univariate analyses were applied in order to identify factors contributing to the net household income from pig production. Vaccination of the sow, type of operation, number of live-born piglets, nursery weight, and nursery interval were the factors significantly affecting the net revenue in Ban pig production systems.

The second study **(chapter 3)** investigated the production efficiency of Ban pig production. Primary data obtained from 171 producers were analyzed by applying cost-benefit analysis and stochastic frontier production function. The benefit-cost ratio per litter was 1.24, indicating that the enterprise was profitable. Compared to other farms, the farms focused on farrow-to-finisher attained the highest net return (€213.71/litter), while inputs were used most effectively by the mixed farms. The result from the Cobb-Douglas production function revealed that labour, feeding cost, stocking density, and pigpen structure had positive effects on the production output. Additionally, farms with the phase of farrow-to-nursery obtained less total revenue, while farms focused on the farrow-to-finisher achieved higher production output than the mixed farms. The level of technical efficiency for each farm ranged between 0.62 and 0.98, with a mean of 0.88. The number of live-born piglets and depreciation cost had positive effects, whereas the nursery interval had a negative impact on technical efficiency. Ban pig producers could increase technical efficiency by efficiently utilizing available resources and improving managerial skills.

The third scientific study **(chapter 4)** approximated Ban pig producers’ willingness to pay for a vaccination programme based on the contingent valuation method data. The Logit and Tobit model was used to explore the determinants of Ban pig producers’ WTP as well as the true maximum WTP values for the vaccination programme. In total, 82% of producers were willing to pay for the vaccine services, and average maximum WTP for each piglet per litter and each sow per year were €2.51 and €3.89, respectively. According to the Logit regression model, WTP of the farmers was influenced by total number of piglets and sows, disease frequency of piglets, vaccination status of piglets and sows, gender of household heads, education level of household heads, age of household head, mortality of piglets at post-weaning, type of operation, reason for raising Ban pig, and location of the pig farms. The coefficients from Tobit regression showed that the gender of the household head and the location of pig farms have significant effects on the maximum WTP for piglets and sows. Additionally, number of piglets at farms and vaccination status of piglets also significantly affected the true maximum WTP for piglets, but for sows, net income and vaccination status of sows were essential factors.

The fourth scientific study **(chapter 5)** was conducted to derive economic weights for production, reproduction and survival traits of indigenous pigs by applying the EWPIG package, which was developed by Wolf et al. (2016) based on a bio-economic model for integrated production systems. The female replacements were reared within the system. Natural mating was applied for both gilts and sows by importing pure-bred boars from outside the farms. Piglets were weaned at an average of 61 days and were reared in the nursery phase until the age of 199 days. All male piglets were castrated after weaning. Some female piglets were selected and reared as breeding animals for replacement or exported after the nursery phase. One part of surplus females and castrated males were sold for slaughtering, while the remaining piglets were finished. The results showed that the bodyweight of sows decreased during the pregnancy period, while it increased during the lactation period. The average annual replacement rate of sows was 25%. Economic weights of 11 production, reproduction and survival traits were calculated for pure-bred pigs, in which, average lifetime daily gain of finished animals was the most important trait with a contribution of 55% to the sum of the absolute values of the standardized economic weights’ overall traits. The following are the number of live-born piglets (16%), the survival rate of piglets at birth (10%), and survival rate of young animals after nursery (7%). Age of gilts at first farrowing, survival rate of live-born piglets at weaning, survival rate of piglets in nursery, farrowing interval, productive lifetime of sows, feed conversion in nursery, and feed conversion in finishing reached similar values of 1% to 2%.

Finally, in **chapter 6**, a general discussion focusing on the most relevant results from the previous sections is given. Some recommendations to improve the traits included in the breeding goal were proposed. Accordingly, straight breeding with a community-based breeding programme was encouraged for genetic improvement in the indigenous pig production systems. Additionally, housing improvement and feeding management were mentioned to improve productivity in pig production and reproduction. Furthermore, a vaccination programme should be established, implementing a bio-security programme to reduce infectious diseases of pigs.

CHAPTER 1

GENERAL INTRODUCTION

1.1. Background

Livestock production plays a significant role in the development of agriculture in Vietnam, with a contribution of about 26% of the total agricultural output value (GSOVietnam, 2016). Pigs are considered to be one of the most important livestock species, as over 13 years (2000-2012) pig production consistently accounted for about 74-80% of total meat production in Vietnam (Nga et al., 2014). Lemke et al. (2006) reported that pigs are kept in 71% of farm households. A steady upward trend in pig production can be observed with an average annual increase rate of 6% from 2000 to 2005 (GSOVietnam, 2006), but during the subsequent 10 years (2006-2015) the pig population in Vietnam remained fairly static at levels slightly below 28 million head (GSOVietnam, 2010 & 2016) because of widespread disease outbreaks and unfavourable changes in output and input prices (Nga et al., 2014). With pork production of 2.68 million tons of carcass weight, Vietnam ranked 5th in global pig production (USDA, 2016). However, the majority of pork products are used to meet domestic demands, and exports are limited (Dzung, 2014).

Pig production is an integral part of mixed farming systems in Vietnam as a way to utilize household leftover food and agricultural by-products. The pig sector plays a significant role in agriculture and the rural economy, especially among small-scale farmers, because it provides an income source, manure, and human nutrition. ACIAR-ILRI-CAP (2008) and Hung et al. (2015) reported that the pig sector contributes to about 14% of total household income and 25% of total household income from agriculture. Despite the "Livestock Development Strategy until 2020" promoting the move from small, family-based farms to larger, intensive and commercialized pig farms (MARD, 2008), the pig sector was still predominated by small-scale production as more than 71% of pig farms kept 1-5 animals (Dzung, 2014), and they are estimated to supply at least 80% of Vietnam's pork production (Nga et al., 2014).

Pork is the most popular meat in the Vietnamese diet as it is consumed by 98% of households (FAO, 2011). Nga et al. (2014) reported that pork accounts for about 57% of total meat consumed in the household. USDA (2016) revealed that Vietnam has the 6th largest pork consumption in the world, with an average of 26.78 kg/capita/year. Most of the Vietnamese consumers demonstrated that they prefer lean pork, fresh, and unchilled meat (Lapar et al., 2011). Unfortunately, pork production is strongly limited by epizootics of piglets, growing pigs, and reproductive failures of sows. Farmers often fail to identify causative agents and randomly apply antibiotics that in many cases are ineffectual (Kamakawa et al., 2006). The most common diseases in piglets, growing pigs and sows are salmonella choleraesuis, pasteurellosis, swine erysipelas, porcine reproductive and respiratory syndrome (PRRS), pseudorabies (Ps) and classical swine fever (CSF). For that reason, meat quality is the other concern of Vietnamese consumers because of rising awareness of food safety, especially toxic residues in pork. Therefore, the pork industry needs to undertake significant changes in the value chain by extending the legal framework of food safety and quality systems, closely monitoring pathogen contamination in food and mitigating antibiotic resistance. With the integration of Vietnam into the World Trade Organization in 2007, the development of food safety policy has significantly improved. The new food law (2010), a national strategy for food safety, was approved for the period 2011-2020 (Sarter et al., 2014). Hence, smallholder farms are encouraged to adopt modern pig-keeping methods to improve both the quality and quantity of pork to satisfy market demand.

In Vietnam, different breeds are kept on small-scale pig farms, including indigenous breeds (such as Muong Khuong, Ban, Mong Cai), exotic breeds (such as Landrace, Yorkshire, and Duroc) and crosses between them. Rößler (2005) described how breeding practices varied between production systems and defined two systems: resource-driven and demand-driven. Resource-driven farms predominantly use local breeds, which are well adapted to scavenging, low input, and low output concepts. Sires are not selected at all but are mated randomly. So-called demand-driven systems implement improved breeds such as Mong Cai which are considered superior to exotic breeds (imported from England, Denmark, Belgium, Canada, and the US: Landrace, Duroc, Yorkshire, Pietrain, Hampshire) due to their high reproductive performance and adaptability. Common breeding techniques include the crossing of Mong Cai sows with exotic boars to gain crossbred fatteners (Rößler, 2005). Although artificial insemination is available, farmers favour natural mating, which has higher conception success. Across all production systems, farmers usually own one breeding sow but no sire. Reasons for culling the female breeding stock are age, failure to conceive, or a lack of maternal instincts. Important selection criteria for farmers are the animal’s ability to feed on a broad spectrum of resources and a fibre-rich diet, a high fodder intake capacity as well as growth rate and carcass quality (Herold et al., 2010). Herold et al. (2010) carried out an in-depth survey on the farmers’ perspective about which traits were perceived to be good and which factors were crucial for the choice of breed. The most importantly ranked trait was feed intake capacity (90% of respondents), followed by sound development of the animal (>80% of respondents), disease tolerance (50% of respondents), health/strength (40% of respondents), growth rate and carcass quality (>30% of respondents) were considered to be useful as well. However, fertility seemed to be of minor importance.

Local breed sows are primarily kept by small-scale producers, especially in northern Vietnam, such as the Mong Cai, Muong Khuong and Ban breed (DLP, 2006), because they are well adapted to farm conditions, as well as the harsh environments and have general robustness. Indigenous pigs are predominantly found in rural, mountainous and remote areas, where they have a variety of functions, including use on special occasions (weddings, celebrations of New Year, feasts, etc.), as a way to hold capital/financial assets, as gifts, and they supply fertilizer for crop production. Nevertheless, compared to the exotic or crossbred pigs, the local breeds tend to be smaller and have lower fertility, growth rate, and lean meat ratio (Kinh et al., 2002). Therefore, they are progressively being replaced by exotic and crossbred pigs.

Although there is rapid development in Vietnamese pig production and strong governmental influences on various parts of the pork value chain, at present, little attention is paid to breeding schemes and goals. Information about the strategies and trait preferences of farmers is sparsely documented, which might be one reason why most smallholder farmers fail to participate in the developing pork market. Lemke and Zárate (2008) observed a rapid transition process from subsistence to increasing market-oriented production, even before the economic reforms of 1986. Differences regarding production systems depending on environmental influences and isolation related to geographical location could be distinguished as well (Lemke and Zárate, 2008).

1.2. Research objectives

The study aims for an in-depth evaluation of current breeding practices, breeding goals and favourable traits in small-scale Vietnamese pig farms as a prerequisite for both the implementation of sustainable and suitable breeding strategies for the Ban pig breed, as well as the economic weighting of newly defined breeding goals. Consequently, the study addresses the transition of traditional Vietnamese pig breeding and pig raising towards a regulated pork production process, that ensures certain quality and safety issues. These objectives will be realized by generating and evaluating empirical data of household surveys in the provinces of northwest Vietnam, including Hoa Binh, Son La, and Yen Bai. This project combines the designing of interdisciplinary research covering animal breeding, animal husbandry, animal production, as well as economic components in terms of cost revenue calculations and economic weighting of traits. The objectives include the following topics:

a. Characterization of Ban pig production systems according to management practices, productivity, and reproductive performance,

b. Derivation of economic efficiency of farmers in Ban pig production systems,

c. Investigating the farmers' willingness to pay for a vaccination programme and assessing the maximum amount of vaccination charges in Ban pig production systems,

d. Derivation of the economic importance of functional (health, behaviour, longevity), production, and survival traits (average daily gain, litter size) for the Ban pig breed, which is expected to influence farm profitability, and

e. Development of an optimized breeding goal and breeding programme for the Ban pig breed.

1.3. Structure of the thesis

Chapter 2 describes Ban pig production systems and classifies them according to their management practices, productivity, and reproductive performance. A two-step clustering approach and K-means clustering combined with categorical principal components analyses (CatPCA) were applied to classify the Ban pig production systems. Furthermore, factors contributing to the net household income from pig production were investigated by applying univariate analyses.

The 3rd chapter scrutinizes the production efficiency of the Ban pig production systems. Benefit-cost analysis was performed to examine the costs and returns from the perspectives of Ban pig farmers. Afterwards, a stochastic frontier production function was used in order to investigate the factors influencing the technical efficiency and to approximate the level of technical efficiency for Ban pig production systems.

Chapter 4 assesses the Ban pig producers' willingness to pay (WTP) for a vaccination programme. Farmers' WTP for vaccination services was elicited by performing the contingent valuation method. Subsequently, the Logit and Tobit model was applied to investigate the determinants of Ban pig producers' WTP as well as the true maximum WTP values for the vaccination programme.

Derivation of the economic importance of production, reproduction, and survival traits of the Ban pig breed, which are expected to influence farm profitability, was performed in chapter 5. The EWPIG package, basing on a bio-economic model for integrated production systems, was applied to calculate the marginal economic values, standardized and relative economic weight of traits that should be included in the breeding goal.

Chapter 6 generally discusses the outcomes of all previous sections, proposes how relevant traits for selection purposes can be further developed, suggests a breeding goal for the Ban pig breed, and also presents general conclusions.

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CHAPTER 2

IDENTIFICATION OF MANAGEMENT AND PRODUCTION PRACTICES IN INDIGENOUS PIG FARMS IN NORTHWEST VIETNAM VIA MULTIVARIATE ANALYSES

2.1. Introduction

Pig raising plays a vital role in the income of Vietnamese farmers and has become an essential cultural symbol. About 71% of farm households raise pigs (Lemke et al., 2006). A steady increase in hog production from 20.19 million in 2000 to 27.75 million in 2015 was reported by the General Statistical Office (GSOVietnam, 2016). The National Institute of Animal Science notified that there were 29.07 million pig heads in 2016 in Vietnam, and it ranked in 5th place in global pig production. However, the majority of pork products in Vietnam were destined for the domestic market, and the export ratio was negligible (Dzung, 2014). Moreover, the income from pig production accounts for 9% to 41% of total income for the farmers in mountainous North Vietnam, indicating that the pig plays a significant role in nutrient recycling (Lemke et al., 2006). Hence, backyard pig farming provides an income-source, and contributes to sociocultural aspects.

Pig production in Vietnam is mainly characterized by small-scale rearing. Smallholders typically only own one to five sows (Center, 2011). Dzung (2014) reported that 70% of pigs and 60% of pork are produced by small-scale farming households. Usually, smallholder farms keep a variety of breeds on their farms, including local breeds (Ban pig), exotic (Landrace, Yorkshire, etc.), or crosses (Improved Mong Cai, Large White x Mong Cai, Large White x Ban, etc.). Local breeds account for 25% of the total national pig herds and are mainly found in mountainous, remote, and rural areas (Le Thi Thanh Huyen et al., 2005). Ban pig breeds are characterized by high-fat content, low lean meat ratio, low growth rate, and low fertility. However, the local breeds can better adapt to the harsh environments, including extreme climate, and low input production conditions. Furthermore, these breeds show less susceptibility to disease, and the consumers appreciated their particular quality traits (Le Thi Thanh Huyen et al., 2005).

Northwest Vietnam is known for its low per-capita income, but is one of the regions with the highest share of household income deriving from pigs (Epprecht, 2005). In this area, pig raising is linked with the culture and tradition of ethnic minorities, e.g., special occasions and celebrations of New Year, and is strongly associated with local customs and feasts (Valle Zárate et al., 2003). The native breeds still predominate but are progressively being replaced by exotic and crossbred pigs (Lemke et al., 2002). They are an essential section of the Vietnamese biodiversity and are still important for the livelihoods of poor farmers. However, no specific study has been conducted to describe the characterization of Ban pig production systems in northwest Vietnam. Thus, this paper can contribute to narrowing this gap.

This research was undertaken by using single-person interviews with a semi-structured questionnaire to obtain information regarding the socio-economic characteristics of the farmers (e.g., age, education, and occupation), the production and management systems, disease prevalence, and veterinary health-care services in small pig farms. Afterwards, multivariate analysis was conducted: 1) to describe management practices, productivity, and reproductive performance of smallholder systems; 2) to classify Ban pig farms according to management practices, productivity, and reproductive performance; 3) to investigate factors had an impact on household income for the smallholders.

2.2. Materials and methods

2.2.1. Study area

The survey was carried out in mountainous regions located in northwest Vietnam. The gross domestic product in the area is €1,001 per capita, which is lower than the Vietnamese average of €1,502 per capita (GSOVietnam, 2016). The population is dominated by ethnic minority groups such as H' Mong, Dao, Thai, Muong, Tay, etc. However, the Thai group still accounts for the largest population group (24%) in this region. The weather in northwest Vietnam is characterized by two broad patterns of topography, the plains and mountains, and is described as having a tropical climate influenced by monsoon. The average temperature is about 25^{o}C, and gradually increases from north to south. The average rainfall varies from 1700 to 2000mm.

The fieldwork was conducted in three provinces Son La, Hoa Binh, and Yen Bai, which contain a high density of commercial and local pigs, and are stratified into the three main climatic zones of the northwest area (Fig. 1) (VNtrip.vn, 2017). One district in each province was selected after consulting with official staff from the Department of Agriculture (Van Ho district – Son La, Tan Lac district – Hoa Binh, and Mu Cang Chai district – Yen Bai). In every district, three communes were chosen based on the following two criteria. First, the study areas were crucial and high-intensity regions for Ban pig production. Then, in order to reduce logistic constraints for data collection, the selected regions had to be relatively easy to access. Hence, the study areas chosen were Chieng Khoa, Van Ho, Long Luong (Van Ho district); Phu Cuong, Phu Vinh, Dich Giao (Tan Lac district); and Che Cu Nha, Khao Mang, Pung Luong (Mu Cang Chai district).

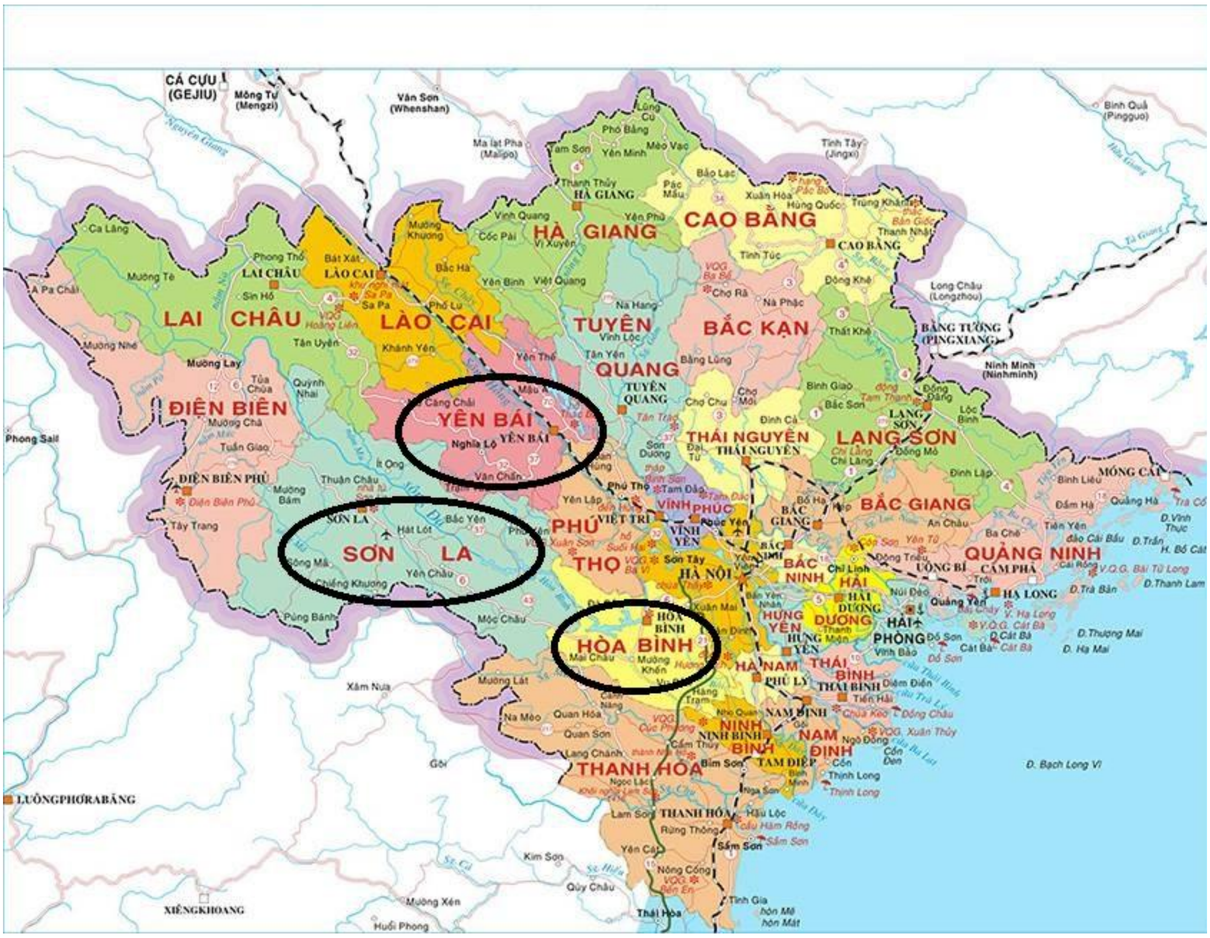

Figure 1. Study areas selected in northwest Vietnam

2.2.2. Data collection

Pig farms keeping sow at the time of data collection were selected. The farms were chosen with the assistance of field extension officers from the Agriculture Department. Veterinary staff from the communities were also involved, especially in offering logistics. Recently, no census of Ban pig breeds has been carried out in the study areas. Hence, snowball sampling was used to identify households who raised local pigs in the communities. This method was used previously in studies on Taenia solium cysticercosis (Sikasunge et al., 2007). The veterinary staff identified the first few farmers who raised local pigs; then, other farms were found based on the information from the first farmers.

Single person interviews with a semi-structured questionnaire were conducted with 180 native pig farmers distributed across nine communities in the three divisions from November 2016 to January 2017. The number of farms was 69, 49, and 62 in Van Ho, Tan Lac, and Mu Cang Chai, respectively, and they were approximately in line with the proportion of the total population size of pigs in each area in 2015 (GSOVietnam, 2016). The main features reflected in the interviews are presented in Table 1. A preliminary assessment of 180 questionnaires led to deleting nine respondents because crucial information was missing for these respondents. As a result, 171 farms were kept in the analysis.

Table 1. Main features reflected in the questionnaire: Farm management, production and reproduction management, disease management, and socio-economic information

Farm management		
Farm management	Time for pig production (h/d)	Type of pigsty
Total square of piggery (m^2)	Number of pigpens (n)	
Size of pig herd		
Number of breeding gilts (n)	Number of suckling pigs (n)	Number of nursery pigs (n)
Number of fattening pigs (n)	Number of sows (n)	
Reproduction management		
Rearing gilts (yes/no)	Interval after weaning to first mating (d)	Rearing boar (yes/no)
Production management		
Suckling interval[1] (d)	Nursery interval[2] (d)	Weight at weaning (kg)
Weight at the end of the nursery phase (kg)	Number of live-born piglets (n)	Supplementary food for suckling pig (yes/no)
Feeding for pig	Type of operation	
Disease management		
Disease frequency of piglets (n)	Disease frequency of sow (n)	Sow vaccinated (yes/no)
Piglet vaccinated (yes/no)		
Socio-economic information		
Gender (male/female)	Age (y)	Level of education
Occupation	Household size (n)	

1: From birth to weaning at constant weaning age
2: From weaning to constant feeder pig age

2.2.3. Data analysis

The survey data was analyzed by IBM SPSS Statistics version 22 (Corp, 2013). All descriptive variables were coded into numbers, and variables with two-levels such as gender, rearing gilts (boar), supplementary food, and vaccination for sow and piglet, which were coded into zero and one. The qualitative variables, including descriptive and yes-no variables, were set into nominal categorical variables and ordinal categorical variables (pigpen type, disease frequency of sow, disease frequency of piglet). Means and standard deviations for continuous variables and frequencies of categorical variables are shown in Table 2.

Table 2. Means and standard deviations for continuous variables and frequencies for categorical variables used in CatPCA

Continuous Variables	Mean ± SD	Categorical variables	Frequency (%)
Pigpen size (m^2)	15.09 ± 7.78	Farm management	
		- Husband	17(10)
		- Wife	129 (75)
		- Both	25 (15)
Total number of piglets (suckling and weaned pigs)	9.63 ± 5.98	Type of pigpen	
		- Temporary[2]	29 (17)
		- Semi-permanent[3]	26 (15)
		- Permanent[4]	116 (68)
Number of sows	1.71 ± 0.78	Main feed given for piglet	
		- Maize	88 (52)
		- Rice bran and maize	60 (35)
		- Maize and cassava	19 (11)
		- Rice bran or cassava	4 (2)
Weaning age (d)	60.67 ± 19.11	Supplementary food for suckling piglet	
		- Yes	97 (57)
		- No	74 (43)
Mating interval (d)[1]	20.87 ± 8.14	Disease frequency of piglet	
		- Rarely	66 (39)
		- Often	68 (40)
		- Never	37 (21)
Number of live-born piglets	7.47 ± 1.1	Disease frequency of sow	
		- Rarely	108 (63)
		- Often	9 (5)
		- Never	54 (32)
Average weaning weight (kg)	5.78 ± 1.35	Vaccination for sow[5]	
		- Yes	78 (46)
		- No	93 (54)
Nursery interval (d)	138.13 ± 40.28	Type of operation	
		- Farrow-to-nursery	106 (62)
		- Farrow-to-finisher	28 (16)
		- Farrow-to-nursery and finisher	37 (22)
Weight of piglet at the end of nursery phase (kg)	18.47 ± 4.39	Vaccination for piglet[6]	
		- Yes	48 (28)
		- No	123 (72)
Time spent on pig (h)	2.41 ± 0.75		
Net income per piglet (€)	18.33 ± 17.88		

1: From weaning to the next insemination of sow
2: Post-and-rail fence or wooden walls with sand or wooden floor and asbestos-cement roof
3: Wooden or brick walls with cement floor and asbestos-cement roof, manure store in pigpen
4: Brick walls with cement floor and asbestos-cement or metal sheet roof
5&6: Vaccination for sows and piglets to against FMD, PRRS, CSF, and pasteurellosis

2.2.3.1. Categorical principal component analysis

The categorical principal component analysis (CatPCA) was performed to reduce a set of original variables into a smaller set of uncorrelated components that contained most of the variance in the original variables. The technique is most useful when a large number of variables prohibit effective interpretation of the relationships between objects (subjects and units). By reducing the dimension, only a few components contained most of the variance to be interpreted.

Twenty variables representing household practices in Ban pig production were included in the CatPCA (Table 2). Following the Kaiser criterion (Ford et al., 1986), the first seven principal components (PC) with eigenvalues greater than 1.0 were kept to conduct clustering analysis in the next step.

2.2.3.2. Cluster analysis

Two-step cluster analysis

There are several approaches available for cluster analysis, such as the BIRCH algorithm (Zhang et al., 1997), fuzzy cluster analysis (Höppner, 1999), hierarchical cluster analysis and two-step cluster analysis (Corp, 2013). Two-step cluster analysis is a well-suited approach for clustering pig farms because it can handle categorical and continuous variables simultaneously. Furthermore, this procedure can deal with multi-attributed and multi-distributed datasets while not being susceptible to deliver variables (Bacher et al., 2004).

In the first step of the two-step cluster approach, original cases are grouped into many small pre-clusters. Then, these pre-clusters were separated into the final groups, based on the standard agglomerative clustering algorithm, and the best number of clusters was determined according to Schwarz's Bayesian information criterion (BIC). The better models were indicated by smaller BIC values (Sarstedt and Mooi, 2014). SPSS spontaneously implements this computation in its two-step cluster algorithm. In this research, nine categorical variables and eleven continuous variables representing household practices in Ban pig production were included in the analysis, and three clusters were automatically determined.

K-means cluster analysis

K-means clustering was applied based on principal components generated from CatPCA. Two separate phases were performed in the K-means algorithm. In the first step, it calculated the k centroid, and then, it took each point to the group that had the nearest centroid from the respective data point. In the K-means algorithm, the distance of the nearest centroid was defined by using the Euclidean distance method. When the grouping was completed, it recomputed the new centroid of each cluster and based on that centroid, a new Euclidean distance was calculated between each centre and each data point and re-allocated the point in the group, which minimized the Euclidean distance. Each cluster in the partition was defined by its member objects and by its centroid. The point where the sum of distances from all the objects in each cluster was minimized was called the centroid for that group. Hence, the K-means algorithm redistributed cases to clusters by way of an iterative process in which it minimizes the sum of distances from each object to its cluster centroid (Dhanachandra et al., 2015). Only continuous variables can be inputted in the K-means cluster analysis. Therefore, the first seven PC determined by CatPCA were used here, and the number of clusters was set to three.

Clusters generated from two-step and K-means analysis were labelled respectively according to the characteristics of each group. Least square means of the eleven continuous variables in every cluster were estimated using ANOVA in SPSS. For categorical variables, the count number in each group was presented, and χ^2 tests were applied to test if the cluster had a significant impact on the nine categorical variables, respectively.

2.2.3.3. Univariate analysis

A univariate model was used to investigate the effect of the 14 variables on the net revenue from pig farming. In matrix notation, the statistical model was:

$$\mathbf{y} = \boldsymbol{\mu} + \mathbf{Xb} + \mathbf{e} \qquad (1)$$

Where **y** = vectors of observations for net revenue from pig husbandry; **μ** = an overall mean; **b** = vector of fixed effects including classification effects, e.g., supplementary feed for suckling pig, disease frequency of piglets, disease frequency of sows, vaccination for sow, vaccination for piglets, and type of operation, and covariates, i.e., total piglets on farms, number of sows on farms, weaning age, number of live-born piglets, average weaning weight, nursery interval, weight at the end of the nursery phase, and time spent for pig production; **e** = vector of random residual effect; and **X** was the incidence matrix for **b**.

2.3. Results and discussion

2.3.1. Socio-economic and production characteristics of the study farms

According to the descriptive statistics, the households were predominantly headed by males with a value of 89% (Table 3). However, pigs were managed by the wife of household heads in 75% of farms, whereas the husbands were directly involved in rearing pigs in only 10% of households. This result is higher than that of surveys on pig rearing in western Kenya (Kagira et al., 2010) where 56% of pig farms were managed by the wives. The reason might be that the wives stayed at home most of the time, thus, were available to care for the pigs. Nevertheless, the wives participated less in the decision-making, e.g., when to sell the pig and to whom.

Table 3. Distribution of gender, age, education, main source of income, household size and pig herd size of 171 pig farms responding to the questionnaire

Characteristics	% of respondents
Gender of household head	
- Male	89
- Female	11
Age	
- 18-29	16
- 30-39	33
- 40-49	29
- 50-59	17
- 60 and over	5
Education	
- Illiterate	18
- Primary school	37
- Secondary school	26
- High school	13
- Higher education	6
Main source of income	
- Crop husbandry and forestry	71
- Animal husbandry	20
- Commerce (buy and sell)	4
- Worker	5
Household size (mean ± SD)	5.04 ± 1.81
Herd size of pig (sow and piglets, mean ± SD)	11.35 ± 6.26

Regarding the age of the interviewed farmers, the highest proportion was aged from 30 to 39 years old, followed by those in their 40s, 50s, and 20s, respectively, and farmers over 60 years old only accounted for 5% of the total farmers. About 37% of respondents had completed primary school; however, 26% and 13% graduated from secondary school and high school, respectively. Only 6% of farmers had received higher education, and the rest (18%) had no formal education. The low level of education of household heads in this study reflects the reported low literacy rates in the northwest of Vietnam (19%) (GSOVietnam, 2016). This situation could be one of the restrictions on the management of pigs and implementing extension services for disease control.

The main source of income for 71% of households came from crop husbandry and forestry, followed by animal husbandry, salary, and commercial activities. This result was in agreement with a previous study conducted in northwest Vietnam (Tuyen, 2016), which found that cropping and forestry contributed 65% of the total income of the ethnic minority households. It showed that crop husbandry and forestry make up a very important contribution to the livelihoods of the farms. The average household size and pig herd size were 5.04 ± 1.814 and 11.35 ± 6.266, respectively.

Nursery pigs were reared in 75% of the households with an average of about 6.97 piglets per farm. There were 31% and 71.93% of farms rearing fattening pigs and gilts for replacement, respectively. The average number of fattening pigs was 3.83, and the corresponding number for gilts was 1.48, while the average number of sows per household was 1.71. These findings reinforce what was reported in the previous study of Lemke and Zárate (2008) in North Vietnam. However, these results were higher in comparison with those from a survey by Nath et al. (2013) in the Sikkim Himalayan region, where the average number of sows, piglets, fatteners and gilts per household were 1.40, 5.20, 3.10, and 1.20 respectively.

In this study, the number of live-born piglets was 7.47 per litter (Table 2), which was a little higher than the seven piglets per litter reported by Herold et al. (2010) for Ban pigs. The piglets were weaned after 60.67 days. This result is in agreement with the results of Lemke and Zárate (2008). Compared to the study of Phengsavanh et al. (2010), the weaning age of piglets in this research was shorter than that in Northern Lao PDR.

The average pigpen size was 15.09 m^2 per farm. The pigs of 68% of the farms were reared in permanent pigpens, constructed with brick walls, cement floors and asbestos-cement or metal sheet roofs, whereas 17% of the farms kept pigs in temporary sheds. This is in contrast with the results of Kumaresan et al. (2009) in Northeast India, where pigs in temporary housing accounted for 98% of the farms. The higher ratio of better constructed pigpens indicated that pig raising is important in these regions, and the farmers pay more attention to pig management.

Kumaresan et al. (2009) reported that 89% of pig farms belonged to the category of farrow-to-fattening in the mountainous area of Northeast India. However, in northwest Vietnam, only 16% of farms reared the pigs up to market weight (50.11 kg), and most of the farms (62%) focused on the phase from farrow-to-nursery. This outcome can be explained by the culture, the tradition of ethnic minorities in these regions, which was stated in the previous study of Valle Zárate et al. (2003), and consumer demand. The long waiting period of 319.29 days for a finisher pig might be one explanation for the lower percentage of farms raising fattening pigs. The nursery interval often took 138.13 days after weaning to reach 18.47 kg of weight per piglet, after that the pigs were sold directly for slaughter or intermediaries. The type of operation in this study was different from the studies of Ieda et al. (2015), Kumaresan et al. (2009), and Kagira et al. (2010), which classified the type of operation into farrow-to-weaner, farrow-to-finisher and mixed. The differences can be interpreted by the husbandry practices of households in these regions. After weaning, piglets were kept on the farms for the nursery phase until the piglets reached a defined weight. After that, some of the farms kept the nursery piglets for rearing to reach the fixed slaughter weight in the fattening phase (farrow-to-finisher farms). The other farms sold all nursery piglets directly to the slaughterhouse or intermediaries who transport the animals to another market (farrow-to-nursery farms). The remaining farms sold some of the piglets to the local market for slaughtering, and the surplus piglets were reared in the finishing phase (mixed farms).

The feeding of pigs in this study was influenced by the characteristics of the traditional production system in Vietnam. The pigs were provided with maize as well as vegetables at most of the farms (98% and 93%); also, rice bran and cassava were available for pigs in 37% and 12% of the farms, which came from crop husbandry and locally available green plant materials. However, only 5% of households supplemented commercial food for pigs, which was in line with the reports by Lemke and Zárate (2008) and Kagira et al. (2010).

There were only 46% and 28% of households respectively that vaccinated sows and piglets, among which, the pigs were mainly vaccinated for classical swine fever and pasteurellosis diseases.

2.3.2. Clustering

2.3.2.1. Characteristics of farms based on two-step clustering

Three clusters were detected based on the 20 variables using two-step clustering analysis. The first cluster included 70 farms (41% of the total farms), the second cluster comprised 39 farms (23%), and the third cluster consisted of 62 farms (36%). Averages and frequencies of the 20 variables in each cluster are presented in Table 4. The differences among groups for each variable were investigated according to the statistical significances from the F-test for continuous variables and chi-square test for categorical variables.

The first cluster covered a significant proportion of farms in Hoa Binh province (60%), while Son La and Yen Bai provinces contributed 26% and 14% of the farms in cluster 1. Farms in this cluster had a long period from the weaning phase to the end of the nursery phase (150.36 days), which was significantly higher in comparison with the other clusters. A high proportion of the farms in this group supplied supplementary food to the suckling pigs (86%). This ratio is much higher than that of the farms in cluster 3 where only 27% of the farms provided supplementary food to suckling pigs. The advantage of this group is that the pigs had low disease frequencies. In piglets and sows from 41% and 51% of farms, respectively, farmers had not observed any disease, although only sows from 20% of households were vaccinated. There were no significant differences in terms of mating interval, number of live-born piglets, weaning age, and average weaning weight with cluster 2. In this cluster, most of the farms (96%) sold piglets to the market after the nursery phase and the average weight after the nursery phase was 16.67 kg per piglet, which was the cluster with the lowest nursery weight. This cluster can also be characterized by the low net return per piglet with an average of €10.51. Therefore, the first group was named "Nursery farms with low disease incidences". The practical explanations for the farms in this cluster indicated that the production system seems close to the traditional Ban pig raising system, which was in line with the report by Roessler et al. (2008).

The second cluster can be defined as "Fattening and mixed farms with high investment and high disease frequency", and mainly comprises households in Son La (59%) and Yen Bai (39%). This cluster was characterized by a large pigsty (20.03 m^2 per farm), and the number of piglets and sows were significantly higher than in the other two groups. In comparison with farms in cluster 3, the means for pigpen size and number of piglets on these farms were nearly double.

Table 4. Clusters based on two-step cluster analysis and the statistically significant differences among clusters based on F-test for continuous variables and chi-square test for categorical variables

Variables	Cluster 1 (70)	Cluster 2 (39)	Cluster 3 (62)	Sig.
Pigpen size	14.97[a]	20.03[b]	12.13[a]	***
Total number of piglets	8.87[a]	14.18[b]	7.61[a]	***
Number of sows	1.53[a]	2.00[b]	1.74[ab]	***
Weaning age	55.29[a]	55.38[a]	70.08[b]	***
Mating interval	18.67[a]	18.90[a]	24.58[b]	***
Number of live-born piglets	7.57[a]	8.06[a]	6.99[b]	***
Average weaning weight	5.36[a]	5.62[a]	6.35[b]	***
Nursery interval	150.36[a]	120.77[b]	135.24[ab]	***
Weight at the end of nursery phase	16.67[a]	21.95[b]	18.32[c]	***
Time spent on pig production	2.44[ab]	2.64[a]	2.23[b]	**
Net income per piglet	10.51[a]	34.27[b]	17.15[c]	***
Farm management (number of farms)				ns
- Husband	10	4	3	
- Wife	50	30	49	
- Both	10	5	10	
Type of pigsty				***
- Temporary[1]	17	1	11	
- Semi-permanent[2]	3	0	23	
- Permanent[3]	50	38	28	
Supplementary food for suckling pig	60	20	17	***
Disease frequency of piglets				***
- Rarely	16	15	35	
- Often	25	24	19	
- Never	29	0	8	
Disease frequency of sow				***
- Rarely	29	37	42	
- Often	5	1	3	
- Never	36	1	17	
Vaccination status of sow (yes)	14	25	39	***
Type of operation				***
- Farrow-to-nursery	67	0	39	
- Farrow-to-finisher	3	14	11	
- Farrow-to-nursery and finisher	0	25	12	
Vaccination for piglets (yes)	20	9	19	ns
Type of feed given to piglet				***
- Maize	13	16	59	
- Maize and rice bran	40	20	0	
- Maize and cassava	14	2	3	
- Rice bran or cassava	3	1	0	

*, **, and ***, show statistical significance levels at 10%, 5%, and 1%, respectively; ns: no statistical significance

[a-c] Values within a row with different superscripts letter differ ($P<0.05$)

1: Post-and-rail fence or wooden walls with sand or wooden floor and asbestos-cement roof

2: Wooden or brick walls with cement floor and asbestos-cement roof, manure store in pigpen

3: Brick walls with cement floor and asbestos-cement or metal sheet roof

Farms within this cluster had a short nursery phase of 120.77 days, but piglets achieved the highest weight at the end of the nursery phase (21.95 kg). Most of the farms (97%) in this cluster kept pigs in a permanent pigsty with brick walls with a cement floor and asbestos-cement or metal sheet roof. The piglets in cluster 2 frequently suffered from disease, with one or two illnesses per litter. Nevertheless, due to a high proportion of vaccination in sows (64%), sows at 95% of farms only had one disease per year. As reported by the respondents, the sows were often vaccinated for some of the common infections, e.g., classical swine fever and pneumonic pasteurellosis. However, the other diseases that the sows often suffered from were respiratory diseases or posterior paralysis, which was influenced by the weather or lack of calcium in their diets.

Additionally, the farms in this cluster focused on the phases from farrow-to-finisher and mixed farrow-to-nursery and finisher were 36% and 64%, respectively. The net income per piglet of households in cluster 2 was the highest (€34.27) in comparison with the other groups. In this cluster, the households invested more finances in pig production (larger pigpen size and population size, good pigpen type). However, the piglets still had low growth rate because of lack of nutritional requirements. Thus, this cluster lay somewhere in-between traditional and commercial systems, which is similar to the characterization of demand-driven pig production systems reported by Lemke et al. (2006).

The third cluster contains mainly households in Yen Bai (51%) and Son La (39%). A long suckling period of 70.08 days was a significant feature for farms in this cluster. In parallel with weaning age, the period from weaning to the first mating of sows was the longest (24.58 days). The farms included in this cluster reared the pigs in smaller pigpen sizes (12.13 m^2 per farm), although pigs were evenly distributed in all three types of pigsty. Also, the number of live-born piglets was lower, with an average of 6.99 piglets per litter. The piglets in most of the farms (95%) were fed with corn, and two-thirds of farmers sold piglets directly for slaughter or intermediaries after the nursery phase. Hence, the third cluster was called “Nursery farms with low investment”, because less time was spent on pig production for farms in cluster 3 and a low percentage of farms gave supplementary food for suckling pigs. The characterization of these farms was similar to the descriptions of traditional Ban pig production systems, which were the same as the farms in the first cluster.

2.3.2.2. Characteristics of farms based on k-means clustering

The results of the CatPCA are presented in Table 5. The first seven PC with eigenvalues higher than 1.0, were retained for the consecutive K-means clustering. The eigenvalues of the seven PC ranged from 1.01 to 3.66, which explained 66% of the total variance.

Table 5. Dimensions and component loadings for variables related to pig production practices

Variables	Component loading						
	PC1	PC2	PC3	PC4	PC5	PC6	PC7
Farm management	-0.069	0.269	0.187	-0.075	0.193	0.511	0.617
Type of pigsty	0.591	-0.202	0.095	-0.007	-0.350	0.234	-0.085
Pigpen size	0.630	-0.232	0.004	0.334	-0.077	0.325	0.033
Total number of piglets	0.629	-0.135	0.137	0.319	0.286	-0.114	0.117
Number of sows	0.476	0.118	-0.190	0.540	-0.026	0.229	0.085
Age at weaning	-0.377	0.706	0.024	0.365	-0.010	0.105	-0.074
Mating interval	-0.296	0.588	-0.099	0.091	0.280	0.149	-0.119
Number of live-born piglets	0.367	-0.403	0.082	-0.008	0.276	-0.349	0.357
Average weight at weaning	-0.041	0.606	0.258	0.441	-0.068	-0.118	-0.219
Supplementary food	0.078	0.534	0.220	-0.260	-0.230	-0.186	0.078
Weight at the end of nursery	0.636	0.129	0.166	-0.395	0.027	0.221	-0.278
Time for pig production	0.466	-0.336	-0.037	0.153	0.199	0.015	-0.447
Disease frequency of piglets	-0.349	-0.394	0.506	0.197	-0.397	0.131	0.043
Disease frequency of sows	-0.364	-0.315	0.570	0.118	-0.457	0.014	0.013
Vaccination status of sows	-0.330	-0.317	0.504	-0.040	0.386	0.129	-0.296
Net income per piglet	0.629	0.381	0.185	-0.196	-0.034	0.105	-0.022
Type of operation	-0.122	0.165	0.590	-0.147	0.421	0.147	-0.078
Vaccination status of piglets	-0.229	-0.395	0.249	0.221	0.333	-0.025	0.090
Nursery interval	-0.352	-0.330	-0.371	-0.252	-0.017	0.474	-0.103
Type of feed given to piglets	0.589	0.297	0.419	-0.201	-0.084	-0.111	0.077
Total (Eigenvalue)	3.664	2.868	1.852	1.361	1.312	1.044	1.009
Proportion of variable	18.321	14.338	9.258	6.803	6.560	5.219	5.044

It seems that the first dimension (PC1) was mainly determined by herd, management and production conditions on the farms, because the number of piglets (born alive) and sows, type of pigsty, pigpen size, hours of labour, weight at the end of nursery phase, type of feed given per piglet, and net return per piglet showed higher loading compared to the other variables. The second dimension (PC2) focused on reproduction, i.e., mating interval, production aspects, e.g., weaning age, weaning weight, and whether providing supplementary feed for suckling pigs. Apparently, PC3 can be identified as a disease dimension because disease and vaccination status for piglets and sows were the most important variables. Dimension 4 can be considered as a combination of PC1 and PC2. However, the loading values were lower than for the first two PCs, and the number of sows became the most critical variable. Dimension 5 overlapped with PC3 because the type of operation, vaccination for piglets and sows were the variables with the highest loading components. The last two dimensions basically lifted up variables that had not been considered in PC1 to PC5, e.g., farm management and nursery intervals. Therefore, the variations among the 171 farms mostly relied on the herd, management, and production conditions. Disease management was only in the second rank.

The K-means clustering distributed 36 farms in cluster 1, 74 farms in cluster 2, and 61 farms in cluster 3 (Table 6). There was no significant difference in terms of pigpen size, number of sows, type of pigsty, disease frequency of sow, and type of feed given to piglets among the groups.

Cluster 1 can be classified as "Farms incorporating male and female farmers in farm management"; consequently, the total number of piglets of 11.72 was also the highest among the three clusters. Compared to farms in the other clusters, a higher number of live-born piglets was reported with an average of 7.99 piglets per farm per litter, while the mating interval and nursery interval showed no significant difference. The proportion of farms in cluster 1 located in Son La, Yen Bai, and Hoa Binh was 33%, 45%, and 22%, respectively. In this group, 64% of farms incorporated both the husband and wife in farm management, who had the same responsibility in taking care of the pig. However, in the other clusters, the pigs were mainly managed by the wives while the husbands had negligible responsibility. The farms in this cluster focused on three types of operation evenly.

The second cluster contained mainly farms in Son La (47%) and Hoa Binh (42%). The smallest number of piglets (8.34) was observed for farms in this group. However, the period from weaning to the first mating of the sows was the shortest (18.22 days). Compared to the other clusters, the longest nursery interval was reported with an average of 150.20 days, but the lowest weight of 17.46 kg at the end of the nursery phase was found in the cluster.

Table 6. Clusters based on K-means cluster analysis using the first principal components generated from the categorical principal component analysis, and the statistical significance differences among clusters based on F-test for continuous variables and chi-square test for categorical variables

Variables	Cluster 1 (36)	Cluster 2 (74)	Cluster 3 (61)	Sig.
Pigpen size	16.47	15.62	13.64	ns
Total number of piglets	11.72^{a}	8.34^{b}	9.95^{ab}	**
Number of sows	1.97^{a}	1.68^{ab}	1.61^{b}	*
Age at weaning	58.47^{a}	53.85^{a}	70.25^{b}	***
Mating interval	21.06^{ab}	18.22^{a}	23.97^{b}	***
Number of live-born piglets	7.99^{a}	7.38^{b}	7.27^{b}	***
Average weight at weaning	5.39^{a}	5.27^{a}	6.62^{b}	***
Nursery interval	133.75^{ab}	150.20^{a}	126.07^{b}	***
Weight at the end of nursery phase	19.72^{a}	17.46^{b}	18.97^{ab}	**
Time spent on pig production	2.08^{a}	2.48^{b}	2.52^{b}	**
Net income per piglet	25.94^{a}	13.46^{b}	19.76^{ab}	***
Farm management (number of farms)				***
- Husband	0	9	8	
- Wife	13	65	51	
- Both	23	0	2	
Type of Pigpen				*
- Temporary[1]	7	9	13	
- Semi- permanent[2]	2	10	14	
- Permanent[3]	27	55	34	
Supplementary food for suckling pigs	17	48	32	ns
Disease frequency of piglets				**
- Rarely	15	22	29	
- Often	15	28	25	
- Never	6	24	7	
Disease frequency of sows				ns
- Rarely	24	42	42	
- Often	3	4	2	
- Never	9	28	17	
Vaccination status of sows (yes)	15	45	18	***
Type of operation				**
- Farrow-to-nursery	16	56	34	
- Farrow-to-finisher	9	8	11	
- Farrow-to-nursery and finisher	11	10	16	
Vaccination status of piglets (yes)	3	42	3	***
Type of feed given				ns
- Maize	15	41	32	
- Maize and rice bran	14	28	18	
- Maize and cassava	5	5	9	
- Rice bran or cassava	2	0	2	

*, **, and ***, show statistical significance levels at 10%, 5%, and 1%, respectively; ns: no statistical significance

$^{a-c}$ Values within a row with different superscripts letter differ (P<0.05)

1: Post-and-rail fence or wooden walls with sand or wooden floor and asbestos-cement roof
2: Wooden or brick walls with cement floor and asbestos-cement roof, manure store in pigpen
3: Brick walls with cement floor and asbestos-cement or metal sheet roof

This group had the advantage of low disease frequencies of piglets, and 32% of farms had never suffered from any disease. An outstanding characteristic in this cluster in terms of disease management was the high proportion of farms implementing vaccination for sows and piglets, i.e., 61% and 57% respectively, which were higher than the vaccination rates in the other clusters. These figures indicated that there was a significant relationship between the vaccination rate and disease frequency of piglets in this cluster. However, these farms received the lowest net revenue per piglet (€13.46) in comparison with the first and the second cluster. The type of operation in cluster 2 was mainly farrow-to-nursery (76%). Thus, this cluster was named “Nursery farms with low efficiency”.

Considering cluster 3, a remarkable difference can be observed for weaning age, meaning that the weaning age was 11.78 days longer than cluster 1 and 16.40 days longer than cluster 2. Therefore, the third group was defined as “Farms with long suckling interval”. However, the piglets in these farms were often sold to intermediaries or directly for slaughter 126.07 days after weaning. Then, the cluster had the shortest nursery interval in comparison with the other groups. In this cluster, more than half of the farms focused on the phase from farrow-to-nursery. There was no significant difference in terms of the weight of piglets at the end of the nursery phase, the total number of piglets, and the net return per piglet with any clusters. The number of live-born piglets and time spent on pig production in cluster 3 were statistically the same as those in cluster two. This group comprised farms in Son La (30%), Hoa Binh (16%), and Yen Bai (54%).

The overlap between clusters determined by two-step and k-means clustering is shown in Table 7. The number of overlapped farms in the clusters produced from the two algorithms was 12, 10, and 25 for clusters 1, 2, and 3, respectively. Therefore, nearly three-quarters of the farms were distributed into different clusters. This means that there were significant inconsistencies between the outputs from the two-step and k-means clustering, although PC for a k-means analysis was produced from variables inputted in two-step clustering and the number of clusters was also determined by a two-step method.

Table 7. The overlap between two-step and k-means analysis results

		Two-step cluster		
	Cluster	1	2	3
K-means	1	12	15	9
cluster	2	36	10	28
	3	22	14	25

2.3.3. Income from pig husbandry

The average net income of households from pig production was 0.63 €/kg live weight of the piglet. This figure is higher than the results of surveys on pig rearing in Xuan Nam commune (Tâm, 2016), in which the average net revenue of small household farms was 0.25 €/kg. However, this result was lower in comparison with the net revenue from domestic pig production reported by Adetunji and Adeyemo (2012) in Oyo State, Nigeria (1.56 €/kg).

The impacts of different effects on the income of households from pig production are shown in Table 8. There were no significant differences between the farms focused on the phase of farrow-to-finisher and a mixture of farrow-to-nursery and finisher. However, significant lower income was identified in the farrow-to-nursery farms (13.95 ± 1.93). This outcome agrees with the findings from the two-step and k-means clustering results above, which showed that the more farrow-to-nursery farms contained in the cluster, the lower the net return.

As expected, there were significant differences between the farms with and without vaccination for sows. Lower income was identified on farms that did not vaccinate sows. This finding is in agreement with the results of Tran and Nguyen (2012), in which the number of vaccinations per litter had a positive effect on the mixed-income of the farms. Additionally, number of live-born piglets and the weight of piglets at the end of the nursery phase had significantly positive effects on the household income from pig production with regression coefficients of 1.89 and 1.71, respectively. Correspondingly, more live piglets and heavier live weights benefited the farmers. However, the nursery interval had a negative impact on the net return of farms, and it decreased income by €0.12 by increasing rearing by one day.

Table 8. The effect of different factors on household income from pig production

Variables	Estimates	Std. Error	Sig.
Supplementary food for suckling pigs			ns
- Yes	20,513[a]	2,213	
- No	20,003[a]	2,189	
Disease frequency of piglets			ns
- Rarely	20,048[a]	2,368	
- Often	19,556[a]	2,127	
- Never	21,170[a]	3,259	
Disease frequency of sows			ns
- Rarely	19,066[a]	1,835	
- Often	17,193[a]	4,580	
- Never	24,514[a]	2,222	
Vaccination status of sows			**
- Yes	23,189[a]	2,127	
- No	17,327[b]	2,363	
Type of operation			***
- Farrow-to-nursery	13,953[a]	1,925	
- Farrow-to-finisher	22,179[b]	3,154	
- Farrow-to-nursery and finisher	24,640[b]	2,786	
Vaccination status of piglets			ns
- Yes	18,709[a]	2,566	
- No	21,806[a]	1,931	
Total number of piglets	0,122	0,204	ns
Number of sows	-1,055	1,449	ns
Age at weaning	0,057	0,076	ns
Number of live-born piglets	1,893	1,020	*
Average weight at weaning	0,342	1,004	ns
Average weight at the end of nursery	1,713	,289	***
Nursery interval	-0,122	0,028	***

*, **, and ***, show statistical significance levels at 10%, 5%, and 1%, respectively; ns: no statistical significance

[a-b] Values within a column with different superscripts letter differ (P<0.05)

2.4. Conclusion

This study comprehensively describes smallholder Ban pig production systems located in northwest Vietnam. The pigs were mostly managed by the wife of the household heads. The Ban pig production systems were characterized by a long suckling and nursery interval. More than two-thirds of the farms focused on the phase from farrow-to-nursery, and the piglets had a slow growth rate. This research classified Ban pig production systems into different clusters based on two-step clustering and k-means clustering after Categorical principal component analysis. The clusters displayed the divergent production and reproduction practices of the farmers in pig production. The research revealed that the households' incomes from pig production were affected by the type of operation, vaccination for sows, number of live-born piglets, the weight of piglets at the end of the nursery phase, the nursery interval and time spent on pig production. The nursery interval and time spent on pig production had a negative effect on the income of households, and the rest of the variables had a positive effect. The findings in this study will be used in a subsequent study to develop the breeding goal and breeding programme for Ban pig breeds.

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CHAPTER 3

PRODUCTION EFFICIENCY ANALYSIS OF INDIGENOUS PIG PRODUCTION IN NORTHWEST VIETNAM

3.1. Introduction

The availability of different domesticated animals enriches the household economy, because livestock production is a significant element of livelihood strategies for the poorest people in the world (Anderson, 2003). In Vietnam, pig production plays a substantial role in livestock husbandry, and pork production accounted for 75.9% of total meat production (Dzung, 2014). Pigs are well known for the ability to convert different kinds of rough feed, including kitchen waste, to protein (Rahman et al., 2008). Additionally, pigs offer early maturity, a short generation interval, and relatively small space requirement (Ezeibe, 2010). Pig production is an efficient way to improve protein utilization, because, compared to cattle, sheep, and goats, pigs grow faster and are more productive (Etim et al., 2014). In northwest Vietnam, one of the main development opportunities for smallholders under conditions of increasing land scarcity and environmental degradation is pig production.

Pig production, especially of the indigenous pig (Ban pig), significantly contributes to the economic income, and social and cultural life for most of the communities in this area. Ban pig can be readily converted into cash, which meets the regular demands on the households, such as expenditure for education and spending on basic daily necessities. As one of the cultural symbols, pork from the Ban pig is also an important food supply at traditional events. Furthermore, manure from pig production is an excellent source of fertilizer to enrich poor soils, and consequently, to improve plant cultivation for farmers. However, the development of Ban pig husbandry is hampered by lack of village veterinary staff, fluctuations in the price, inadequate technical assistance from the extension services, high-fat proportion, low growth rate, low fertility, and poor infrastructure facilities.

Small-scale Ban pig production is a widespread pork production system in northwest Vietnam because of limited resources available to households, e.g., land, labour, and feed produced from agricultural products. Therefore, farmers have to utilize their resources as efficiently as possible. Efficiency is one of the crucial elements influencing productivity growth, especially in agricultural economic development, where resources along with opportunities for developing and adopting technology are limited (Ali and Chaudhry, 1990).

The stochastic frontier is a helpful tool to approximate production efficiency in agriculture. This model was introduced by Aigner et al. (1977), Meeusen and van Den

Broeck (1977), and Førsund et al. (1980). The principle of this model is based on the concept of the production function, depending on the relationship between the set of inputs and the set of outputs in production. In the classical perspective, producers produce the maximum achievable outputs based on a given technology and level of inputs. This is the definition of the production possibility frontier, which is identified by an optimal relationship between inputs and outputs, and the potentially sub-optimal production activities of the producers are modelled using the concept of technical efficiency. The definition of technical efficiency is the rate of the farm's observed production and the optimal level of production at a given state of inputs and technology. The level of technical efficiency of a farm is identified by the relationship between detected production and potential production.

Over the last decades, stochastic frontier models have been widely used in agricultural economics studies (Battese and Coelli, 1995; Ojo, 2003; Abdulai and Tietje, 2007; Shomo et al., 2010; Adetunji and Adeyemo, 2012; A. Belete et al., 2016). Capturing random variables that are beyond the producer's control is the main advantage of this model, because the estimation is more in accordance with the potential output under "normal" working circumstances (Belete et al., 2016).

Several studies were conducted to investigate productive efficiency in pig farming systems using the stochastic frontier production function, i.e., Etim et al. (2014), Umeh et al. (2015), Aminu and Akhigbe-Ahonkhai (2017). However, indigenous pig breeds were not considered in these studies. Hence, it is necessary to analyze the socio-economic factors influencing the economic efficiency of Ban pig production and identify the most efficient source from pig producers' in the local farms.

Specifically, the objectives of the present research were 1) to examine the costs and returns from the perspective of local Ban pig farmers; 2) to approximate the level of technical efficiency for Ban pig producers; and 3) to investigate the factors that influence the technical efficiency of Ban pig farms in northwest Vietnam. The findings in this study will be applied in the study areas to improve the production efficiency of local breeds.

3.2. Materials and methods

3.2.1. Study area and data collection

The study area covered three provinces in northwest Vietnam, i.e., Son La, Hoa Binh, and Yen Bai, with a high density of commercial and indigenous pigs, and which are stratified into the three main climatic zones. One district in each province was chosen based on suggestions from the Provincial Department of Agriculture. Afterwards, three communes in each district were selected according to the following criteria: firstly, the selected areas were high-intensity regions for local pig production; secondly, they were easy to access to reduce logistic constraints for data collection.

Following Tran et al. (2017), demographic data were provided based on a farm-level survey organized from October 2016 to January 2017. Personal interviews were carried out on every farm according to the content of a semi-structured questionnaire. The main features reflected in the interviews were socioeconomic characteristics, management practices, labour use, availability of housing and equipment, capital, and output. A total of 180 households were included in the survey by adopting snowball sampling, resulting in 171 farms in the analysis because crucial information was not present for nine respondents.

3.2.2. Data analysis

The survey data were analyzed using Stata version 12. The stochastic frontier production function model was applied to estimate the level of technical efficiency and its determinants in Ban pig production. The descriptive statistics of variables (Table 9), such as means, standard deviations, frequencies, and percentages were used to interpret socio-economic characteristics of the farmers, as well as inputs and outputs of the local farms.

3.2.2.1. Cost-benefit analysis

The cost-benefit analysis was applied to approximate farm net revenue for Ban pig production systems. Theoretically, net revenue (NR) is the difference between the total revenue (TR) and the total cost (TC):

$$\mathrm{NR} = \mathrm{TR} - \mathrm{TC} \tag{2}$$

Total cost is the accumulation of the entire variable cost (VC) and fixed cost (FC) items:

$$\mathrm{TC} = \mathrm{VC} + \mathrm{FC} \tag{3}$$

The variable cost came mainly from feeding cost, labour cost, and health care cost.

Table 9. Descriptive statistic (standard deviation: SD; minimum: Min; maximum: Max) for revenue, inputs, production management, disease management, type of operation, and socio-economic information

Variable	Unit	Mean	Std. Dev.	Minimum	Maximum
Total revenues per litter	Euro	634.64	233.15	278.60	1382.55
Total net revenues per litter	Euro	123.65	131.11	-227.82	597.96
Labour	Man day	19.88	7.18	10	50
Feeding cost	Euro	281.59	157.56	69.63	980.35
Health care cost	Euro	7.07	7.27	0.00	39.80
Stock density	Pigs/m^2	1.28	0.68	0.29	3.00
Pigpen structure		2.51	0.77	1.00	3.00
Farm location		1.95	0.85	1.00	3.00
Age	Years	41.02	10.11	24.00	65.00
Educational level	School years	5.72	4.09	0.00	12.00
Nursery interval	Days	138.13	40.28	60.00	240.00
Number of live-born piglets	Number	7.47	1.10	5.20	10.60
Depreciation	Euro	16.32	12.72	0.84	82.11
Disease frequency of pigs	Times	2.18	0.76	1.00	3.00
Vaccination for piglets		0.28	0.45	0.00	1.00
Vaccination for sows		0.46	0.50	0.00	1.00
Farrow-to-nursery operation		0.62	0.49	0.00	1.00
Farrow-to-finisher operation		0.16	0.37	0.00	1.00

Total revenue is identified as the total amount of money that a producer received from the sale of fattening pigs and piglets:

$$TR = \sum P_n Q_n \quad (4)$$

Where P was the price per 1 kg live weight of the pig n^{th}; Q was the live weight of the pig n^{th}. The total revenues came mainly from the selling of nursery pigs, finisher pigs, and culled sows.

Gross margin (GM) is the total revenue minus the total variable cost:

$$GM = TR - VC \quad (5)$$

The return's ratio is used to calculate the amount of return on an investment relative to the investment cost. It is presented by:

The rate of returns (RR):

$$\mathrm{RR} = \mathrm{NR}/\mathrm{TC} \quad (6)$$

Gross ratio (GR):

$$\mathrm{GR} = \mathrm{TC}/\mathrm{TR} \quad (7)$$

Benefit-cost ratio (BCR):

$$\mathrm{BCR} = \mathrm{TR}/\mathrm{TC} \quad (8)$$

3.2.2.2. The stochastic frontier production function

The general stochastic frontier production function can be defined as:

$$y_i = f(x_i; \beta)\exp(v_i - u_i) \quad (9)$$

Where y_i denotes the output of the i^{th} sample farm (i =1, 2, …n); x_i is a vector of inputs used by the i^{th} farm; β is a vector of parameters to be estimated; v_i represents random error, not under the control of the farmers (measurement error; environment, diseases; etc.), it follows normal distribution with $N(0,\sigma_v^2)$; u_i is the one sided-error component that reflects technical inefficiency and is assumed to be independently and identically distributed as a half-normal distribution $N^+(0,\sigma_u^2)$.

The technical efficiency (TE) of the i^{th} sample farm can be estimated by:

$$TE_i = \frac{y_i}{y^*} = \frac{F(x_i; \beta)\exp(v_i - u_i)}{F(x_i; \beta)\exp(v_i)} = \exp(-u_i) \quad (10)$$

TE ranges from 0 to 1, indicating the minimum to the maximum level of technical efficiency.

Two functional forms, i.e., log-linear Cobb-Douglas and Translog production forms, can be applied for the stochastic frontier production function. In this paper, the log-linear Cobb-Douglas form was adopted. The model was:

$$\ln y = \beta_0 + \sum\beta_j \ln x_{ij} + \beta_{pp} PPstruct_i + \beta_{D_1} D_{1i} + \beta_{D_2} D_{2i} + (v_i - u_i) \quad (11)$$

Where yi denoted the total revenue of pig production per litter (Euro); x_{ij} was input quantities j^{th} used by the i^{th} pig farm, including labour (man/days), feeding cost (Euro), health care cost (Euro), stocking density (Animal/m^2). $PPstruct_i$ was the type of pigpen structure (1 for temporary, 2 for semi-permanent, and 3 for permanent); D_{1i} and D_{2i} were dummy variables of operation. For D_{1i}, values of 1 were assigned for farms focused on the farrow-to-nursery phase, and 0 was given for other farms. For D_{2i}, farms with farrow-to-finishing phase were assigned as 1, and the other farms received 0.

The inefficiency model (u_i) was specified as:

$$u_i = \delta_0 + \delta_1 Age_i + \delta_2 Edu_i + \delta_3 Dis_{PL_i} + \delta_4 NurIn_i + \delta_5 NumPig\_Alive_i + \delta_6 CAP_i + \delta_7 Vac\_PL_i \quad (12)$$

Where Age was the age of farmer (in years); Edu was the educational level of the household's head (in school years); Dis_PL was the disease frequency of pigs (Dis_PL = 1, 2, and 3 for none, low, and high disease frequencies, respectively); NurIn was nursery interval (in days); Numpig_Alive was number of live-born piglets (in number); CAP was depreciation (in Euro); Vac_PL was vaccination for piglets (dummy).

The parameters of the log-linear Cobb-Douglas and inefficiency model were estimated simultaneously by the maximum likelihood method. The variables used in the model are listed in Table 9.

3.3. Results and discussion

3.3.1. Costs and returns for pig production

Table 10 shows full detailed information about the costs, returns, and profitability of Ban pig production in the research area. The average total cost per litter was €510.99, and the average total revenue was €634.64. The total cost consists of the variable costs and the fixed costs, in which the average variable cost accounted for 97%, and the fixed cost took 3%. Additionally, the feed cost was the most important variable, because it covered the highest proportion of the variable cost of production (78%), followed by the labour cost of 20%, the health care cost of 0.01%, and other costs of 0.01%.

The average gross margin and the net revenue per litter were €139.97 and €123.65, respectively. The rate of return on investment in northwest Vietnam was 0.24, indicating that for every €1 investment, €0.24 was gained from pig production as a profit. This result is lower than that of studies on pig production in Ekiti State (Aminu and Akhigbe-Ahonkhai, 2017) and Oyo State (Adetunji and Adeyemo, 2012), where the rate of return on investment were 0.34 and 0.82, respectively. The benefit-cost ratio of 1.24 depicted that Ban pig production was a profitable business in northwest Vietnam as it was greater than one. The gross ratio was 0.81, implying that €0.81 was spent for every €1 return in the production.

Table 10. Average costs, returns, and profitability of Ban pig production in €/Litter

Variable	Amount (€)	% of TC
Total revenues (TR)	634.64	
Variable costs (VC)	494.67	0.97
- Feed	383.32	0.78
- Labour	99.46	0.20
- Medication	7.07	0.01
- Other costs	4.82	0.01
Fixed costs (FC)	16.32	0.03
Total costs (TC)	510.99	
Gross margin (GM)	139.97	
Net revenues (NR)	123.65	
Return rate (RR)	0.24	
Benefit-cost ratio (BCR)	1.24	
Gross ratio (GR)	0.81	

The difference in costs, returns, and profitability of pig production for farms with three types of operations are presented in Table 11. The farms focused on the phase of farrow-to-finish achieved the highest profit of €213.71 per litter, while the profit decreased to €75.46 per litter if farms only concentrated on the phase of farrow-to-nursery. However, the rate of return in the farms that mixed both phases (0.35) was higher than the farms only undertaking one phase, i.e., farrow-to-finish (0.28) or farrow-to-nursery (0.17). Also, the gross ratios of the three types of farms were 0.74, 0.78, and 0.85, suggesting that for every €1 return from the pig production system, €0.74, €0.78, and €0.85 were spent by the farmers in the mixed, farrow-to-finish, and farrow-to-nursery farms, respectively. This implies that pig producers from mixed farms use inputs more efficiently than others.

Table 11. Average costs, returns, and profitability of Ban pig production in €/Litter in farms focused on phases of farrow-to-nursery, farrow-to-finish, and a mixture of both

Variable	Farrow-to-nursery	Farrow-to-finish	Mixed farm
Total revenues (TR)	488.64	986.13	786.91
Variable costs (VC)	403.18	753.11	561.20
- Feed cost	301.30	619.09	439.88
- Labour cost	90.15	121.36	109.56
- Medication cost	7.06	7.35	6.89
- Other costs	4.67	5.31	4.87
Fixed costs (FC)	13.80	19.32	21.25
Total costs TC	416.98	772.43	582.45
Gross margin (GM)	85.46	233.03	225.71
Net revenues (NR)	71.66	213.71	204.47
Return rate (RR)	0.17	0.28	0.35
Benefit-cost ratio (BCR)	1.17	1.28	1.35
Gross ratio (GR)	0.85	0.78	0.74

3.3.2. Parameters of the production factors

Parameters estimated from the stochastic frontier production function are presented in Table 12. The results revealed that the coefficients of most of the inputs were statistically significant at different levels, except for the healthcare cost. The coefficient of labour was positive, with 0.07 and significant at 10%. This means that a 1% increase in the man-day will increase the total revenue by 0.07% when other factors are kept constant. This finding is in line with research on the profitability and technical efficiency of pig production in Ekiti State (Aminu and Akhigbe-Ahonkhai, 2017), and the study on efficiency in small-scale pig production in Akwa Ibom State (Etim et al., 2014). The coefficient of the feeding cost was 0.27 and significant at 1%, indicating that every 1% increase in the feeding cost will raise the total return by 0.27%. The large elasticity of feed cost is an indicator of the importance of concentrates in pig production. These results conform to prior studies by Adetunji and Adeyemo (2012) and Etim et al. (2014). The health-care cost has a negative coefficient but not significant, even at the 10% level.

The elasticity of stocking density was 0.03 and positively significant at the 10% level, suggesting that a 1% increase in the stocking density increases output by 0.03%. In contrast, a significant negative coefficient of stocking density was reported in pig production in Akwa Ibom State (Etim et al., 2014). The positive value of the coefficient of stocking density in this study suggests that increasing the stock of animals tends to increase the timeliness of resources used, as a result leading to an increase in technical efficiency.

Table 12. Coefficient, standard error, and Z-value of parameters estimated from the stochastic frontier production function for Ban pig production

Variable	Parameter	Estimates	Standard Error	Z value
Production function				
Constant term	β_0	4.91^{***}	0.21	23.03
Labour	β_1	0.07^{*}	0.04	1.78
Feeding cost	β_2	0.27^{***}	0.03	8.35
Health care cost	β_3	-0.002^{ns}	0.003	-0.77
Stock density	β_4	0.03^{*}	0.02	1.66
Pigpen structure	β_{pp}	0.04^{**}	0.02	2.09
Farrow-to-nursery	β_{D1}	-0.30^{***}	0.03	-8.64
Farrow-to-finisher	β_{D2}	0.10^{***}	0.04	2.73
Inefficiency model				
Constant term	δ_0	1.06^{ns}	1.69	0.63
Age	δ_1	0.004^{ns}	0.02	0.20
Education level	δ_2	0.001^{ns}	0.05	0.01
Disease frequency of piglets	δ_3	0.02^{ns}	0.25	0.08
Nursery interval	δ_4	0.01^{**}	0.05	2.21
Number of live-born piglets	δ_5	-0.78^{***}	0.2	-3.96
Depreciation cost	δ_6	-0.04^{**}	0.02	-1.99
Vaccination for piglets	δ_7	-0.47^{ns}	0.43	-1.10
Log-likelihood function		86.20		

*, **, and *** show statistical significance levels at 10%, 5%, and 1%, respectively; ns: no statistical significance

Additionally, the type of pigpen and operation had significant impacts on the total revenue of pig production. The production elasticity concerning the pigpen style was positive with 0.04 and significant at 5%, indicating that the better the pigsty conditions, the higher revenue farmers can earn from pig production. The coefficient of farms with the phase farrow-to-nursery was negative, while farms focused on farrow-to-finisher had a positive coefficient, and both were significant at the 1% level. The elasticity of -0.30 implied that the farrow-to-nursery farms tend to get 0.30% of total revenue less than the mixed farms. In contrast, higher output (0.10%) can be achieved for farms with farrow-to-finisher compared with the mixed farms.

3.3.3. Determinants of technical inefficiency in Ban pig production

The estimated coefficients of the inefficiency model are listed in Table 12. The coefficient of nursery interval (0.01) was positive and significant at the 5% level, suggesting that technical inefficiency effects increase with an increase in nursery interval. Hence, every one-day increase in nursery interval declined output by 0.01% in Ban pig production. The result also revealed that technical inefficiency reduced with an increase in the number of live-born piglets per litter. This suggests that the farms that have a higher number of live-born piglets per litter achieve a higher level of technical efficiency. The variable depreciation had a coefficient of -0.04 and was significant at the 5% level, indicating that technical efficiency rises with an increase in the expenditure for housing and equipment in pig production, consequently, pointing to the importance of investment in accommodation in Ban pig production. Interestingly, the coefficient of age and education level of the household's head in this research was not statistically significant even at the 10% level as reported in the previous studies by Adetunji and Adeyemo (2012), and Aminu and Akhigbe-Ahonkhai (2017).

3.3.4. Distribution of respondents by technical efficiency

The specific level of technical efficiency for pig producers obtained from the stochastic frontier model is presented in Table 13. Substantial differences in technical efficiency scores among Ban pig producers were identified. The predicted levels of technical efficiency for each farm ranged from 0.62 to 0.98, with a mean of 0.88, which were in consonance with previous findings by Aminu and Akhigbe-Ahonkhai (2017) but lower than the estimations by Etim et al. (2014) and Umeh et al. (2015). Two-thirds of the farms (78%) operated at levels of technical efficiency below 0.95, while 22% of the pig producers achieved levels of technical efficiency from 0.95 to 0.98. This indicated that none of the pig farms could produce on the frontier of the pig production function. In contrast, Ly et al. (2016) reported that 8% of households were fully efficient.

The average technical efficiency of pig breeders was 0.88, suggesting that the Ban pig farmers in northwest Vietnam were producing 88% of potential production levels. Therefore, on average, the level of technical efficiency could be increased by 12% for the Ban pig producers through efficiently utilizing available resources with the current state of technology. The least efficient producer could save costs by 35% (1-63/98) if production could be as efficient as the farm with maximum technical efficiency.

Table 13. Efficiency distribution of the Ban pig producers

Technical efficiency level		Frequency	Percentage
0.62-0.80		30	17
0.81-0.90		60	35
0.91-0.94		44	26
0.95-0.98		37	22
Minimum efficiency	*0.62*		
Maximum efficiency	*0.98*		
Mean efficiency	*0.88*		

3.4. Conclusions

This research was conducted to estimate the profitability and technical efficiency of Ban pig production in northwest Vietnam. Inputs were utilized the most effectively by the mixed farms, while farms focused on farrow-to-finisher attained the highest net return. The production inputs, e.g., feeding cost, labour, stocking density, and pigpen style, contributed positively to the output from the Ban pig production. Farms focused on the phase farrow-to-finisher achieved the highest economic efficiency, while the farms with the phase farrow-to-nursery had the lowest economic efficiency.

The main factors that affected technical efficiency in indigenous pig enterprises were nursery interval, number of live-born piglets, and the investment in housing and equipment. The findings of the present study revealed that all of the pig farms operated below the frontier threshold. The results showed that on average, the technical efficiency of Ban pig producers could be raised by 12%, through improving managerial skills, housing, and equipment for pig production.

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CHAPTER 4

WILLINGNESS TO PAY OF INDIGENOUS PIG PRODUCERS FOR VACCINATION IN NORTHWEST VIETNAM

4.1. Introduction

Pig production is an essential component of the household and national economies in developing countries. With 29.07 million registered pigs in 2016, Vietnam became the largest pig producer in Southeast Asia (GSOVietnam, 2016). Pig production plays a significant role in the livelihood strategies of smallholders in rural areas in Vietnam (Ly, 2000). The pig population increased dramatically from 20.19 million to 27.44 million from 2000 to 2005, and the average annual increase rate was 6% (GSOVietnam, 2006). However, this growth has ceased since 2006 (GSOVietnam, 2010 & 2016) because of the widespread disease outbreaks, especially porcine reproductive and respiratory syndrome (PRRS), classical swine fever (CSF), and foot and mouth disease (FMD), and the fluctuations in pig prices (Nga et al., 2014). Both the livelihoods of pig producers and the national economy are influenced significantly by infectious diseases in pigs. The economic losses due to CSF (2000-2010), PRRS (2007-2010), and FDM (2006-2010) in Vietnam were $79 million, $72 million, and $64 million, respectively (McLeod et al., 2013). Correspondingly, the losses per pig due to PRRS, FMD, and CSF were 63%, 32%, and 10% of gross margin for smallholder pig farms (Pham et al., 2017). These infectious diseases mainly occur on smallholder pig farms in the midland and upland areas where village veterinary staff are not available, and only inadequate assistance from the public veterinary services can be provided (Nga et al., 2014).

Vaccination is one of the best ways to control infectious diseases in pig production, so consequently increases the economic efficiency of pig farms. However, the proportion of indigenous pig farms in northwest Vietnam was quite low, and only 46% and 28% of households vaccinated their sows and piglets, respectively (Tran et al., 2017). In Vietnam, like many other developing countries, in order to control the outbreak of infectious disease, some vaccinations are supported by the government and can be given to pig producers for free, such as classical swine fever, pasteurellosis, and foot and mouth disease. However, while subsidy from government decreases the production cost, it increases fiscal pressures on the national budget and the dependence of farmers. Thus, it is necessary to design a vaccination programme in which the pig producers have to pay for the services themselves. Nevertheless, some policymakers have assumed that farmers would not be willing to pay for these services because of financial difficulties.

Several studies were conducted to investigate the livestock producers' willingness to pay for veterinary services (Kathiravan and Thirunavukkarasu, 2008; Kumar et al., 2011). However, the willingness to pay for vaccination in pig production was not considered in their studies. Hence it is imperative to find out if Ban pig producers in northwest Vietnam will be willing to pay for a vaccination programme, the maximum amount of payment and the factors that influence their willingness.

Specifically, the objectives of this study were 1) to investigate the farmers' willingness to pay (WTP) for a vaccination programme in Ban pig production system; 2) to assess the maximum amount of vaccination charges which pig producers are willing to pay for every piglet per litter and every sow per year; and 3) to identify the factors influencing the WTP. The findings from the present research will serve as a reference to inform policy for disseminating vaccinations in Vietnam.

4.2. Materials and methods

4.2.1. Data collection

A total of 180 pig farms was visited, and the sampling procedure was presented in Tran et al. (2017). The survey was conducted in Son La, Hoa Binh, and Yen Bai provinces where high densities of commercial and indigenous pigs were located. The data was collected from personal interviews with semi-structured questionnaires for the 180 Ban pig producers. However, nine respondents were excluded for missing key information. The main features reflected in the interviews were socioeconomic characteristics, management practices, cost, return, and true maximum WTP for vaccinations of sows and piglets.

The contingent valuation method (CVM) is a survey-based approach, which is widely used to elicit preferences for non-marketed goods (Carson, 1998). CVM has also been referred to as a "stated preference" method because it requests the respondent to state their values directly rather than inferring them from observed behaviours in regular marketplaces. This method is applied mainly to elicit individuals' preferences for basic infrastructural projects such as water supply, sanitation facilities, reduction of traffic congestion, or vaccines for protecting public health (Gunatilake, 2007). CVM also has been used in previous studies to elicit WTP for a poultry vaccination programme in different villages (Terfa et al., 2015; Mbabazi, 2015), extension services (Ajayi, 2006), or veterinary services (Kumar et al., 2011; Kathiravan et al., 2007). In the present study, CVM was applied to investigate the pig producers' maximum WTP for vaccine services. To elicit farmers' WTP, the following questions were shown to them:

"In your area, the veterinary staff provide a package with the aim of increasing the disease resistance of pigs through vaccination for the common diseases for both sows and piglets (FMD, swine erysipelas, pasteurellosis, PRRS, and CSF). After vaccination, the veterinary staff have to inspect your pigs regularly to see if they are infected by the vaccinated diseases. In the case that sows and piglets are contaminated by the diseases that were vaccinated against, they will be treated for free. Would you be willing to pay to participate in this programme?"

If the answer was "yes", the following question was asked: "What is the maximum amount of vaccination fee you would be willing to pay for every sow per year and every piglet per litter? (In Vietnamese dong: VND)."

Various approaches were available to elicit the WTP, for example open-ended (Yu and Abler, 2010), a payment card (Yang et al., 2013), dichotomous choice approach (Ready et al., 1996), and choice experiment (Alfnes and Rickertsen, 2011). Among them, a payment card is a well-suited approach for eliciting WTP because it not only combines the advantages of both the open-ended method and dichotomous approach but also allows the respondents to select a number or an interval from a list of given payments. After showing the respondents the vaccination package, a payment card for the vaccination fee ranging from 30,000 VND (€1.26) to 220,000 VND (€9.22), with equal intervals of 10,000 VND (€0.42), was given to the farmers.

4.2.2. Data analysis

The logit model was used to identify the determinants of Ban pig producers' WTP for the vaccination programme. The principle of this model is based on the cumulative probability function with the ability to deal with a binary dependent variable for which the probability could be estimated by way of prognostication of a dichotomous dependent variable from a set of independent variables (Niringiye, 2010). The logit model for this research was specified as:

$$\Pr(y = 1) = \frac{1}{1 + \exp^{-x\beta}} \qquad (13)$$

Where:

$$\begin{aligned} x\beta = \beta_0 + \beta_1 x_1 + \beta_2 x_2 + \beta_3 x_3 + \beta_4 x_4 + \beta_5 x_5 + \beta_6 x_6 + \beta_7 x_7 + \beta_8 x_8 \\ + \beta_9 x_9 + \beta_{10} x_{10} + \beta_{11} x_{11} + \beta_{12} x_{12} + \beta_{13} x_{13} + \beta_{14} x_{14} + \beta_{15} x_{15} + \beta_{16} x_{16} \end{aligned} \qquad (14)$$

Pr(y=1) denoted the probability of respondent willingness to pay for vaccination; x_1 was the total number of piglets; x_2 was the disease frequency of piglets (x_2 = 1, 2, and 3 for none, low, and high disease frequencies, respectively); x_3 was the vaccination status of piglets (dummy); x_4 was the number of members in the household ; x_5 was the gender of the household's head (dummy); x_6 was the disease frequency of sows (x_6 = 1, 2, and 3 for none, low, and high disease frequencies, respectively); x_7 was the vaccination status of sow (dummy); x_8 was the number of sows; x_9 was the net income from pig production (in Euro); x_{10} was the location of farms (x_{10}=1, 2, and 3 for Son La, Hoa Binh, and Yen Bai, respectively); x_{11} was the age of the household's head (in year); x_{12} was the education level of the respondent (by school year); x_{13} was the mortality of piglets at post-weaning (dummy); x_{14} was type of operation (x_{14} = 1, 2, 3 for farrow-to-nursery, farrow-to-finisher, and mix, respectively); x_{15} was the mortality of sows (dummy); x_{16} was the purpose of rearing pig (dummy); and β_i were vectors of unknown parameters to be estimated.

To test the relative magnitude of the effects of the explanatory variables, the marginal effect was computed. It is an instantaneous effect that measures the impact of a change in a particular explanatory variable on the predicted probability of y when the other variables are fixed. The marginal effect of x_k was given by:

$$\frac{\partial \Pr(y=1)}{\partial x_k} = \frac{e^{x\beta}}{(1+e^{x\beta})^2}\beta_k \quad (15)$$

Maximum likelihood estimation was implemented to estimate the parameters of the logit model. The log-likelihood function was:

$$\log L(\beta_i) = \sum_{i=1}^{n} y_i\,(x_i\beta_i) - \sum_{i=1}^{n} \log\left[1+\exp(x_i\beta_i)\right] \quad (16)$$

Among 171 Ban pig producers, some households were unwilling to pay for vaccination. Therefore the maximum willingness to pay for such respondents was zero. Thus, a censored regression model was considered since the WTP was censored at level 0. In this study, the Tobit model is an appropriate approach to evaluate factors influencing the maximum amount of money producers are willing to pay for vaccination. The Tobit model was given by:

$$WTP_i^* = \delta X_i + \varepsilon_i \quad (17)$$

$$WTP_i = \begin{cases} WTP_i^* \; if \; WTP_i^* > 0 \\ 0 \; if \; WTP_i^* \leq 0 \end{cases} \quad (18)$$

Where WTP_i^* was the latent or unobserved maximum willingness to pay for vaccination; WTP_i was Ban pig producers' maximum willingness to pay for vaccination of every piglet per litter or every sow per year; X_i was a vector of independent variables that are hypothesized to influence maximum WTP, these variables were the same as in the equation (2); δ was a vector of unknown parameters; ε_i was the error term, $\varepsilon_i \sim N(0, \sigma^2)$.

The log-likelihood function for the Tobit model was given by:

$$\ln L = \sum_{WTP_i=0} \ln\left[1 - \Phi\left(\frac{x_i\delta}{\sigma}\right)\right] + \sum_{WTP_i>0} \ln\left[\frac{1}{\sigma}\varphi\left(\frac{x_i\delta}{\sigma}\right)\right] \quad (19)$$

Where Φ(.) and φ(.) were the cumulative density function and probability density function, respectively, of the standard normal distribution. The descriptive statistics of the variables used in the models are presented in Table 14.

4.3. Results and discussion

4.3.1. Ban pig producers' willingness to pay for vaccinations

Only 18% of the 171 respondents showed their unwillingness to pay for the pig vaccination, while the majority (82%) was willing to pay (Figure 2). These results are in conformity with the findings of Kusina et al. (2001) who reported that more than 80% of farmers were willing to have their poultry vaccinated against Newcastle disease. Although the Ban pig producers were free to give reasons for their unwillingness to pay for the immunization programme, a significant number of farmers gave similar reasons. The main reasons for unwillingness were: "The pigs were healthy, they do not need a vaccine" (60%), "Vaccination was ineffective" (53%), and "Vaccination was the government's responsibility" (30%). Three percent (3%) of Ban pig producers were concerned about the effectiveness of vaccination and then chose unwillingness.

The frequency distributions of the maximum amount of money that farmers are willing to pay for vaccinating piglets and sows are presented in Figures 3 and 4. More than half of respondents (53%) were willing to pay €2.00 to €3.00 for vaccination of every piglet per litter, and the vaccination fees of less than €2 (23%) and higher than €4 (18%) took the second and third places. Interestingly, only 6% of farmers wanted to spend €3.01 to €4.00 on piglet vaccination. The minimum and maximum amount of money that the Ban pig producers would pay for every piglet per litter were €1.26 and €6.28, respectively, with a mean of €2.51 (Table 14). The farmers' WTP for vaccination of piglets approximates the average vaccination cost provided currently by the government or private sector (€2.61 piglet^{-1}).

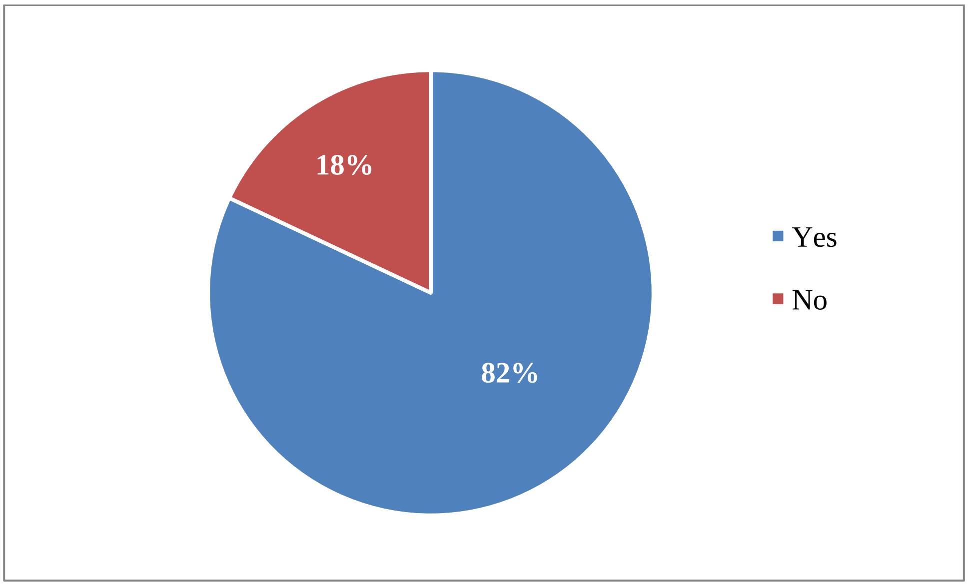

Figure 2. Farmers' willingness to pay for a vaccination package

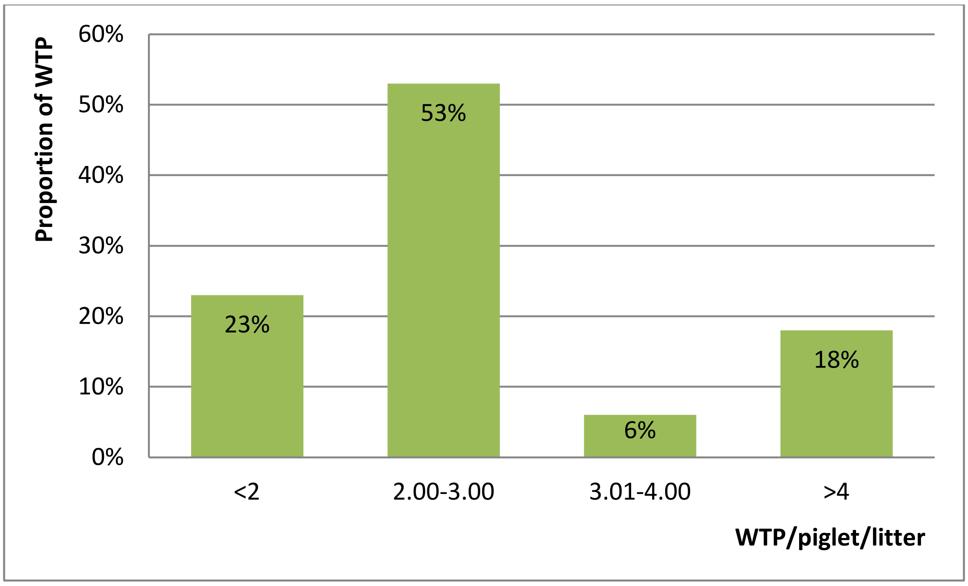

Figure 3. The maximum amount of money that the pig producers were willing to pay for vaccinating piglets

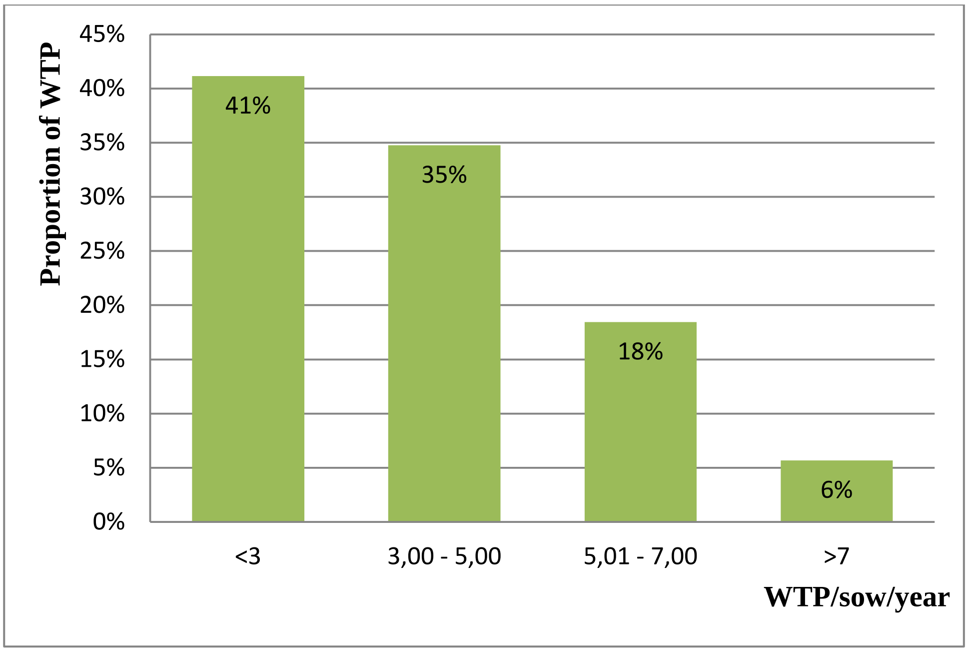

Figure 4. The maximum amount of money that the pig producers were willing to pay for vaccinating sows

The minimum and maximum of producers' WTP for every sow per year was €2.09 and €8.38, correspondingly, with an average of €3.89. This payment is less than the average vaccination cost provided by the government or private sector (€5.23 sow^{-1}). A large proportion of farmers (41%) were willing to pay less than €3 for a vaccination package, while only 6% of them could spend more than €7.00. Ranks of the vaccination fees of €3.00 to €5.00 and of €5.01 to €7.00 lay between the two extreme groups.

In contrast with piglets, farmers would spend more vaccination fees on sows, indicating the economic importance of sows in indigenous pig production systems. Additionally, for sows, a clear decrease in frequencies can be observed with the increase of vaccination fees. However, the pattern was not clear for piglets because the most favourable amount of vaccination costs stood in the middle. It revealed that farmers intended to accept a vaccination package that costs as little as possible for sows, while optimizing the vaccination costs, vaccination effects, and probably other factors for piglets.

Table 14. Descriptive statistics of the variables integrated in the logit and tobit model (minimum: Min, maximum: Max, and the mean of continuous variables; frequency and percentage of categorical variables)

Variable	Mean	Min	Max	Frequency	Percentage
WTP for every piglet per litter (Euro)	2.51	1.26	6.28		
WTP for every sow per year (Euro)	3.89	2.09	8.38		
Age (Year)	41.02	24	65		
Education level (School years)	5.72	0	12		
Household size (Number)	5.40	2	12		
Net income/Loss per litter (Euro)	123.56	-227.83	579.96		
Total number of piglets (Number)	9.63	1	27		
Number of sows (Number)	1.71	1	4		
Willingness to pay for vaccination					
- Yes				141	82
- No				30	18
Gender of respondents (Dummy)					
- Male				153	89
- Female				18	11
Location of farms (Dummy)					
- Son La				65	38
- Hoa Binh				49	29
- Yen Bai				57	33
Disease frequency of piglets (Dummy)					
- No disease				37	22
- One per litter				66	38
- More than one				68	40
Vaccination status of piglets (Dummy)					
- Yes				48	28
- No				123	72
Vaccination status of sows (Dummy)					
- Yes				78	46
- No				93	54
Disease frequency of sows (Dummy)					
- No disease				54	32
- One per litter				108	63
- More than one				9	5
Type of operation					
- Farrow-to-nursery				106	62
- Farrow-to-finisher				28	16
- Farrow-to-nursery and finisher				37	22
Mortality of sows					
- Yes				33	19
- No				138	81
Mortality of piglets at post-weaning					
- Yes				71	42
- No				100	58
Purpose for rearing pig					
- Increase income				111	65
- Other reasons				60	35

4.3.2. Factors influencing willingness to pay for vaccination

Total number of piglets and sows on the farm, disease frequency of piglets, vaccination status of piglets and sows, gender of household heads, education level of household heads, age of household head, mortality of piglets at post-weaning, type of operation, reason for raising Ban pigs, and location of the pig farms significantly affected WTP of the Ban pig producers for vaccination (Table 15). The coefficient of the total number of piglets and sows on the farms was significant at the 1% and 5% level, respectively, but in opposite directions. According to the marginal effect, one more piglet at the farm increased the likelihood of farmers' WTP by 3%. Mbabazi (2015) and Terfa et al. (2015) confirmed this finding and clarified that in the case of a disease outbreak, the farms with a higher number of animals were able to suffer greater losses than those with fewer animals, resulting in a higher level of WTP. However, farms with one more sow intended to reduce WTP by 9%. On the one hand, this is probably because of the limited financial budgets for vaccination. On the other hand, farmers believe that the sows have better disease resistance and resilience than piglets and sows are separated into different pigsties, which mean the transmission is blocked.

Significant differences in the willingness to pay for vaccination were found between farms with none or one disease per litter and those with more than one disease per litter. The negative coefficients of the disease frequency of piglets indicate that Ban pig producers are less likely (32% and 12% decrease, respectively) to pay for immunization if none or one diseased piglet was observed at the farms, compared to the farms with more diseased piglets. These findings demonstrate that the more disease occurs, the more likely the producers are willing to pay for the vaccination programme. Because the farmers possibly believe that the programme could protect their piglets from diseases.

The current status of vaccination for piglets and sows was also significant at the 10% level and had positive impacts on WTP. Specifically, it means that the farms with vaccinated piglets and sows are 12% and 11%, respectively, more likely to pay for the programme than the farms that had never vaccinated. It is probable that the vaccinated farms experienced an increase in the survival rate of their piglets and sows, and recognized the importance of vaccination in disease control. Hence, they show a higher willingness to pay than non-vaccinated farms.

Table 15. Coefficients, standard errors, Z-statistics and marginal effects of factors influencing willingness to pay of farmers from the Logit regression model

Variable	Estimates	Standard Error		Z- statistics	Marginal effect
Total number of piglets	0.33***	0.09		3.70	0.03
Age	0.06*	0.04		1.71	0.005
Education level	0.21**	0.09		2.34	0.02
Disease frequency of piglets					
No disease	-4.06**	1.81		-2.24	-0.32
One per litter	-1.87**	0.74		-2.51	-0.12
Vaccination status of piglets	1.51*	0.90		1.68	0.12
Household size	-0.13ns	0.17		-0.80	-0.01
Gender of respondents	1.56*	0.94		1.65	0.12
Disease frequency of sows					
No disease	-0.81ns	1.89		-0.43	-0.04
One per litter	-2.25ns	1.72		-1.31	-0.14
Vaccination status of sows	1.43*	0.80		1.77	0.11
Number of sows	-1.09**	0.47		-2.32	-0.09
Net income from pig production	- 0.0002ns	0.003		-0.83	-0.00
Location of farms					
Hoa Binh	-4.92***	1.76		-2.79	-0.29
Yen Bai	-3.92**	1.68		-2.34	-0.19
Mortality of sows	0.69ns	0.88		0.82	0.05
Mortality of piglets	-2.48***	0.77		-3.23	-0.19
Type of operation					
- Farrow-to-finisher	0.90ns	1.01		0.89	0.07
- Mixed farm	2.49**	1.09		2.28	0.16
Purpose for rearing pigs	2.65***	0.84		3.16	0.21
Constant	1.86ns	2.76		0.67	
Log-likelihood			-42.83		
LR chi2 (19)			73.16		
Prob > chi2			0.000		
Pseudo R2			0.46		

*, **, and *** show statistical significance levels at 10%, 5% and 1%, respectively; ns: no statistical significance

Basically, the effects of the socio-demographic variables match expectations. The location of farms, education level, age, and gender of the household head are crucial factors for WTP. Education of respondents was significant at the 5% level, and had a positive marginal effect, suggesting that one more year of education level increases the likelihood of farmers' WTP by 2%. This finding is in line with research on WTP for a village poultry vaccine service (Terfa et al., 2015) and studies on farmers' WTP for vaccination of village free-range poultry against Newcastle disease (Mbabazi, 2015). Farmers with higher education levels are able to recognize the risks of pig diseases and are aware of the importance of vaccination in reducing the impact of infectious hog diseases for pig production systems.

Gender of the household head was also significant at the 10% level. The coefficient was positive with a marginal effect of 0.12, indicating that the male is more likely to pay for vaccination by 12% than the female. This finding is in agreement with a previous study conducted by Doss and Morris (2000), who postulated that male household heads were more likely to adopt or accept change due to resource ownership. Mwaura et al. (2010) also confirmed this finding and clarified that male household heads were more likely to pay for extension services in crop and animal husbandry than females.

Age of the household head had a positive coefficient and was statistically significant at a 10% level, suggesting that farmers, who are one year older, are more likely to pay for vaccination than the younger farmers (0.005%). However, negative effects of age of the household head on WTP were reported by Terfa et al. (2015) and Oladele (2008). Additionally, significant differences were detected between farms located in Son La and Yen Bai and farms located in Hoa Binh. The negative coefficients of farm locations illustrated that WTP of farmers in Son La and Yen Bai provinces are lower than the willingness of the farmers in Hoa Binh province for 29% and 19%, respectively.

A significant difference was identified between the farms focused on the phase of farrow-to-nursery and the mixed farms (farrow-to-nursery and finisher). The coefficient was positive and statistically significant at the 5% level, which indicates that the mixed farms are 16% more likely to pay for the vaccination package than the nursery farms. The mixed farms have to keep pigs on the farm longer than the nursery farms. Thus, these farmers tend to pay for vaccination to reduce disease occurrences. Interestingly, the coefficient of the mortality of piglets at post-weaning was negative and statistically significant at the 1% level, denoting that farms where piglets had died are less likely to pay for vaccination by 19% than farms where piglets had not died.

The farmers who reared pigs mainly for increasing income were 21% more likely to pay for vaccination than their counterparts who kept pigs for other purposes (home consumption, cultural purposes, etc.), which is in line with the reports by Mbabazi (2015). Because pig production is a source of income for these farmers, they are willing to pay for vaccination to alleviate the risk of losses and increase the chances of profits.

4.3.3. Factors influencing the maximum willingness to pay for piglets per litter

Only four independent variables, including the total number of piglets, the gender of the household head, vaccination status of the piglets, and locations of the farm were statistically significantly related to the maximum amount of money that the farmers were willing to pay for the vaccination package (Table 16). Although the education levels and total revenues were expected to positively influence the maximum amount of vaccination fees, the Tobit regression model gave insignificant results, and so the relationships could not be confirmed. Additionally, the disease frequency of piglets was not statistically significant as well in spite of the decreasing maximum WTP for lower disease frequencies.

The total number of piglets increased the maximum amount of money that the producer wanted to pay. Farms with one more piglet would spend more money, i.e., €0.04 on the vaccination package. Kathiravan et al. (2007) also reported that the number of sheep on the farms had a positive effect on the farmers' WTP for annual health care services in South India. As mentioned above, the pig producers with a higher number of piglets are willing to pay more for vaccination, because vaccination could reduce the losses in case of a disease outbreak.

Male and female household heads showed different maximum WTP for the vaccination package as its coefficient was significant at the 10% level. The positive coefficient of 0.70 for gender verified that male household heads tended to pay €0.70 more than females for every piglet. In line with this, Kathiravan and Thirunavukkarasu (2008) postulated that the true maximum WTP of male farmers were higher than female farmers for health care services for buffaloes.

In comparison with the non-vaccinated farms, pig farmers who already vaccinated their piglets were likely to spend €0.48 more on every piglet, and the coefficient was significant at the 10% level. Farms in the three provinces also presented varied maximum WTP. The farmers in Hoa Binh and Yen Bai could pay €0.91 and €1.08 more fees for each piglet than the farmers in Son La, respectively.

Table 16. Coefficients, standard errors, and t-statistics of factors influencing the maximum willingness to pay of Ban pig producers for vaccinating each piglet per litter from the Tobit regression model

Variable	Estimates (€)	Standard Error	t-statistic
Net income	0.001^{ns}	0.001	1.39
Total number of piglets	0.04**	0.02	2.08
Disease frequency of piglets			
One per litter	-0.20^{ns}	0.39	-0.52
More than one	-0.07^{ns}	0.38	-0.19
Age	0.02^{ns}	0.01	1.35
Household size	-0.06^{ns}	0.07	-0.86
Education level	0.04^{ns}	0.03	1.30
Gender of respondents	0.70*	0.41	1.73
Vaccination status of piglets	0.48*	0.28	1.72
Location of farms			
Hoa Binh	0.91**	0.37	2.46
Yen Bai	1.08***	0.30	3.64
Constant	-0.63^{ns}	0.91	-0.69
Log-likelihood		-285.89	
LR chi2(11)		30.58	
Prob > chi2		0.001	
Pseudo R2		0.05	

*, **, and *** show statistical significance levels at 10%, 5% and 1%, respectively; ns: no statistical significance

4.3.4. Factors influencing the maximum willingness to pay for sows

Coefficients of parameters influencing the maximum WTP for sows were also estimated from the Tobit regression model (Table 17). The net income was significant at the 5% level with a positive coefficient of 0.003. Hence, the maximum amount of money that pig producers planned to pay for every sow per year increased by €0.003 if their net income increased €1 more. This result is in agreement with a previous study conducted in the Tamil Nadu State of India by Kathiravan and Thirunavukkarasu (2008), who also stated that the farmers' true maximum WTP for annual health care services for cows increased with an increase of annual household income. The farms with higher income from pig production are often willing to invest more in the production facilities, including vaccination.

Table 17. Coefficients, standard errors, and t-statistics of factors influencing the maximum willingness to pay of Ban pig producers for vaccinating each sow per year from the Tobit regression model

Variable	Estimates (€)	Standard Error		t-statistic
Net income	0.003^{**}	0.001		1.99
Number of sows	0.01^{ns}	0.24		-0.06
Disease frequency of sows				
One per litter	0.17^{ns}	0.47		0.37
More than one	0.44^{ns}	0.86		0.51
Vaccination status of sows	1.26^{***}	0.39		3.22
Age	0.03^{ns}	0.02		1.35
Education level	0.06^{ns}	0.05		1.11
Gender of respondents	1.30^{**}	0.61		2.13
Household size	-0.13^{ns}	0.10		-1.24
Location of farms				
Hoa Binh	1.89^{***}	0.55		3.43
Yen Bai	1.94^{***}	0.45		4.30
Constant	-1.12^{ns}	1.34		-0.83
Log-likelihood			-346.88	
LR chi2 (11)			36.39	
Prob > chi2			0.000	
Pseudo			0.05	

*, **, and *** show statistical significance levels at 10%, 5% and 1%, respectively; ns: no statistical significance

The difference between the coefficients of the farms with and without vaccination for sows was also significant. The vaccination status of sows had a coefficient of 1.26, indicating that the farms with vaccinated sows would pay €1.26 more for vaccinating sows than those without vaccinated sows. Similar to the explanation for piglets, the farms with vaccination for sows also experienced a decrease in the disease occurrences of their sows. Hence, they know the importance of vaccination and show higher WTP than the farms without any inoculation.

Compared to female household heads, males were likely to pay €1.30 more for every sow per year as the coefficient was positive and significant at the 5% level. In line with this, Mwaura et al. (2010) postulated that male household heads would pay more for extension services in crop and animal husbandry than their female counterparts. In contrast, Ajayi (2006) reported that female farmers were willing to pay more for extension services than male farmers. Similarly to the results for piglets, farms located in Hoa Binh and Yen Bai spent €1.89 and €1.94, respectively, more on sow vaccination than the farms located in Son La province.

4.4. Conclusions

This study ascertained WTP for vaccination of Ban pig producers in northwest Vietnam. The majority of surveyed pig producers (82%) were willing to pay for the vaccination programme. This demonstrates the potential interest in indigenous pig vaccination and the possibility of designing and implementing pig vaccination services. The average amounts that farmers could afford were €2.51 for every piglet per litter and €3.89 for every sow per year. Policy-makers and concerned stakeholders could consider the values as reference amounts in proposing a fee for a vaccination package in northwest Vietnam. The WTP of Ban pig producers was significantly influenced by the total number of piglets and sows, the disease frequency of piglets, vaccination status of piglets and sows, gender of household heads, education level of household heads, age of household heads, mortality of piglets at post-weaning, type of operation, reason for raising Ban pigs, and location of the pig farms. The results from Tobit regression revealed that the gender of household heads and the location of the farms affected the maximum amount of money that producers were willing to pay for the vaccination package including both piglets and sows. Additionally, the total number of piglets and vaccination status of piglets also significantly affected the maximum WTP for piglets. For the maximum WTP of sows, net income and vaccination status of sows should be taken into account as well.

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CHAPTER 5

DERIVATION OF ECONOMIC WEIGHTS FOR PRODUCTION, REPRODUCTION AND SURVIVAL TRAITS FOR PIGS KEPT IN ALTERNATIVE PRODUCTION SYSTEMS

5.1. Introduction

A large number of pure-bred pigs (Ban pigs) are still kept in small-scale farming systems, especially in the northwest area, even though crosses and exotic pig breeds are more prevalent in Vietnam. The indigenous pigs are characterized by adaptability to poor feed quality, the ability to thrive within a wide range of environmental conditions, and resistance to diseases. In the past decade, the Vietnamese government has taken several measures to conserve and increase the population of native pigs by releasing a series of policies. However, to improve the long-term sustainability of animal production, the development of breeding goals is an essential step. All of the traits which affect the profitability of pig production should be included in the breeding goal. Traits involved in pig breeding goals are typically categorized into maternal traits (litter size, survival rate, sow longevity) and terminal traits (daily gain, feed conversion ratio) (Serenius et al., 2007). The number of traits comprised in the breeding goal continues to increase over time, and they depend on their economic weights as an essential prerequisite, and the requirement of different stakeholders in the pork value chain, e.g., farmers, retailers, and consumers. Therefore, it is necessary to have precise knowledge about the economic weights for all of the traits to ensure that the selection emphasis is proportional to their economic importance in the pig production system (Houška et al., 2010). Roessler et al. (2009) reported the economic weight values on Vietnam pigs for the traits of number of live-born piglets, average daily gain, farrowing interval, backfat thickness, and body weight.

The economic weight for a trait measures the change in predicted profit by improving one unit of this trait, holding all other traits constant. Economic weights for traits of pig production systems using a bio-economic model were applied in previous research studies by Houška et al. (2004), Quinton et al. (2006), Houška et al. (2010), and Amer et al. (2014). However, these studies did not derive the economic weights for all traits affecting the profitability of the production system, and simple, independent models were used to derive the economic weights of traits in pigs. The general bio-economic model to calculate the economic weights of all traits for an integrated pig production system, and under different breeding systems, was developed by Wolf et al. (2016) (EWPIG package). This model considers the impact of biological, management, and economic conditions on the economic efficiency of a given production system and how specific constituents interact to affect farm profit.

The objective of the present study is, therefore, to derive the economic importance of production, reproduction and survival traits for indigenous pig breeds in northwest Vietnam, which are expected to influence farm profitability by applying the EWPIG package. The economic weights estimated are important to identify the traits that should be included in the Vietnamese pig breeding goal.

5.2. Materials and methods

5.2.1. Production system description

Economic weights of traits were calculated for an indigenous pig breed (Ban pig). One hundred and seventy-one pig farms were visited in three provinces in the mountainous areas of northwest Vietnam (Son La, Hoa Binh, and Yen Bai). The herd size varied from 1 to 4 sows, with an average of 9.63 piglets per farm (Tran et al., 2017). The female replacements were reared within the system. The basic structure of the production system is presented in Fig. 5. The production system is described mainly following Wolfová et al. (2017).

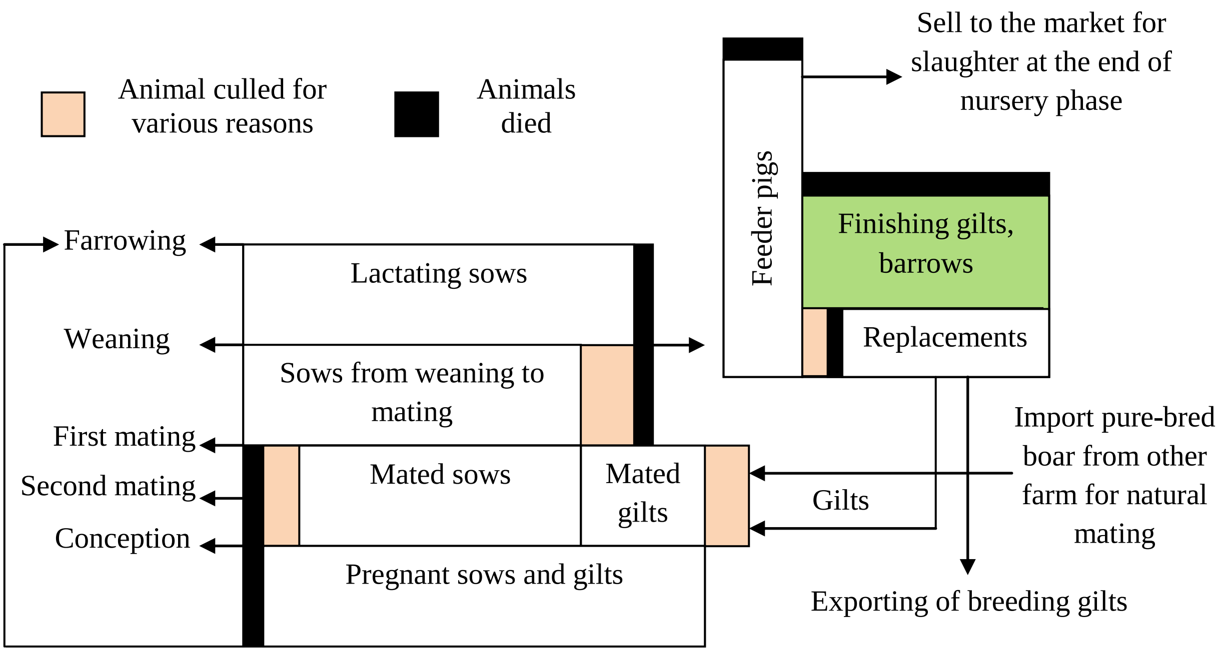

Figure 5. Integrated Ban pig production system in northwest Vietnam

The pure-bred boar is imported from outside for natural mating when the sows and gilts are in oestrus, and the maximal number of mating is two. Healthy and productive sows with good maternal ability are kept in the sow herd until they have completed the maximal number of farrowings (9 reproductive cycles). The male piglets are castrated after weaning. Weaned piglets are transferred to the nursery phase (feeder pigs) for rearing until they reach a defined weight. After the nursery phase, some female pigs are selected and reared as breeding animals for replacement or exported to other farms. One part of the surplus females and castrated male progeny is sold to the local market or intermediaries for slaughtering after the nursery phase, and the remaining piglets were kept on the farm for rearing to reach the fixed slaughter weight (from 40 to 80 kg) in the finishing phase.

5.2.2. Model description and input data

The programme package EWPIG (Wolf et al., 2016) was used to estimate the economic values for the traits of a pure-bred pig production system. The bio-economic model in this programme is illustrated in detail by Wolfová et al. (2017). Accordingly, the deterministic approach with some stochastic elements was applied to model the production system. The model can be separated into five parts: 1) calculation of the sow herd structure in the defined production system; 2) calculation of progeny structure per reproductive cycle; 3) calculation of the nutrition requirement and growth patterns for different animal groups and growth phases; 4) calculation of costs for all growth phases of young animals and sows in different reproductive statuses as well as revenues and profit for all production units and per sow per year; 5) calculation of marginal economic values for production and functional traits as well as the relative economic weights of selected traits.

The structure of the sow herd was estimated by the programme based on the number of reproductive cycles, sow conception rate, sow mortality rate, and sow culling rate for different reasons, using the main input parameters given in Table 18. The mortality rate of sows during lactation fluctuated from 0.4% to 4% and during pregnancy between 1% and 4%. The proportion of culled sows after piglet weaning for different reasons ranged from 1% to 2%. The conception rate of the sows in each parity varied between 91% and 97%.

The structure of progeny was defined in accordance with the respective growth phases of the animals, taking into account the sex, utilization, and survival of the animals as well as management measures. Piglets were weaned at an average of 61 days and were reared in the nursery phase until the age of 199 days. The mortality rate of piglets at birth, live-born piglets until weaning, and during the nursery phase was 6.22%, 2.12%, and 7%, respectively. The mortality rate in the rearing of breeding gilts was 0.4%. After rearing, 1.1% of gilts were negatively selected for different reasons. Surplus female piglets intended for export as breeding gilts accounted for 6%, while 68% of surplus female piglets were exported after the nursery phase. All other surplus gilts were reared in the finishing phase. Seventy-two percent (72%) of the castrated piglets were exported after the nursery phase, and the surplus of them was fattened.

Table 18. Mean reproductive characteristics per reproductive cycle for Ban sows

Parameters	**Reproductive cycle**								
	1	2	3	4	5	6	7	8	9
Sow mortality rate in lactation	0.01	0.02	0.04	0.02	0.03	0.01	0.004	0.004	0.00
Sow mortality rate in pregnancy	0.02	0.02	0.02	0.01	0.04	0.03	0.01	0.01	
Sows culled because of different reasons	0.01	0.01	0.01	0.02	0.01	0.02	0.02	0.02	
Conception rate of sows	0.97	0.92	0.91	0.92	0.94	0.93	0.94	0.95	
Number of piglets born/litter	6.60	7.60	8.20	8.40	8.50	8.50	8.30	7.90	7.80
Number of piglets weaned/litter	6.17	6.92	7.42	7.61	7.81	7.83	7.64	7.33	7.30

The growth of all categories of sows and their progeny was described based on live weight at specific ages by multi-phase growth curves assuming linear functions for the individual phases. The differentiated growth phases included: growth from birth to weaning, growth of animals in the nursery phase, growth of pigs in the finishing phase separately for each sex, growth during rearing of breeding animals for gilts and boars, growth of sows during lactation and pregnancy at different parities, and growth of boars from entry into the breeding unit to mature weight. The growth pattern of progeny and sows was described by using the most important input parameters in Table 19.

The energy requirement for growth, maintenance, and pregnancy for the Ban pig was estimated based on growth rates of protein and lipid mass in the empty body weight (EBW). Protein and lipid mass of EBW for growing pigs were approximated by applying an allometric function as given by Whittemore (1994):

$$Y = a * EBW^{b} \quad (20)$$

Where Y is the component of the entire body of the growing pigs, a and b are coefficients of the function-specific to each breed and sex (barrows and females), respectively.

The EBW was estimated according to Council (2012):

$$EBW = BW - 0.277 * BW^{0.612} \quad (21)$$

Where *BW* is body weight.

The growth of pregnant animals is indicated by the growth of conceptus, empty uterus, mammary gland tissue, and body tissue. The weight of conceptus (kg) at day *t* of pregnancy WC_t was calculated by using the equation taken from Council (2012):

$$WC_t = 0.001 * e^{8.621+0.114*TNB-21.02*e^{-0.053*t}} \quad (22)$$

Where *TNB* is the total number of piglets born after each parity.

Table 19. Input parameters used for calculating growth pattern of animals

Parameter (units)	**Value**
Birth weight of piglets (kg)	0.60
Weight of piglets at weaning (kg)	5.80
Weight of piglets at the end of the nursery phase (kg)	18.50
Age of piglets at the end of the nursery phase (d)	199.00
Weight of breeding at selection (kg)	18.70
Age of breeding gilts at selection (d)	200.00
Weight of breeding boar at selection (kg)	31.40
Age of breeding boar at selection (d)	330.00
Weight of breeding gilt at first mating (kg)	31.90
Age of breeding gilts at first mating (d)	315.00
Weight of sows at 1st farrowing/weaning (kg)	45.8/33.3
Weight of sows at 2nd farrowing/weaning (kg)	54.6/41.7
Weight of sows at 3rd farrowing/weaning (kg)	61.9/49.1
Weight of sows at 4th farrowing/weaning (kg)	69.1/56.0
Weight of sows at 5th farrowing/weaning (kg)	75.3/62.2
Weight of sows at 6th farrowing/weaning (kg)	81.3/67.9
Weight of sows at 7th farrowing/weaning (kg)	86.0/72.9
Weight of sows at 8th farrowing/weaning (kg)	90.6/77.4
Weight of sows at 9th farrowing/weaning (kg)	93.3/80.3

The weight of empty uterus (WU_t) and mammary gland tissue (WMG_t) at day t of pregnancy was estimated by applying the equation given by Šimeček (1994):

$$WU_t = 0.47 + 0.0319 * t \quad (23)$$

$$WMG_t = \begin{cases} 8.43 - 0.1626 * t + 0.001158 * t^2 \; for \; 1st \; pregnancy \\ 6.59 - 0.1319 * t + 0.001167 * t^2 \; for \; 2nd \; pregnancy \\ 7.40 - 0.1398 * t + 0.001244 * t^2 \; for \; pregnancy \geq 3 \end{cases} \quad (24)$$

The basic input parameters for calculation of the metabolizable energy (ME) requirement for different categories are presented in Table 20. These input parameters were taken from Britain (1981), Šimeček (1994), Dourmad et al. (2008), van Milgen et al. (2008), and Council (2012).

Table 20. Input parameters used for the estimation of metabolizable energy requirement for different animal groups

Parameter (units)	**Value**
Net energy value of body protein (MJ NE[a]/kg protein)	23.80
Net energy value of body lipid (MJ NE/kg lipid)	39.70
Coefficient for the efficiency of utilization of metabolizable energy for protein gain (MJ NE/MJ ME[b])	0.54
Coefficient for the efficiency of utilization of metabolizable energy for lipid gain (MJ NE/MJ ME)	0.74
Exponent for the calculation of metabolic body weight from body weight of young growing pigs	0.63
Standard metabolizable energy needed per kg metabolic body weight and per day for growing pigs (MJ ME/kg)	0.719
Standard metabolizable energy needed per kg metabolic body weight and per day for barren and pregnant sows or pregnant gilts (MJ ME/kg)	0.418
Coefficient for the efficiency of utilization of metabolizable energy from feed for pregnancy product	0.53
Standard metabolizable energy needed per kg metabolic body weight and per day for lactating sows (MJ ME/kg)	0.46
Exponent for the calculation of metabolic body weight from body weight of sows	0.75
Efficiency of metabolizable energy from feed for milk production	0.72
Efficiency of net energy from body reserves for milk production	0.87
Efficiency of metabolizable energy from feed for body weight gain of sows	0.69
Efficiency of net energy from body reserves for pregnancy	0.80
Dry matter content in the mammary tissue at the end of pregnancy (kg DM/kg fresh matter)	0.48
Net energy content in the dry matter of mammary tissue at the end of pregnancy (MJ NE/kg)	34.4

[a] Megajoule net energy

[b] Megajoule metabolizable energy

The total revenues and total costs were calculated for the entire integrated production system per farrowed sow and per reproductive cycle and were then expressed per sow per year. The total profit was calculated as the difference between the total revenues and total costs and was used as a criterion for economic efficiency. Another efficiency criterion, the profitability of the production system was computed in percentages as the total profit gained per unit of used expenses. The revenues came mainly from culled sows, exported breeding gilts, exported piglets after nursery phase, and finished gilts and barrows. The price per kg live weight, which does not change with live weight, was used to calculate revenues from the pig production system. On average, the price per kg live weight for breeding gilts, negatively selected breeding gilts, culled sows, exported piglets after the nursery phase, and finishing pigs were €4.24, €4.06, €2.17, €4.06, and €2.31, respectively.

The costs in the Ban pig production system were differentiated into feeding costs and non-feed costs. The feeding costs were estimated based on daily net energy and protein requirements of animals in different categories of sows and their progeny. The input parameters for the calculation of feeding costs are presented in Table 21.

Table 21. Input parameters used for the calculation of feeding costs

Parameters (units)	**Value**
Amount of supplementary feed (next to sow's milk) until weaning (kg/piglet)	2.32
Price of supplementary feed for piglets until weaning with 13.5 MJ MEb/kg (€/kg)	0.36
Price of feed for piglets in nursery phase with 5.92 MJ ME/kg (€/kg)	0.11
Price of feed for gilts and barrows in the finishing phase with 5.74 ME/kg (€/kg)	0.12
Price of feed for breeding gilts in rearing with 6.55 MJ ME/kg (€/kg)	0.14
Price of feed for pregnant gilts with 7.30 MJ ME/kg (€/kg)	0.15
Price of feed for barren and pregnant sows with 7.07 MJ ME/kg (€/kg)	0.15
Price of feed for lactating sows with 9.15 MJ ME/kg (€/kg)	0.17

The non-feed costs were distinguished as specific and non-specific non-feed costs. Specific costs were typically associated with a particular category of animal or at least with a specific group of animals, while the non-specific non-feed costs were associated with the particular unit (breeding, nursery, finishing unit, or unit for rearing breeding animals). The main input parameters related to non-feed costs are listed in Table 22. Farm size, length of the production cycle, housing and feeding technology, mating and hygiene management, and preventive veterinary care are the main factors that affect the non-feed costs.

The marginal economic value of a trait was expressed as the partial derivative of the profit function concerning that trait. The derivative was computed numerically as a difference quotient because the model is very complicated. The marginal economic value of the trait was approximated by the following difference quotient:

$$ev_l = \frac{Tprof_h - Tprof_l}{TV_l^h - TV_l^l} \quad (25)$$

Where: TV_l^h and TV_l^l were increased and decreased value of trait *l* by 0.5% of its value; $Tprof_h$ and $Tprof_l$ were the total profit belonging to TV_h and TV_l, respectively.

Table 22. Input parameters used for the calculation of non-feed costs

Parameters (units)	**Value**
Non-specific non-feed costs in the breeding unit (€ per farrowing place per year)	5.00
Price for each natural mating	4.85
Specific costs for health care for sows (€/sow and farrowing interval)	5.49
Specific costs for health care for piglets until weaning (€/piglet)	0.62
Specific costs for health care of replacement gilts from including in the herd to first farrowing (€/gilt)	1.10
Non-specific non-feed costs in the nursery unit (€/piglet place per year)	5.72
Specific costs for health care for piglets in the nursery unit (€/piglet)	0.49
Non-specific non-feed costs in the unit for the rearing of breeding gilts and boars (€/animal place per year)	5.00
Specific costs for health care of gilts and boars in the rearing unit (€/animal)	0.49
Non-specific non-feed costs in the finishing unit (€/finishing place per year)	7.69
Specific costs for health care of animals in finishing (€/animal)	0.00

Some traits were expressed only once during an animal's lifetime (direct traits), i.e., lifetime daily gain of finished animals, survival rates of piglets in the nursery and after nursery, age of gilts at first mating, and feed conversion of piglets in nursery and finishing. Some other traits were expressed repeatedly in females (maternal traits), i.e., number of live-born piglets, survival rates of piglets at birth and until weaning, and productive lifetime of sows. There were also traits that might have both direct and maternal components. For example, the total conception rate that was expressed only once in the animal's lifetime referred to the gilts, while the maternal component referred to the sow and was expressed repeatedly (at each parity).

In this research, the EWPIG package was applied only for the pure-bred pig production system. Therefore, the economic weights (*ew*) of the selected traits were equal to the marginal economic values (*ev*). Additionally, the economic weights were standardized (*ewst*) by multiplying the economic weights with the genetic standard deviation (GSD) of the corresponding traits in order to evaluate the selection importance of traits. Moreover, the relative standardized economic weights (*ewr*) of the selected traits were calculated in percentages to express the relative importance of different traits as follows:

$$ewr[i] = 100 \text{ x } \frac{ewst[i]}{sewst} \tag{26}$$

Where: *ewr[i]* is the relative economic weight of trait i^{th}; *ewst[i]* is the standardized economic weight of trait i^{th}; *sewst* is the sum of the standardized economic weights.

Recently, the values for genetic standard deviation are not available for all traits of the Ban pigs. Therefore, these values were taken from other breeds studied by Muth et al. (2014); Chimonyo and Dzama (2007); Su et al. (2007); Serenius et al. (2007); Roehe et al. (2010); Sevón-Aimonen and Uimari (2013); Godinho et al. (2018); Norris et al. (2006); Roessler et al. (2009); and Hermesch et al. (2015).

5.3. Results and discussion

The structure and growth of the sow herd are described in Table 23. Accordingly, within the period of the average farrowing interval, the proportions of sows per herd in the first three parities were 14%, 13%, and 13%, respectively. The bodyweight of the sows decreased during the pregnancy period, while it increased during the lactation period in different parities of lifetime productivity. In contrast to the result in this research, the output in previous studies of Thomas (2017) and Tantasuparuk et al. (2001) indicated that growth of sows increased during the pregnancy period and decreased in the lactation period. The reason for these differences is that during pregnancy, the sows were not able to cover the energy requirement for growing fetuses from the feed and they had to cover the requirement from their body reserves; therefore, they lost weight. Later, during lactation, because of the small size of piglets, they grew slowly, the sows recovered from the loss of body weight and also developed new body reserves for the next pregnancy; as a result, they had a positive daily gain.

Table 23. Structure and growth of the sow herd in different parities

Parity	Structure of sow herd[1]	Daily gain of the sow (g/day)	
		In pregnancy	In lactation
1	14%	-18.03	337.16
2	13%	-35.75	177.15
3	13%	-39.45	202.7
4	12%	-45.76	203.19
5	11%	-47.25	204.95
6	10%	-52.42	200.85
7	10%	-50.82	199.97
8	9%	-63.45	189.06
9	9%		

The most important categories indicating the structure of progeny are given in Table 24. Reproductive performance of sows, together with the main performance of progeny, is presented in Table 25. Average productive lifetime of sows with this age structure was 7.26 farrowings. At this high productive lifetime of sows, only 25% of breeding gilts were needed for herd replacement. In comparison to the finding of Krupa et al. (2017), where the average annual replacement rate of sows was over 45%, the ratio in this study is much lower. The survival rate of piglets at birth, until weaning and in nursery phase was 94%, 98%, and 93%, respectively. The low lifetime daily gain of piglets can be observed in this research with a value of 176.66 g day^{-1}. Compared to the study of Krupa et al. (2017), the lifetime daily gain of piglets in the present calculation was one fourth. The reason is that the farmers often use farm grains and by-products, which are deficient in both quality and quantity of protein to increase the body-weight of piglets during the nursery and fattening phase (Tra, 2003).

[1] The structure of sow herds indicates the proportion of the sow within the period of the average farrowing interval in each parity. This proportion was calculated based on the sow mortality rates, culling rates and conception rates in all parities

Table 24. Structure of progeny per reproductive cycle and per sow

Category of progeny	Average number of animals per reproductive cycle and per sow
Piglets alive at the end of the nursery phase	6.78
Females exported after the nursery phase	2.24
Castrated males exported after the nursery phase	2.39
Gilts finished	0.85
Barrow finished	0.92
Breeding gilts exported	0.20
Breeding gilts culled for not showing heat	0.02
Breeding gilts farrowed	0.14

Table 25. Performance of sows and progeny

Characteristic (unit)	Value
Average farrowing interval (d)	199.00
Average productive lifetime of sows (farrowings)	7.26
Average annual replacement rate of sows (%)	25.30
Number of piglets born per litter averaged over parities	7.93
Number of live-born piglets per litter averaged over parities	7.45
Number of piglets weaned per litter averaged over parities	7.29
Survival rate of piglets at birth (%)	93.88
Survival rate of piglets until weaning (%)	97.89
Survival rate of piglets in nursery (%)	93.00
Average daily gain of gilts and barrows in finishing (g/d)	304.77
Lifetime daily gain of gilts and barrows (g/d)	176.66

Table 26 illustrates the economic characteristics of the integrated Ban pig production system. Economic results were expressed as the present value of profit per sow and year and as the profitability ratio. Profit is calculated from the four units: breeding, nursery, and finishing units, and unit for the rearing of breeding animals. Accordingly, average costs per kg slaughtered animal were €2.25, and profitability rate was 24%, indicating that for every €1 investment, €0.24 was gained as profit from pig production.

Table 26. Economic characteristics for the integrated production system

Characteristic (units)	Value
Costs in breeding unit (€/sow per reproductive cycle)	110.69
Revenues in breeding unit (€/sow per reproductive cycle)	18.74
Costs in nursery unit (€/sow per reproductive cycle)	267.13
Revenues in nursery unit (€/sow per reproductive cycle)	347.75
Costs in rearing unit (€/sow per reproductive cycle)	5.38
Revenues in rearing unit (€/sow per reproductive cycle)	36.44
Costs in finishing unit (€/sow per reproductive cycle)	134.90
Revenues in finishing unit (€/sow per reproductive cycle)	237.36
Total costs (€/sow per year)	952.00
Total revenues (€/sow per year)	1176.52
Average cost per kg slaughtered animal (€)	2.25
Profit (€/sow per year)	224.52
Profitability (%)	24

The economic weights for the evaluated traits are generated in Table 27. The negative economic weights for the age of gilts at first farrowing and feed conversion in nursery and finishing indicated that a numerical increase in the mean value for these traits is economically detrimental. These findings are in agreement with the results of Krupa et al. (2017), where the economic weights of the age of gilts at first mating, feed conversion in nursery and finishing got negative values. The farrowing interval had a negative economic weight because an extension of this period caused a decrease in the number of litters per sow per year, lower number of piglets weaned and sold per sow per year, and higher sow costs.

The average lifetime daily gain of finished animals showed a positive value because increased feed requirement with an increasing gain was balanced by higher revenues from selling the piglets. Additionally, the survival rate of pigs in all of the periods had positive economic weights, suggesting that a numerical increase in the mean value for these traits increased revenues or lowered costs or both. These results are in conformity with the outputs of Quinton et al. (2006), Hermesch et al. (2014), and Krupa et al. (2017). The positive economic weight for the number of live-born piglets (46.53) denoted that an increase of one live-born piglet per parity resulted in a rise of €46.53 sow^{-1} $year^{-1}$.

Table 27. The marginal economic weight of selected traits estimated in the pig production system (in € per unit of the trait, per sow, and per year)

Traits (Unit)	**Marginal EW**
Average lifetime daily gain of finished animal (g/d)	5.99
Number of live-born piglets (piglet)	46.53
Survival rate of piglets at birth (%)	3.64
Survival rate of live-born piglets until weaning (%)	3.50
Age of gilts at first farrowing (d)	-0.07
Survival rate of piglets in the nursery (%)	7.08
Farrowing interval (d)	-0.59
Productive lifetime of sows (number of farrowings)	5.34
Feed conversion in the nursery (kg feed/kg weight gain)	-33.68
Feed conversion in finishing (kg feed/kg weight gain)	-28.17

The calculated marginal economic values are difficult to compare directly with the available literature. The difficulty comes from the different units used for the economic values of the traits, the divergent market conditions and production systems in various countries, even if the same model was applied (Houška et al., 2004; Houška et al., 2010; Krupa et al., 2017). For example, De Vries (1989), Houška et al. (2004) and Quinton et al. (2006) calculated economic weights of traits for the commercial farms that bought all female replacements and finished all of their progenies. On the other hand, Amer et al. (2014) calculated the economic weights for the commercial sow herd producing its own replacement gilts, and the weaned piglets are sold to special finishing farms, while the economic weights were estimated only within the finishing farms in Hermesch et al. (2014). Although a direct comparison is unavailable, the relation of the marginal economic values of lifetime daily gain of finished pigs, number of live-born piglets, and the survival rate can be compared. The ratio of the economic value for one extra live-born piglet and one extra gram of lifetime daily gain was 52:1 and 67:1 in the calculation of Krupa et al. (2017) and Houška et al. (2004), respectively, while in the present study it was 8:1. Various reasons resulted in this difference, e.g., the low selection pressure and low genetic gain for growth ability in the Vietnamese production system, but relatively high selection pressure and high genetic gain for litter size traits in maternal breeds in the Czech Republic and The Netherlands. Quinton et al. (2006) indicated that the economic value of litter size is highly dependent on the mean of this trait because the economic value for litter size decreased from $30.7 to $13.9 when the mean litter size increased from 8 to 20 pigs.

The relation of economic values for one extra live-born piglet and one percent survival rate (or mortality rate) up to weaning estimated in the present study (13:1) was quite different from the relation of 8:1 and 7:1 given by De Vries (1989) and Krupa et al. (2017), respectively. The economic values for survival rate were also calculated by Amer et al. (2014) and Hermesch et al. (2014). However, they expressed economic values of survival rate per survival animal that is different from the present calculation, where economic values of these traits were expressed per percent of survival rate.

Table 28 presents the standardized and relative economic weight of traits for the integrated indigenous pig production system. Accordingly, the standardized economic weight for average lifetime daily gain of finished animals was €105.43 GSD^{-1}. This result is much higher than that of the calculation on pigs in the Czech Republic (Houška et al., 2004) where the standardized economic weight for average lifetime daily gain of finished animals was €3.02 GSD^{-1} (CZK90.6 GSD^{-1}). Compared to the study of Hermesch et al. (2014), the standardized economic weight for average lifetime daily gain of finished animals in this research was nearly seven-fold.

Table 28. Standardized economic weights and relative economic weight of selected traits estimated in pig production system

Traits	**Standardized EW (€ GSD^{-1})**	**Relative EW (%)**
Average lifetime daily gain of finished animal	105.433	59
Number of live-born piglets	29.780	17
Survival rate of piglets at birth	18.954	11
Survival rate of live-born piglets at weaning	3.815	2
Age of gilts at first farrowing	-1.244	1
Survival rate of piglets in the nursery	3.893	2
Farrowing interval	-3.869	2
Productive lifetime of sows	3.407	2
Feed conversion in nursery	-3.705	2
Feed conversion in finishing	-3.380	2

In this study, the standardized economic weight for an average number of live-born piglets was €29.78 GSD^{-1}, which was higher than €10.66 GSD^{-1} (CZK319.9 GSD^{-1})

reported by Houška et al. (2004). However, this was lower in comparison with the results from the calculation by Houška et al. (2010) in Hungary as well as Amer et al. (2014) in Australia, where the standardized economic weight for the average number of live-born piglets was €33.07 GSD^{-1} and €48.95 GDS^{-1} ($AU75.38 GSD^{-1}), respectively. Additionally, the standardized economic weight for the survival rate of piglets at birth (€9.93 GSD^{-1}) was higher than €5.56 GSD^{-1} ($AU 8.57 GSD^{-1}) reported by Amer et al. (2014).

Quinton et al. (2006) reported that the trait of survival rate of piglets at weaning for the finished and sold feeder pigs farms with an average of 8 pigs born per litter had a value of €2.84 GSD^{-1} ($3.3 GSD^{-1}) and €1.47 GSD^{-1} ($1.7 GSD^{-1}), respectively. However, in the present estimation, the result was higher (€3.82 GSD^{-1}). Compared to the study of Amer et al. (2014), the standardized economic weight for the productive lifetime of the sow in this study was much less than that in the Australian pig production system.

The most important trait was average lifetime daily gain of finished animals, which contributed 59% to the sum of the absolute values of the standardized economic weights of overall traits. This differs from a previous study of Amer et al. (2014) on typical Australian pig production where the post-weaning survival was the most important trait. The second most important trait, the number of live-born piglets accounted for 17% in the breeding goal. The relative importance of the survival rate of piglets at birth was 11%. Age of gilts at first farrowing, survival rate of live-born piglets at weaning, the survival rate of piglets in the nursery, farrowing interval, productive lifetime of sows, feed conversion in nursery, and feed conversion in finishing reached similar values of 1% to 2%.

5.4. Conclusion

The results of this research revealed that a low rate of breeding gilts was needed for herd replacement, and piglets had a low lifetime daily gain. Negative economic weights for the age of gilts at first farrowing, farrowing interval, and feed conversion in nursery and finishing can be observed, while the other traits had positive economic values. Average lifetime daily gain of finished animals was the most important trait, whereas the trait age of gilts at first farrowing was the least important regarding the relative economic weight of selected traits estimated in the pig production system. The economic weights of traits approximated in the present study can be used as the basis to develop the breeding goals and the construction of selection indices for the indigenous pig in northwest Vietnam.

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CHAPTER 6

GENERAL DISCUSSION

This chapter provides a discussion on the major findings of the four papers in order to give a more in-depth explanation of the research and gives some recommendations to improve the traits included in the indigenous pig breeding goal. The chapter is divided into five sections: the survey activities, characterization of indigenous pig production systems, technical efficiency of Ban pig production, the willingness to pay of farmers for the vaccination programme, and how to improve the traits included in the breeding goal.

6.1. The survey

In the present study, semi-structured interviews were conducted with Ban pig producers to collect the inputs and outputs of production. Semi-structured interviews incorporate both the structured and unstructured interview approaches; they can gather the advantages of both worlds. A significant advantage of this approach is that it offers the opportunity for previously unknown information to come out (O'Keeffe et al., 2016). Traditionally, semi-structured interviews consist of open-ended questions. However, in this study, both open-ended and direct questions are contained in the questionnaire in order to collect the qualitative and quantitative data because the quantitative data is best obtained by using direct questions.

Single-person interviews were conducted to obtain the required data to avoid the possibility of one or a few smallholders influencing the answers of others. In some cases, the responses of the interviewee were affected by the presence of other producers during the interview. Most of the interviews were conducted by the researcher himself. This enabled higher flexibility, allowing for putting further questions and scrutinizing some issues more closely. A disadvantage of this approach, however, was that data collection was very time-consuming.

To conduct the survey, the researcher faced the problem of finding a database of pig producers in the target areas. Even though the local governments and governmental institutions were contacted, their databases were a few years out of date with no categorization of farms to support determining the respondents of the survey, i.e., farms still operating Ban pig production, and farms keeping Ban pig boars. Therefore, snowball sampling was applied to select Ban pig producers in the villages.

6.2. Characterization of Ban pig production systems

In northwest Vietnam, the majority of householders are involved in Ban pig production as a source of additional income, resulting in small herd sizes. The Ban pig producers in the study area were practising small-scale production, which used home-made feeds and relied on household-based labour. They were considered less costly and affordable to the farmers.

Most of the Ban pig producers in this area were employing natural mating by using pure-bred boars that were imported from private boar owners within their village, or they were using their own male progeny. This was in agreement with the findings of Nantima et al. (2015) and Ikwap et al. (2014). However, the habit of sharing boars or using their own male progeny for breeding purposes leads to the higher inbreeding coefficient in the Ban population (Lemke et al., 2006) and weakening of the genetic pools (Munzhelele, 2015). Additionally, this may compromise bio-security measures to control epizootics and increase the risk of spreading diseases and parasites (Nantima et al., 2015; Ikwap et al., 2014).

The workforce in pig farming was mainly made up of women (housewives). These findings reinforce what was reported in the previous studies of Karimuribo et al. (2014) and Ikwap et al. (2014). However, this contrasts with the results of Mulugeta (2016) and Fualefac et al. (2014), where the predominance of men in pig production was observed. It is noteworthy, however, that although women played an essential role in pig management, they were less involved in decision-making, because these activities were largely the responsibility of the household heads who were mainly the husbands.

In terms of housing, the pigs from the majority of the farms were permanently penned, and pigsties were constructed as separate pens. Pigpens with individual pens allowed sows and their progenies after weaning to be kept and fed separately (Lemke et al., 2006). However, a low standard for pig rearing was observed in most of the pens because the pigsties were built by farmers themselves based on their experiences and land available. It is expected that a good pigsty will protect pigs from predators and diseases (Kyriazakis, 2006), or stress, which causes slow growth and unnecessary mortalities. Most of the farmers constructed their pigsties near the house to facilitate pig management.

Ban pig producers in the northwest of Vietnam fed pigs on a mixture using cooked farm-produced feed resources (maize, cassava), agricultural by-products (rice bran) and locally available green plant materials. In times of shortage, maize, cassava, and rice bran were bought from the markets. This traditional feeding practice may reduce the feeding costs;

however, it may have led to nutritionally imbalanced diets and underfeeding due to the limited availability and nutritional limitations of the feedstuffs used (Nath et al., 2013).

Pigs in a large number of farms face disease incidents. Sows and piglets from 68% and 79%, respectively of farms had one to two diseases. The main diseases in the study area included swine fever, respiratory problems, and diarrhoea of piglets; respiratory disease and posterior paralysis for sows. Although a veterinary service was available at most of the villages, farmers tended to treat pig diseases themselves, seeking veterinarians' support only in severe cases. Additionally, the vaccination coverage was low in this study area.

In line with the previous reports of Paixão et al. (2018) and Nath et al. (2013), surgical castration of male piglets had to be practised in most of the Ban pig production systems. The piglets were castrated after weaning, and these castration activities were performed by farmers themselves. This is in contrast with the recommendation of EU regulations that surgical castration on animals older than seven days should only be done under anaesthesia and prolonged analgesia by a veterinarian (Council, 2009). Njoku et al. (2013) indicated that the growth of the castrated pigs was more than that of non-castrated ones. However, Njoku et al. (2013) and Paixão et al. (2018) also revealed that the feed conversion ratio and cost/kg weight of non-castrated boars was lower than that of castrated boars. Although there have been proposals to stop castration relating to animal welfare, male pigs are still castrated by producers to reduce boar taint (Puppe et al., 2005), aggression and sexual behaviours such as mounting (Zamaratskaia et al., 2008).

The reproductive performance of Ban sows in northwest Vietnam was relatively low. These results are in conformity with the findings of Abah et al. (2019) and Nath et al. (2013). In contrast, Perumal (2014) demonstrated comparatively longer farrowing intervals in the Naga local pig. The higher mean farrowing interval might be related to the extended suckling period of pig production and non-productive days, and the poor nutrition that animals experienced. Kirkden et al. (2013) stated that low feed intake during lactation results in increased weight loss and poor body condition, which has a negative impact on sow post-weaning reproductive performance. A longer farrowing interval of sows could reduce the number of parities per sow per year.

On average, the age at first farrowing of sows in the study area (432 days) was much longer in comparison to the results conducted by Nath et al. (2013) and Abah et al.

(2019). Lemus et al. (2003) reported a comparatively higher age at first farrowing for Mexican indigenous pigs. The different age at first farrowing came from the divergent rearing system and management conditions. Love et al. (1993) stated that the age at first farrowing has a decisive influence on the number of piglets in the first litter. Likewise, Babot et al. (2003) reported that a higher age at first farrowing significantly influences the number of live-born piglets.

6.3. Economic efficiency of pig production systems

Results in the present study reinforced the findings of Kyriazakis (2006) that feed is an irrefutable pig farm input of the utmost importance. It was the foremost determinant of profitability in small-scale pig production systems. Cooked mixtures were used for different categories of pigs, and their composition depends on the age of pigs and the purpose of their production. All feed mixtures included the most important feed component like maize, cassava, and rice bran. The fact is that the utilization of commercially compounded rations will yield better quality products as well as improve reproduction and overall production. However, it was not financially feasible in the case of smallholder pig farmers. Therefore, farm-grown feed and alternative feed sources will continue to be used by producers for the foreseeable future.

Labour is the second most valuable input in pig production systems. Typically, there are three sources of workforce involved in pig production, including employees, hired workers, and family members. However, in northwest Vietnam, only family members were used as the source of labour in most small-scale pig farms. Although family members are involved full time in farm activities, it is easy to determine the involvement of labour per hour spent on the production activities on pig farms. In the production function, the use of labour significantly increases revenue. This might be plausible because farmers can easily utilize family labour in pig production activities. Due to the labour-intensive nature of pig production, producers may use more labour for food preparing and pen cleaning purposes.

In regards to the depreciation costs (building, machinery, equipment), they are differently considered in Ban pig production systems. Data collected on these inputs depend on how farmers provide the evidence because most farmers do not use accounting and book-keeping evidence. The empirical results indicated that depreciation costs significantly increase the output of pig production. This finding conforms to prior studies by Aminu and Akhigbe-Ahonkhai (2017) for pig production in Ekiti State, Nigeria. While the results of Etim et al. (2014) revealed that capital is not related to the revenue of pig production.

Measurements of technical efficiency will help producers to decide about different activities in production to increase the profitability of their production. The findings of this research show the average values of technical efficiency from all aspects. The results indicate that there are no fully technically efficient farms in the study areas. The heterogeneity in management and production practices of pig producers may explain the distribution of technical efficiency. The failure to adopt appropriate management practices results in the failure of most of the farmers to maximize output. These farms could increase their efficiency by changing the management practices concerning the inputs and outputs of production.

The empirical results illustrated that technical efficiency is influenced by several factors that are not related to the social-economic conditions. That is in contrast with the findings of the previous studies (Aminu and Akhigbe-Ahonkhai, 2017; Adetunji and Adeyemo, 2012), where social-economic conditions were significantly associated with technical efficiency. Nursery interval, number of live-born piglets and depreciation are the main elements explaining the variation in technical efficiency. While the role of depreciation is presented in the above discussion, the role of nursery interval and number of live-born piglets has not been present in the previous studies.

6.4. Willingness to pay of farmers for the vaccination programme

The results of the current research overwhelmingly indicate that Ban pig producers have a strong preference for the vaccination programme. This is supported by the high percentage of "yes" responses to the willingness to pay (82%). In this research, previous vaccination was one of the most influential factors of WTP. This can be explained by the fact that farmers who had tried vaccines appreciated them more than producers without similar experience. These findings reinforce the results of Campbell et al. (2019). The high impact of previous vaccination on WTP indicates that smallholders are able to experience first-hand a notable reduction in disease occurrences.

The education level of the household head does not influence the maximum amount of money the producers are willing to pay for every sow per year and each piglet per litter, but the level of education had significant impacts on WTP for the vaccination programme. Education of respondents had a positive sign on its coefficient because farmers with higher education may very well understand the need to sustain the vaccination programme. Therefore, such farmers are willing to pay to improve the disease resistance of animals so that they can maximize their profits. A study conducted in the Narok South District of Kenya also revealed that the level of education influences the accountability of WTP for contagious bovine pleuropneumonia vaccination (Kairu-Wanyoike et al., 2014). On the other hand, Kumar et al. (2011) showed that livestock producers' education did not affect their WTP for veterinary services. Farmers' knowledge, skill, and adequate development are common influential factors affecting sustainable farming (Roy and Chan, 2018). Onuche et al. (2015) stated that education makes the adoption of innovation easier due to the exposure and the ability to decipher the information it confers.

There were significant differences between male and female household heads in the probability of WTP for the vaccination programme, and the maximize WTP of Ban pig producers for vaccinating each piglet per litter and each sow per year. The sign of the coefficient of the sex variable is positive because this may be linked to the household decision-making process in the context of northwest Vietnam. The male is usually responsible for all major household decisions, including vaccination payments. Therefore, Doss and Morris (2000) reported that it is important to understand the issues that affect the household's female heads before designing policies that aim to intervene in their situation.

Chebil et al. (2009) revealed that the age of the farmer played an essential role in the utilization, acceptance, and willingness to pay for the service. In this research, although the age of the household heads did not significantly influence the WTP maximization for the vaccination programme, a positive correlation between the probability of WTP and the age variable has been identified. Mwaura et al. (2010) disclosed that the reason for increased likelihood of WTP for extension services among young farmers is that they have more opportunities to access information in alternative linkages, and are risk-takers. Moreover, they are likely to be more educated, more likely to change their perception, and have disposable income. However, young people are less experienced in animal husbandry than older farmers. Therefore, experienced farmers may be willing to pay more to the vaccination programme if they find it helpful.

6.5. Improving traits included in the breeding goal

This research has identified the number of live-born piglets as an important breeding objective trait in indigenous pig breeding programmes. The marginal economic weight of the number of live-born piglets is very high (€46.53) because an increase in litter size by one piglet at farrowing caused an increase in the number of weaned piglets per sow per year. This leads to a corresponding change in profit per sow per year. Marginal economic weight values of the traits of age of gilts at first farrowing, farrowing interval, and feed conversion in nursery and finishing had negative signs because increasing the values of these traits denoted deterioration and caused increased costs.

This study has also confirmed the importance of survival traits (survival rate of piglets at birth, until weaning, in nursery, and young animals after nursery). A change in the values of these traits caused an increase in the number of exported piglets per sow per year. Additionally, a rise in the mean value of survival rate traits would result in a decrease in the loss of the cumulated costs of the animals at death. The results also recognized the significance of average lifetime daily gain of the finished animal trait in the pig production systems. An increase in average daily gain engendered a reduction in the number of days to slaughter age. As a result, the profit per sow per year increased €5.99 by saving investments in feed, labour, and capital.

In reality, the traits included in breeding goals (objectives) depend on the breed and the livestock development strategy of countries. Morris et al. (1978) did not include reproduction traits and survival traits in breeding objectives for New Zealand pig improvement. Visser (2004) indicated that the traits included in breeding objectives for pigs in South Africa are reproductive traits, production traits, carcass traits, and meat quality traits. However, longevity and survival traits are not included in the breeding objectives. On the other hand, Mbuthia et al. (2015) allocated breeding objectives for pigs in Kenya without the number of live-born piglets, average daily gain, or longevity traits. The breeding objectives for Large White pigs in South Africa did not integrate longevity and farrowing interval, as well as survival traits (Dube et al., 2013).

As this was the first study in this area for the Ban pig, the breeding goal was set to improve the farm profit for Ban pig production systems. Accordingly, traits identified by the bio-economic model for pigs (EWPIG) to have the main effect on profit, were included in the breeding goals. As stated in chapter 5, the traits that should be included in the breeding goal are growth rate (average lifetime daily gain of finished pigs), reproduction traits (number of live-born piglets, farrowing interval), survival rate (at birth, in suckling, and nursery phase), and feed conversion ratio (in nursery and finishing phase). Synthetic solutions should be taken into account to improve these traits, including breeding strategies, housing, feeding, and health-care programmes.

6.5.1. Breeding strategies

This research was conducted for the Ban pig breed in small-scale production systems with poor nutritional conditions. In general, alternative tools can be considered for genetic improvement in livestock breeds, e.g., straight breeding, crossbreeding, or a combination of both (FAO, 2010). Olivier et al. (2002) revealed that straight breeding (selection within breed) is an appropriate strategy for breed improvement in low-input production systems of developing countries because local breeds have high productive adaptability. Amer et al. (2015) stated that straight breeding generally involves both a programme based on a central nucleus and a community-based breeding programme (CBBP). However, the programme based on a central nucleus depends on organizational, technical, and financial support (Mueller et al., 2015). Karnuah et al. (2018) stated that the CBBP is suitable for smallholder conditions because it is designed for extensive/low input, small-scale, and community-owned operations. Additionally, smallholder farmers individually or in cooperation with technical stakeholders are integrated in planning, designing, and implementing the CBBP's activities (Karnuah et al., 2018). Furthermore, the farmers can easily assimilate and understand the processes and technical aspects of the CBBP regarding their level of formal education (Ahuya et al., 2001). Therefore, a community-based breeding programme is an appropriate programme to improve the indigenous pig breeds in northwest Vietnam.

A community-based breeding programme for pigs was set up in Son La province by Roessler (2009). However, within breed selection for local breeds was not included in the project because attempts to return to pure-breeding in local pigs did not seem promising. That interpretation is not entirely correct because the pig producers still keep the local breed not only for economic purposes but also for cultural aspects as well. Therefore, straight breeding with a community-based indigenous pigs breeding programme in northwest Vietnam should be taken into account. This strategy could be based on the guidelines for setting up community-based sheep breeding programmes in Ethiopia (Haile et al., 2011).

In the village, the "best" sows of some farms are selected as the mother of the next generation of gilts, and they are identified as nucleus farms. The nucleus systems not only have to generate genetic progress but also disseminate the appropriate gilts in quality and quantity to base population farmers. Additionally, for practical reasons, it is difficult for the individual farmer to raise male candidates from birth until final selection; therefore, purebred males with the best performances are determined by screening among village herds. The young candidate males are gathered and placed in one typical station or farm for performance testing. In the nucleus farms, the best females will be mated with the best males to produce the best next generation of young animals. Gizaw et al. (2009) suggested that the exchange of boars between cooperating villages should be practised to avoid the high rate of inbreeding. The farmers will identify the best gilts and boars in the whole population as replacement breeding stock according to their own criteria, and they will be registered in a herd book. Animal identification is performed based on ear tags, which includes farm and pig number. In this breeding strategy, "open" nucleus farms can be created because in some cases, outstanding females born on the base farms can replace the worst females in the nucleus if nucleus born replacements are insufficient in quality.

Each nucleus farmer undertakes performance and pedigree recording. Two recording formats are designed for the farmers to document information on sows and their progeny. All of the traits, included in the breeding goals, will be combined on the recording form. The sow format contains information such as farrowing date, age at first farrowing, parity, litter size, number of live-born piglets, and number of piglets weaned. The progeny data format has information about pig identity and performance such as weight of piglets at weaning, the weekly weight of piglets after weaning, the number of piglets that died in the nursery phase, daily feed intake. Appropriate training in data entry and processing should be organized for the producers, and they should be supported by the local veterinaries in implementation.

Young boars should be selected based on the recorded data (own and maternal performance) for the set of agreed selection traits. The selection process should be implemented at different stages. Firstly, farmers should cull animals with undesirable phenotypic characteristics (body and leg conditions), and clearly observable and genetic defects (testicle deformation, lack of sexual behaviour). The rest of the young males are then further judged based on morphometric traits and body weight. As the breeding programme is fully functional, the best young boars should be identified by their breeding value computed from recorded data and based on their pedigree.

6.5.2. Housing

As mention in the second chapter, 68% of farms kept pigs in a permanent pigsty with a brick wall, cement floor, and asbestos -cement or metal sheet roof. In 15% of the farms, pigs were kept in semi-permanent pigpens with wooden or brick walls, cement floor, and asbestos-cement roof. The remaining pig farms (17%) kept pigs in temporary sheds with post-and-rail fences or wooden walls, sand or wooden floor, and asbestos-cement roof. The building materials were varied, and the usage was dependent on the availability and level of production. However, most of the pigsties observed during data collection in the study area did not meet the required standard for pig rearing.

Housing in small-scale indigenous pig production systems in northwest Vietnam is characterized by a lack of wind protection and bedding materials, poor sanitation, and wet floors (Figure 6.1). These characterizations lead to physical damage through fighting, predisposition to rapid disease transmission, worm infestation, and weight loss of pigs (Lekule and Kyvsgaard, 2003). Renaudeau (2009) found a significantly higher average daily gain of pigs kept in clean housing in comparison to those housed in dirty environments. Additionally, Douglas et al. (2015) indicated that average daily gain was influenced by bedding, floor space, and floor type, while feed conversion ratio was influenced by building type and floor space. The relationship between the survival rates and farrowing systems and conditions was reported in the research of Aumaitre and Le Dividich (1984). Accordingly, the use of bedding material has a positive influence on the survival rate in comparison to an insulated concrete floor.


Figure 6. Housing in small-scale indigenous pig production systems

Therefore, housing facilities should be constructed to protect the animals from rain, direct sunlight, and wind as well as temperature extremes. Pens should be constructed so that they are easy to clean and collect manure and run-off. Flooring should be elevated above ground level and have a gentle slope. Housing for piglets should provide a secure and warm space, and keep the sow at a distance to prevent crushing.

Additionally, bedding materials should be taken into account to enrich the pig environment because they can increase the ambient temperature and raise the baseline body temperature of the pigs (Douglas et al., 2015), especially in cold weather. In addition, producers should maintain sanitary conditions to improve the growth performance of pigs by increasing the frequency of floor cleaning and removing manure.

6.5.3. Feeding management

Pigs need several essential nutrients to meet their requirements for maintenance, growth, reproduction, lactation, and other functions. Dietze (2011) revealed that an appropriately balanced ration of protein, energy, minerals, and vitamins would keep a pig in good health, develop its weight, and maintain its reproductive capacities. As mentioned in the second chapter, pigs in small-scale production systems in northwest Vietnam are fed mainly with maize, cassava, and by-products like rice-bran, which come mostly from farm-produced feed resources. The low input of these feeding regimes may lead to unbalanced diets and cause low performance of sows and of fattening pigs (Pham et al., 2009). Lekule and Kyvsgaard (2003) reported that an unbalanced diet of, for example, maize, cassava or rice-bran would only provide approximately 30% of the pig's requirements of lysine and methionine, which are typically considered as the most limiting amino acids in pig feeds. Therefore, the average feed conversion rate in Vietnam is high, with 4.4 kg/ 1 kg weight gained (Dzung, 2014). Pham et al. (2009) indicated four key problems in feed supply, including the inadequate supply of quantities of protein and/or amino-acids, no knowledge of the fatty acid composition of feeds, little understanding of the concentrate level or supplements required in a diet, and appropriate level of feed energy for pigs at each age.

A strategy for feeding management is vital for indigenous pig production systems in northwest Vietnam. Accordingly, the pig producers should be supported with training on feed requirements in pig farming. Additionally, improving pigs' dietary quality should be promoted by providing more nutrient-rich feeds for pigs, combined with adding fish and shrimp-by-products to the feeding formulation in order to supplement the amino-acids as well as other vitamins which would improve pig reproduction and pig performance. Koketsu (1997) demonstrated that a high voluntary feed intake during lactation was associated with reduced weaning to service interval, increased litter size, and litter weight at weaning. Lekule and Kyvsgaard (2003) found that the daily weight gain of pigs increased significantly by adding fishmeal to the diet, but the feed cost per kg product was higher in comparison to the food without fishmeal. Therefore, feeding for smallholder pig production should be rationed feeding with a balanced ration according to the age and stage of animals. Pham et al. (2009) and Dietze (2011) proposed that paying more attention to the nutritive value of locally grown feedstuffs and the value of added protein sources provides an opportunity to sustainably improve the production of smallholder pig farms.

6.5.4. Health care management

Dietze (2011) reported that animal health is an essential factor for sustained pig production because unhealthy animals will cause a decrease in terms of production performance as well as loss of profitability. Cornelison et al. (2018) supported this opinion indicating that an increase in health challenges resulted in a reduction in average daily gain and average daily feed intake, an increase in mortality, and financial losses. Additionally, Lewis et al. (2009) analyzed the effect of PRRS on reproductive traits and concluded that under conditions of PRRS outbreak, the total number of live-born piglets and total weaned declined. Additionally, Alvarez et al. (2015) showed that pigs with porcine epidemic diarrhoea virus (PEDv) infection have lower ADG and higher FCR and mortality rate in comparison to pigs without PEDv infection. The economic losses from infectious pig diseases were reported in previous studies by Holtkamp et al. (2013), Nampanya et al. (2015), Muroga et al. (2012), McLeod et al. (2013), and Pham et al. (2017). Therefore, improving health-care management by reducing infectious diseases of pigs is an essential task.

One of the essential solutions to reduce infectious pig diseases is increasing vaccine adoption among pig producers. A vaccination programme should be designed based on results from the fourth chapter to increase access to vaccines and demand from pig producers. Accordingly, veterinarians have to be encouraged to participate in this programme. Firstly, they have to develop a contract between the vaccination service supplier and pig producer. The content of the deal has to express clearly and in detail the responsibilities and rights of stakeholders as well as the price list for each vaccination package. Additionally, confirmation of insurance for the vaccinated pigs should be mentioned in the contract. Secondly, the vaccination strategies will be designed based on the season, the infection pattern, the production system and management practices, the type of herd, and the preferences of the pig producers. The vaccination plan should be created in detail for sows, piglets in suckling, nursery, and finishing phase.

Furthermore, the implementation of a biosecurity programme at the farm level should be taken into account in order to reduce the risk of the introduction and spread of disease agents. A guideline for applying biosecurity in pig production systems was developed by Madec et al. (2010). Accordingly, three main elements of biosecurity are clarified, including segregation, cleaning, and disinfection. Segregation is conducted to limit the potential opportunities for infected animals and contaminated materials to enter an uninfected site while cleaning is implemented to remove most of the pathogens that contaminate the materials. When disinfection has been done, it will inactivate any pathogens that are present in materials that have already been thoroughly cleaned.

6.6. General conclusions and recommendations

This thesis provides essential information on the characterization of indigenous pig production systems in northwest Vietnam. The wife of the household head is predominantly responsible for pig management. Therefore, they should be integrated into training courses on pig production which are organized by extension organizations. A prolonged suckling and nursery period, unsatisfactory housing for pig raising, and unbalanced diets affect the production efficiency. For these reasons, pig producers should be trained on the fundamental aspects of pig farming because good livestock management is the main catalyst of good production.

This research also identifies crucial factors that have an effect on the pig producers' WTP and maximize WTP for the vaccination programme. The vaccination status for sows and piglets was found to positively and significantly influence the pig producers' WTP towards disease control. Therefore, the government, via local extension organizations, should support and encourage vaccination through massive awareness and vaccination campaigns, along with encouraging the producers to contribute towards disease control. The results illustrated that 82% of farmers are willing to pay for the vaccination programme. This vital evidence is the basis for establishing a vaccination programme for this region. The price of the vaccination programme should be based on the maximized WTP of producers for every piglet per litter and every sow per year. The vaccinators should be trained in the proper procedures for care and administration of the vaccine, and for recording which animals and herds have been vaccinated to facilitate the setting up of a vaccination programme.

This study presents vital information on the traits that should be incorporated into breeding goals for indigenous pig production systems in northwest Vietnam. The economic weights, as well as relative importance of traits, were estimated by the bio-economic model for pigs (EWPIG). The results revealed that genetic improvement could be attained in traits of economic importance, which will improve the production efficiency of producers in the long run. The present study did not include carcass traits and meat quality traits in the breeding goals; therefore, further research on the estimation of economic weights for carcass traits and meat quality traits and their influence on genetic improvement is needed. Some solutions were proposed to improve the traits included in the breeding goals, for which setting up a community-based breeding programme with straight breeding strategies is the critical component. The success of this breeding strategy requires special attention and support from local government and stakeholders (i.e. organizational, financial, and technical).

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Ich erkläre: Ich habe die vorgelegte Dissertation selbständig und ohne unerlaubte fremde Hilfe und nur mit den Hilfen angefertigt, die ich in der Dissertation angegeben habe. Alle Textstellen, die wörtlich oder sinngemäß aus veröffentlichten Schriften entnommen sind, und alle Angaben, die auf mündlichen Auskünften beruhen, sind als solche kenntlich gemacht. Bei den von mir durchgeführten und in der Dissertation erwähnten Untersuchungen habe ich die Grundsätze guter wissenschaftlicher Praxis, wie sie in der "Satzung der Justus-Liebig-Universität Gießen zur Sicherung guter wissenschaftlicher Praxis" niedergelegt sind, eingehalten.

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