Transboundary and Emerging Diseases

ORIGINAL ARTICLE

Financial Impacts of Priority Swine Diseases to Pig Farmers in Red River and Mekong River Delta, Vietnam

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Summary

A study was conducted between May 2013 and August 2014 in three provinces of Vietnam to investigate financial impacts of swine diseases in pig holdings in 2010–2013. The aim of the study was to quantify the costs of swine diseases at producer level in order to understand swine disease priority for monitoring at local level. Financial impacts of porcine reproductive and respiratory syndrome (PRRS), foot and mouth disease (FMD), and epidemic diarrhoea were assessed for 162 pig holders in two Red River Delta provinces and in one Mekong River Delta province, using data on pig production and swine disease outbreaks at farms. Losses incurred by swine diseases were estimated, including direct losses due to mortality (100% market value of pig before disease onset) and morbidity (abortion, delay of finishing stage), and indirect losses due to control costs (treatment, improving biosecurity and emergency vaccination) and revenue foregone (lower price in case of emergency selling). Financial impacts of swine diseases were expressed as percentage of gross margin of pig holding. The gross margin varied between pig farming groups ($P < 0.0001$) in the following order: large farm (USD 18 846), fattening farm (USD 7014) and smallholder (USD 2350). The losses per pig holding due to PRRS were the highest: 41% of gross margin for large farm, 38% for fattening farm and 63% for smallholder. Cost incurred by FMD was lower with 19%, 25% and 32% of gross margin of pig holding in large farm, fattening farm and smallholder, respectively. The cost of epidemic diarrhoea was the lowest compared to losses due to PRRS and FMD and accounted for around 10% of gross margin of pig holding in the three pig farming groups. These estimates provided critical elements on swine disease priorities to better inform surveillance and control at both national and local level.

Introduction

Pork is one of the most important agricultural products in Vietnam, with around 3 million tonnes of pig meat produced each year accounting for 74% of total meat yield produced in Vietnam (GSO, 2012a). Pig population had increased considerably since 1992 to 2005 with an average annual increase of 6% (GSO, 2012b), which is probably in accordance with the improvement in pig husbandry. However, since 2006 this production trend has been flat (GSO, 2012b). This is linked to the increasing threat of a large range of pig diseases and fluctuation of pig price (Nga et al., 2014). Between 2006 and 2012, nearly 5650 foot-and-mouth disease (FMD) outbreaks were reported in 62

provinces of Vietnam, from which 1767 FMD outbreaks occurred in pig holdings (Nguyen et al., 2013). Since the first official report in 2007, highly pathogenic porcine reproductive and respiratory syndrome (PRRS) virus has affected pigs in almost all provinces in Vietnam and caused 3614 outbreaks with the culling of 60 000 pigs between 2007 and 2012 (Do et al., 2013). The occurrence and reoccurrence of PRRS outbreaks at pig holdings could be linked to traditional pig-raising practices in Vietnam such as using uncooked food wastes for feeding pigs, regular import of pigs without quarantine, using irrigated water and lacking a weekly farm disinfection (Truong and Gummow, 2014).

Infectious diseases of swine such as PRRS, FMD and classical swine fever (CSF) have been shown to cause significant impacts for both pig producers' livelihood and national economy worldwide. In the United States, the total productivity losses at national breeding and growing herds due to PRRS were estimated at USD 664 million annually (Holtkamp et al., 2013). At farm level, the economic impact of PRRS during an outbreak period (18 weeks) in the Netherlands varied between farms, ranging from USD 85 to USD 548 per sow, with higher losses observed in nucleus herds (Nieuwenhuis et al., 2012). Estimation of losses due to FMD at cattle smallholders in Lao PDR ranged from USD 381–1124 per household, accounting up to 60% losses of annual household income (Nampanya et al., 2013). The average cost of FMD per household in Southern Cambodia was estimated to represent 7.4% of the annual household income (USD 67) (Shankar et al., 2012). Results of a case study in Northern Laos indicated that estimation of financial losses of non-vaccinated animal contracting FMD ranged from USD 52–71 while it was around USD 2 per animal in fully vaccinated village (Rast et al., 2010). Economic impacts of animal diseases are not only due to production losses but also due to the disease control costs and losses in related sectors. For example, FMD outbreaks in the Republic of Korea in 2010–2011 resulted in an economic loss of USD 2.78 billion, which was linked to stamping out of infected herds (Yonhap news agency, 2011). A total of 292 FMD outbreaks were reported in Japan in 2010, with the destruction of 290 000 animals, resulting in a cost of USD 550 million (Muroga et al., 2012). FMD epidemic in Japan in 2010 had spillover impacts on related industries such as meat processing and animal feed production, and losses were estimated to be USD 105 million and USD 562 million, respectively (Japantimes, 2010).

In Vietnam, few economic impact assessments of infectious swine diseases were implemented at national and local levels. A study performed in 2007 estimated the losses of FMD for small pig holders (representing 18% of household total incomes) but did not assess the impact in different pig farming systems (breeding farms, fattening farms or mixed farms) (Dinh and Nguyen, 2007). Zhang et al. (2012) estimated the economic impact of PRRS in Vietnam considering the increase in mortality; however, no information on the cost of disease mitigation was mentioned. Recently, the costs of PRRS (2007–2010), FMD (2006–2010) and CSF (2000–2010) in pig at the national level were estimated to be USD 72 million, 64 million and 79 million, respectively (McLeod et al., 2013). Almost all costs considered for PRRS (97%) and FMD (100%) were linked to control activities, whereas 87% of the CSF costs were linked to the losses of productive assets and production losses and only 13% linked to disease prevention and outbreak control costs (McLeod et al., 2013). However, these estimations relied on national surveillance data, the quality of which as well as the surveillance system's sensitivity remains uncertain (the costs might be under- or overestimated depending on reporting level and governmental incentive regimes).

The objective of our study was to estimate the costs of swine diseases at the farm level by assessing swine disease impact on pig holdings' gross margins, in order to understand the perception of swine disease priority at the local level. This study was carried out within a broader framework of economic evaluation of swine disease surveillance system in Vietnam. Results of this study will provide relevant information on local swine disease situation to inform national disease management strategies.

Material and Methods

Study area

The study was carried out in two provinces in the Red River Delta (RRD), Northern Vietnam, and one province in the Mekong River Delta (MRD), Southern Vietnam, to account for the variability in terms of pig farming, pig population, pig density and ecological condition which could influence swine disease circulation patterns and impacts.

Hung Yen (HY) and Hai Duong (HD) provinces in RRD and Long An (LA) province in MRD were selected because of their high pig population and diversity of farming systems. PRRS outbreak in Vietnam was first reported in HD province during the 2007 and 2010 epidemics and then spread to other Northern provinces including Hung Yen (Nguyen, 2011). FMD occurred in HY and HD sporadically, but it has not been reported officially in HD and HY since 2011 (DAH, 2013). PRRS and FMD have been reported in LA every year since 2010.

Selection of farmers and data collection

The selection of five districts (two in HY, two in LA and one in HD) in three provinces was based on consultation of province and district veterinarians and reports of PRRS and/or FMD outbreaks. In selected districts, 2–4 communes per district ($n = 14$) were initially chosen based on

the following criteria: importance of pig production, diversity of pig farming systems, and official reporting of at least PRRS or FMD outbreaks during the 2010–2013 period. To select farms for the financial impact assessment, focus group discussions were organized firstly with a random and stratified selection of pig holders based on the different farming categories: mixed farm (combined farrow-to-weaner and farrow-to-finisher) and fattening pig farm. The aims of those focus group discussions were (i) to investigate the swine disease situation in the area, (ii) to identify the swine disease priority at the local level, and (iii) to identify farms affected with those most important swine diseases. From these focus groups, three main priority diseases were identified and selected for financial impact study (PRRS, FMD and epidemic diarrhoea) (unpublished results). The list of farms included in the impact study sample originated from those focus groups and was complemented with the list of farms affected by one of the selected diseases and provided by the local veterinarian. Finally, 8–25 pig holdings affected by PRRS or FMD or both diseases in 1–4 villages per commune were interviewed ($n = 162$) with the agreement of commune veterinarians and farmer's willingness to participate.

Field surveys were conducted between May 2013 and August 2014 by a group of researchers with experience in swine production and diseases. Individual semi-structured interviews using open and probing questions were performed along with the use of questionnaire to gather specific data on economic parameters of pig production (breeding, feeding regimes, management practices, pig performance), history of disease occurrence at pig farm (i.e. mortality, morbidity, delay finishing stage due to disease onset, market price in normal and in case of emergency selling) and cost of disease prevention and treatment practices.

Estimation of swine disease occurrence in the study sample pig holdings

Due to the retrospective nature of this study, no sample was available for laboratory tests. Therefore, the estimation of the frequencies of the priority swine diseases was based on specific case definitions previously defined with the pig holders in the study area during the initial focus group discussions using participatory epidemiological methods (Mariner and Paskin, 2000; Catley, 2005). Briefly, the clinical signs of major swine diseases were defined using matrix scoring technique. The link between the swine disease symptoms and a specific swine disease was then validated by experts in swine diseases, by experienced veterinarians in the study areas and by looking at literature data (Muirhead and Alexander, 1997; Tieu and Nguyen, 2011). The following case definitions of PRRS, FMD and epidemic diarrhoea were used:

PRRS ('Tai xanh' in Vietnamese): pig farm holdings were considered as affected by PRRS if the following clinical signs were observed at herd level: high fever with/without red body skin, distress, anorexia, together with any following symptoms: respiratory distress with cough, difficult breathing, nasal discharges, swollen eyes with discharges, diarrhoea with yellow/black faeces, blue ears, abortion, mummified or weak piglets. The described outbreaks might affect all pig ages at farm or occur in the weaners, growers or feeders batch only. Clinical signs in sows such as abortion, mummified or weak piglets may not be clear in farms that reported PRRS in previous years. PRRS was differentiated from local pneumonia (Viêm phổi địa phương) by number of pigs affected in batch, ordered occurrence of clinical signs and spread rate. Pig herd affected by local pneumonia which was caused by *Mycoplasma Hyopneumoniae* often have first clinical signs as cough, reduction of feed intake, difficult breathing. The disease spreads gradually within herds with morbidity of 20% and case fatality of 12% (Le et al., 2012).

FMD (Lở mồm long móng): pig holdings were considered as affected by FMD if at herd level there were occurrences of clinical signs as: bleeding and swelling hooves, lameness, vesicular hoof lesions, and vesicular mouth lesions, together with any of the following symptoms: sudden deaths of suckling and weaning pigs, vesicular teat lesions in sow, sudden deaths of growers and feeders, fever, hypersalivation and reduction of feed intake.

Epidemic diarrhoea (Tiêu chảydị ch): pig holdings were considered to have experienced an episode of epidemic diarrhoea if at herd level affected pigs had the following clinical signs: anorexia, miasma, watery brown/black faeces (adult pigs), watery yellow faeces (piglet), rapid dehydration and vomit (piglets). The outbreaks affect all age groups of pigs at farm and spread rapidly between pig batches. Mortality rate of 100% might be seen in suckling piglets less than 1 week of age.

Farm typology

Cluster analysis was applied to identify the different typologies of pig holdings in the study area. Briefly, principal component analysis (FactoMineR package (Husson et al., 2013)) was first performed to extract the principal component based on the characteristics of pig holding: number of sows and/or boars, number of weaners produced, number of weaners sold or purchased, number of fattened pigs sold, and breeding and feeding regimes (commercial feed and home-mixed feed or by-product feed). Then, hierarchical clustering on principal component (HCPC) was used to classify pig farms in the study area. The number of clusters was defined as a result summarized by the agglomeration process (Husson et al., 2010).

Data management and analysis

All pig production and economic data were extracted from the interviews and the questionnaires and inputed into a Microsoft Excel 2007 database. Different categories of information such as general information on the farm, pig production and swine disease history were stored in separate Excel spreadsheets and linked together using farm unique identification number. Formulas used to calculate farm gross margins and swine disease costs were developed in Excel sheets that were linked back to the main database. Data then were exported to R software for statistical analysis.

Gross margin estimation

Gross margin is generally estimated by subtracting the variable costs from farm output (Rushton, 2009). In this study, gross margin was estimated per pig holding per year and the variables considered are presented in Table S1. Farm outputs were defined as amount of money arising from the sales of pigs (weaning, growing and finishing pigs) and sales of semen and/or manure less herd depreciation. Herd depreciation was estimated by the cost of sow and boar replacement minus sow plus boar cull receipts. Variable costs are costs that changes in proportion to the farm production (as opposed to fixed costs which do not change according to the number of pigs produced). Variable costs include the costs of items such as feed, veterinary medicine, water, electricity, transportation and other equipments (broom, plastic water tube, etc.). Transportation costs (for pigs and feed) were not mentioned in this study because they were included in the pig price or feed price and were not considered separately.

Financial impact of swine diseases at farm level

Swine disease economic impacts were estimated following the framework published by Rushton (2009) with an adaptation to swine production in Vietnam. Costs of swine disease were estimated, including direct losses due to mortality (100% market value of pig before disease onset) and morbidity (abortion, delay of finishing stage) and indirect losses due to control costs (treatment, improving biosecurity and emergency vaccination) and revenue foregone (lower pig price in case of emergency selling). Invisible losses such as reduced fertility and/or change in herd structure were not estimated due to missing data. However, losses due to abortion, which was considered as consequence of infection, were estimated by combining feed cost during gestation time and during the 7 days before mating (average time of dry sow) plus cost of artificial insemination and of sow depreciation. Labour cost for taking care of sick animal was not included in the calculation because of the variability of farmer's activities (houseworks, fish pond, poultry raising and crop production) and missing data of working hours spent on pig production. The same approach was applied for all diseases to allow for comparative analysis. Cost of swine diseases was estimated as USD per pig holding, using VND21800 = USD 1 exchange rate. Financial impacts of swine diseases were expressed as a percentage of gross margin of pig holding.

Assumptions

Gross margin and disease impacts were estimated on the assumptions that:

1 Pig farms have fixed size, always maintaining the same number of sows and boars (if any) in year
2 The reduction of growth rate of infected pigs was assessed based on the number of days delaying the finishing stage (recovered pigs were assumed to be kept until reaching the required weight for slaughtering), and the feed intake of affected pigs was averaged to half of the normal amount of feed during extending period; no compensation growth following recovery was considered in the estimation
3 Market prices of live fattening pig and weaning pig at farms keeping more than 20 sows and/or 200 fattening pigs were VND 48 000 (USD 2.2) per kg and VND 120 000 (USD 5.5) per kg, respectively; in smallholders keeping >20 sows and/or 200 fattening pigs, the market prices were VND 45 000 (USD 2.1) per kg for finishing pigs and VND 70 000 (USD 3.2) per kg of weaning pigs. These different prices between the two pig farming systems were linked to differences in the quality of the fattening pigs and breeding pigs resulting from different breeds or feeding regimes. These prices were considered as mean values of pig prices between 2010 and 2013 that were collected during interviews of pig farmers.

Statistical analysis

All the analysis were performed using R software version 2.15.3 (R core team, 2013). Measurements of gross margin and disease losses were analysed using a restricted maximum likelihood (REML) in nlme package (Pinheiro et al., 2013). Pig farming group (cluster) was entered as fixed effect and commune was as random effect. Linearity, homoscedasticity and normality assumptions were checked by diagnostic plots of standardized residues of the models. Data transformations were used to satisfy the test criteria. The effects of pig farming typologies on gross margin and on swine disease impacts were analysed using post hoc test in multcomp package (Hothorn et al., 2008) with a P-value of <0.05 indicating significant differences. The provincial and regional effects were not tested due to unbalanced distribution of pig farming categories in provinces and regions. Most of pig holdings in LA and HD fall into smallholder category while most of pig holdings in fattening pig

group were located in HY province. Therefore, province/region and pig farm typology (cluster) were confounded.

Results

Characteristics and typology of pig holdings in the study area

Three groups of pig holdings in the study area were highlighted by the cluster analysis from the 162 pig holdings interviewed in the three provinces (HY, HD and LA) (Table 1). The variance between clusters represented 65.4% of the total variability (Figure S1). Group 1 and 3 consisted in mixed production farms (combined farrow-to-finisher and farrow-to-weaner/grower) which kept sows, boar and produced weaning, growing, and fattening pigs while most of pig holdings in group 2 (86.7%) kept fattening pigs only. Pigs were kept in door in all groups but herd size, housing types, investment for pig housing and feeding practices differed among the three clusters.

Group 1 (large farms) was composed of mixed farms keeping from 20 to 50 sows and up to 900 fattening pigs. Pig production (weaners and fattened pigs) was their main business and contributed on average to 80% of the family income. Semen was not for sale, and sold manure was only contributing to a minor part in the farm output. Almost all pig farms in this group used commercial feed for pig. However, some farms used home-mixed feed made of corn, rice barn and concentrate feed for feeders in case of dropping pig price. Biosecurity at pig holdings in this group was considered as higher than in other groups but still being medium as the all-in-all-out was not applied strictly. Vaccination, medication and disinfection were regularly applied, but pig pens could be easily accessed by guests due to the closeness of pig pens and farmer's house.

Group 2 (fattening farms, >100 pigs) was the smallest cluster. Weaners were cross-breds of exotic breeds and bought from large family farms or pig companies. Investment for pig housing was medium with open pen, concrete floor and automatic drinking water. Pig feed was commercial feed or mixed feed of corn, rice bran and concentrate feed. Vaccination and pig housing disinfection were not applied strictly, and only several vaccines against CSF, Pasteurellosis and Erysipelas, were used. Vaccination against PRRS and FMD was done before season at risk of disease occurrence or in case of disease outbreak in surrounding areas.

Group 3 (smallholders) was the dominant group in the three studied provinces. Activities of these farms were more diverse, and pig production contributed to half of the family income. Pig farmers might sell weaners, growers in case of limited space but they might buy more weaners, growers to keep for fattening when performance of their sow was low. Buying weaners or growers to fatten was more common for pig holders in HD and LA province and at pig holdings keeping few sows. Pig breed was cross-bred of indigenous breeds and exotic breeds. Rice bran, food waste, vegetable, maize and by-product of home job were main ingredients in pig feed. Commercial feed was only used for lactating sows and weaners. Medication, disinfection and vaccination were not strictly applied and often followed the disease seasonality or were used in case of disease outbreaks in surrounding areas.

Table 1. Characteristics of pig farm typologies

	Large farm	Fattening farm	Smallholder
N (%)	18 (11.1)	15 (9.3)	129 (79.6)
HY (n = 58) (%)	8 (13.8)	13 (22.4)	37 (63.8)
HD (n = 50) (%)	6 (12.0)	1 (2.0)	43 (86.0)
LA (n = 54) (%)	4 (7.4)	1 (1.8)	49 (90.7)
Farming system (%)			
Mixed farm	100	13.3	91.5
Fattening farm	0	86.7	8.5
Herd size (min–max)			
Number of sows	20–50	0–4	0–16
Number of boars	0–3	0	0
Number of weaners sold per year	0–400	0	0–220
Number of weaners purchased per year	0	130–400	0–120
Pig breed (%)			
Cross-bred (exoticbreed x exoticbreed)	100	100	13.9
Cross-bred (local breed x exoticbreed)	0	0	86.1
Feeding regime			
Utilize by-product of home job or foodwastes (%)			
No	100	100	49.6
Yes	0	0	50.4
Home-mixed feed (%)			
No	72.2	26.7	3.1
Yes	27.8	73.3	96.9
Income contribution (min–max) (%)	50–100	40–100	10–100

Frequency of priority swine disease outbreaks in pig holdings

Of 162 interviewed pig holdings, 143 (88%) mentioned at least one PRRS outbreak (45 in HD, 48 in HY and 50 in LA) during 2010–2013 (Table S2). In 2010, the number of pig farms indicating PRRS outbreaks was the highest in two Northern provinces (29 in HD and 23 in HY), while the highest number of affected farms in LA was in 2011 (26 pig holdings). During 2010–2013, 14, 7 and 13 pig holdings in HD, HY and LA, respectively, reported two PRRS outbreaks.

The number of FMD affected pig holdings was 32, 32 and 8, being 64%, 55% and 15% of interviewed farms in

HD, HY and LA, respectively. No pig holdings indicated more than one occurrence of FMD at their farms during 2010–2013. Vaccine against FMD was perceived as very effective. Thus, FMD infection often occurs in non-vaccinated pigs.

Epidemic diarrhoea was considered as an emerging disease in HD and HY and mentioned by 24% and 33% of the interviewed farmers, respectively. Epidemic diarrhoea was described as occurring in winter time, when the weather was cold and wet. The disease spread rapidly among pig herds and clinical outbreak occurred 2–3 weeks at farm. The disease was considered difficult to prevent and caused significant impacts for lactating piglets only. No pig holders in LA indicated clinical signs meeting the case definition of epidemic diarrhoea.

Gross margin of pig farm holdings

The estimate of gross margin per pig holding per year was USD 18 846, USD 7014, USD 2350 in large farm, fattening farm and smallholder, respectively ($P < 0.0001$). Large farm had the highest gross margin per farm per year as a result of higher production yield in term of growth performance and number of pig sale (Table 2). Feed conversion ratio and average daily gain of pigs in large farm were significantly higher than those of pigs in smallholders. However, large farm had invested more on pig production and management, resulting in considerably higher variable costs (i.e. veterinary and medicine cost).

Financial impacts of swine diseases

Both direct and indirect costs due to PRRS were extremely high in large pig farm (Table 3). The morbidity rate of PRRS at affected pig holdings ranged from 87% to 96% in the three pig farming groups with mortality rate of 53%, 30% and 58% in large farm, fattening farm and smallholder, respectively. The total cost of PRRS was estimated at USD 7722, USD 2673 and USD 1470 ($P < 0.0001$), which represented 41%, 38% and 63% of gross margin of large farm, fattening farm and smallholder, respectively. PRRS induced the highest costs among the three diseases considered.

The morbidity rates of FMD were as high as those induced by PRRS, ranging from 67% to 98% in the three pig farming groups. However, the mortality rates due to FMD were lower than those caused by PRRS (29% in large farm, 6% in fattening farm and 29% in smallholder). The total losses due to FMD were estimated at USD 3668, USD 1754 and USD 744 in large farm, fattening farm and smallholder, respectively ($P < 0.0001$), which were mainly derived from pig death and from control costs and revenue forgone (Table 3). The total cost of FMD accounted for 19%, 25% and 32% of gross margin of large farm, fattening farm and smallholder, respectively.

The morbidity rate of epidemic diarrhoea in pig farming groups was extremely high (97–100%), but mortality rate ranged between 5% and 19%. The total cost of epidemic diarrhoea was the lowest with USD 1816 in large farm, USD 574 in fattening farm and USD 247 in smallholder, accounting around 10% of gross margin of pig holding.

Financial impacts of PRRS in large farm and smallholder decreased significantly over years ($P < 0.0001$) (Fig. 1). The highest losses were observed in large farm at the PRRS epidemic in 2010 with nearly USD 15 000 per pig holding, and then, they decreased rapidly and were around USD 5000 in 2013. The total losses due to PRRS in smallholder were USD 3400 in 2010 and settled at USD 811 in 2013. Cost of PRRS in fattening farm was the highest in 2012.

Table 2. Estimates of pig holding gross margin according to pig farm typologies

Variable	Large farm Mean (95% CI)	Fattening farm Mean (95% CI)	Smallholder Mean (95% CI)	*P-value*
Number of weaners/sow/year (head)	19.8 (19.2–20.4)		18.7 (18.3–19.2)	0.1
Number of sale weaners/sow/year (head)	4.1 (1.4–6.8)		3.1 (2.1–4.1)	0.4
Number of purchased weaners/sow/year (head)	0		1.7 (0.2–2.9)	
Number of sale fatteners/farm/year (head)	591 (548–634)[a]	236 (187–285)[b]	91 (73–109)[c]	<0.0001
Feed conversion ratio (kg feed/1 kg weigh gain)	2.6 (2.5–2.7)[a]	2.8 (2.7–2.9)[ab]	3.1 (2.9–3.3)[b]	0.003
Average daily gain (g)	622 (610–634)[a]	618 (596–640)[a]	576 (567–584)[b]	<0.0001
Output (USD/producer)	87 515 (63 865–119 923)[a]	34 205 (23 324–50 163)[b]	12 047 (10 328–14 052)[c]	<0.0001
Feed cost (USD/producer)	64 035 (46 065–89 014)[a]	25 467 (17 088–37 955)[b]	8978 (7669–10 509)[c]	<0.0001
Veterinary and medicine (USD/producer)	2458 (1585–3814)[a]	497 (291–849)[b]	221 (177–276)[c]	<0.0001
Other cost (USD/producer)	1022 (762–1372)[a]	169 (120–239)[b]	146 (129–165)[b]	<0.0001
Gross margin (USD/producer/year)	18 846 (12 971–27 381)[a]	7014 (4444–11 069)[b]	2350 (1884–2931)[c]	<0.0001

Different letters (a, b and c) indicate the difference in observed variable at a *P* value of <0.05.
CI, Confidence Interval.

Table 3. Financial impacts of priority swine diseases in pig farm typologies

Variable	Large farm Mean (95% CI)	Fattening farm Mean (95% CI)	Smallholder Mean (95% CI)	*P-value*
PRRS infection				
Number of infected farms	16	12	115	
Morbidity at affected farm (%)	87.4 (77.5–94.8)	95.7 (85.3–99.9)	94.0 (90.6–96.7)	0.2
Mortality at affected farm (%)	52.6 (36.1–68.9)	30.4 (11.8–53.2)	57.5 (50.2–64.7)	0.08
Loss due to mortality (USD/producer)	6635 (5267–8160)[a]	1600 (762–2745)[b]	1102 (843–1398)[b]	<0.0001
Production loss due to morbidity (USD/producer)	927 (689–1200)[a]	352 (166–606)[b]	131 (89–180)[b]	<0.0001
Control cost (USD/producer)	572 (459–698)[a]	195 (110–304)[b]	101 (78–127)[b]	<0.0001
Losses due to control cost and emergency selling (USD/producer)	883 (520–1340)[a]	614 (231–1181)[ab]	254 (148–387)[b]	0.0003
Total losses (USD/producer)	7722 (5294–11 264)	2673 (1582–4518)	1470 (1199–1800)	<0.0001
Percentage losses compare to Gross Margin	41	38	63	
FMD infection				
Number of infected farms	9	8	55	
Morbidity at affected farm (%)	67.1 (43.2–77.1)[a]	97.6 (82.2–98.5)[b]	90.5 (82.7–96.1)[b]	0.03
Mortality at affected farm (%)	28.7 (10.5–51.5)	6.4 (0.1–23.4)	28.9 (20.7–37.8)	0.07
Loss due to mortality (USD/producer)	1925 (1073–3024)[a]	585 (153–1294)[ab]	438 (270–647)[b]	0.002
Production loss due to morbidity (USD/producer)	398 (194–673)[a]	596 (313–969)[b]	66 (30–116)[c]	<0.0001
Control cost (USD/producer)	110 (66–165)[a]	81 (38–139)[ab]	31 (18–46)[b]	0.0002
Losses due to control cost and emergency selling (USD/producer)	1093 (468–1980)[a]	125 (5–607)[ab]	163 (45–353)[b]	0.004
Total losses (USD/producer)	3668 (1970–6828)[a]	1754 (907–3390)[ab]	744 (579–957)[b]	<0.0001
Percentage losses compare to Gross Margin	19	25	32	
Epidemic diarrhoea				
Number of infected farms	9	3	18	
Morbidity at affected farm (%)	96.6 (90.1–99.7)	100.0	96.8 (92.6–99.3)	0.4
Mortality at affected farm (%)	18.5 (10.4–28.3)	5.1 (0.1–17.3)	16.8 (11.1–23.4)	0.2
Loss due to mortality (USD/producer)	1019 (740–1343)[a]	374 (125–758)[ab]	159 (86–255)[b]	<0.0001
Production loss due to morbidity (USD/producer)	740 (450–1100)[a]	326 (65–786)[ab]	56 (7–151)[b]	<0.0001
Control cost (USD/producer)	188 (126–262)[a]	121 (44–234)[ab]	31 (15–54)[b]	<0.0001
Total losses (USD/producer)	1816 (1084–3039)[a]	574 (235–1400)[ab]	247 (170–358)[b]	<0.0001
Percentage losses compare to Gross Margin	10	8	11	

Different letters (a, b and c) indicate the difference in observed variable at a *P* value of <0.05.
CI, Confidence Interval.

However, number of PRRS affected fattening farms was limited and had not occurred every year since 2010.

Discussion

The aim of the study was to assess the impacts of important swine diseases such as PRRS and FMD. Therefore, the study focused on PRRS- or FMD-infected pig holdings in affected areas. However, this non-random sampling approach could be a limitation in term of representativeness of the output of this study. The study represents the first attempt to estimate the impact of the main swine infectious diseases on gross margin of different types of pig holdings, not to estimate the total impacts based on disease prevalence level. Anyhow those results could be used as baseline data to estimate the overall impact of swine diseases if the real disease prevalence level in each farming system was known. The typology analysis performed in this study highlighted three different groups of pig holdings: large farms, fattening farms and smallholders. Those three pig farming systems which differ in terms of herd size, feeding regimes, housing and health management practices are very common in pig production in RRD and MRD regions of Vietnam. Moreover, the detailed impact assessment framework applied in this study could be applied for other areas in Vietnam to increase the representativeness of the study outputs.

Usually, one major constraint in the estimation of gross margin in smallholder farming system is to quantify non-commercial purpose of animal production such as generation of manure, or dowry (Rushton et al., 1999). In our study, it is important to highlight that almost all pig holders raised pigs for commercial purposes (contributing to the household income). Slaughtering pig for home consumption was very rare. It might occur in some special occasions such as 'Tet' holiday (Vietnamese New Year celebration) or weddings, but it is also accounted for in the financial output of the household. The use of home by-products such as tofu, noodle or alcohol production for

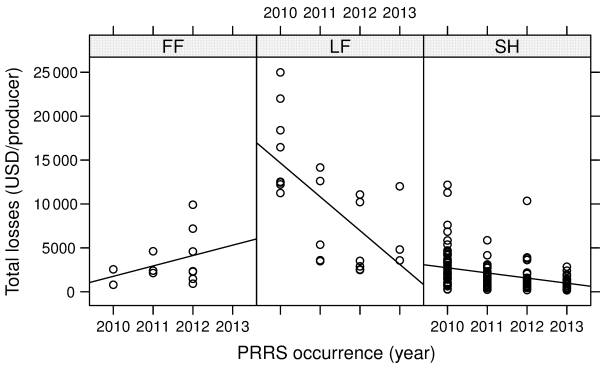

Fig. 1. Financial impacts of PRRS over years in pig farm typologies (LF, large farm; FF, fattening farm; SH, smallholder).

feeding pig is also common in small holders. However, the costs of these by-products were also accounted for as input for pig production by the farmers. It is also important to mention that farmers often record financial input and output of their farm after selling each batch of pigs (fattening farms) or at the end of year (large farms, smallholders), ensuring therefore the reliability of the financial data collected in the study. Moreover, smallholders often buy feed on credit and feed cost is also recorded for repayment after each batch or at the end of year. Only costs of cheap equipments (i.e. syringe, plastic tube and broom) were sometimes not reported by some farmers.

The impact of the swine diseases considered in this study varied among pig farming groups. Different factors would affect the impact of the disease such as the diversity of production systems, disease status, variation of market prices in geographical areas and cost of disease management and control (Rushton, 2009). In this study, market prices of weaning and fattening pig were fixed; therefore, the variation of disease impact could mainly be imputed to the status of disease infection and differences in disease management practices in the different pig farming groups in the study area. Indeed, biosecurity in small pig holdings was poor, with regular introduction of weaning or growing pigs, use of food wastes, and poor vaccination and medication. Therefore, impacts of swine diseases on gross margin per household per year are more likely to be higher in such small pig holdings. The impacts of PRRS are known to be more severe if secondary infections occur, with agents such as *Mycoplasma hyopneumonia*, swine influenza virus, *Salmonella choleraesuis* or *Streptococcus suis* (Holck and Polson, 2003). The persistence of these pathogens at pig holdings in Vietnam has been shown in several studies (Hoa et al., 2011; Le et al., 2012; Trevennec et al., 2012; Baudon et al., 2015). Therefore, the difference in epidemiological characteristics of secondary pathogens in geographical areas along with the management of PRRS-infected pigs could explain the variation of PRRS impacts.

The study highlighted that losses due to FMD in large farm and smallholder were mainly due to pig death and drop in meat market price in case of emergency selling. Seasonal vaccination of FMD (using FMD vaccine before risky season of FMD infection) or emergency vaccination (using FMD vaccine when there is FMD outbreak in surrounding area) was found to be very common in pig holdings among the study pig groups and areas. Such vaccine coverage would influence the morbidity and mortality of FMD in village; therefore, it had impacted on FMD losses (Rast et al., 2010). Emergency selling of infected pigs was also observed and the reduction of market price in case of emergency selling ranged from 6% to 90% depending on the age of the pig (Table S2). A reduction of 30% of the animal value in case of selling animal at time of outbreaks had also been mentioned in previous studies (Rast et al., 2010; Shankar et al., 2012).

Porcine epidemic diarrhoea (PED) has been detected in Vietnam since 2009 (Thanawongnuwech, 2011; Vui et al., 2014). PED outbreaks were reported in several Southern provinces of Vietnam in 2009–2010 such as Ho Chi Minh, Binh Duong, Dong Nai and Baria-Vung tau (Nguyen et al., 2012). The clinical signs described in those outbreaks were similar to the case definition of epidemic diarrhoea used in this study. PED was not reported in LA which would support the result in our study that this disease has not yet occurred in this province. PED might cause significant losses for swine industry worldwide due to high mortality rate in suckling piglets (50–100%) (Puranaveja et al., 2009; Nguyen et al., 2012; Chang et al., 2015). In this study, most of the investigated pig holdings were smallholders keeping only few sows; thus, the density of suckling piglets presented during PED outbreaks could only be low in such holdings. This could explain the overall low impact of PED compared with FMD and PRRS even though morbidity of this disease was higher. No emergency selling of fattening pigs during PED was mentioned by any pig holders.

Pig farmers and local veterinarians had great experience on clinical signs of swine diseases. Indeed, PRRS outbreaks were reported with laboratory confirmation in the study area during 2007 and 2010, especially in LA province where it has been reported every year since 2010 (DAH, 2013). The knowledge of local veterinarians and farmers on swine diseases and disease differential diagnosis has improved since PRRS outbreaks in 2007, thanks to training courses supported by governmental extension services and feed/drug companies. Moreover, it was not difficult for pig farmers to recognize FMD and epidemic diarrhoea as their clinical signs were clearly distinguished from other swine diseases. Therefore, the level of confidence on differential diagnostic of the swine disease considered in this study was considered as high. Despite that, the case definition used for PRRS will match with high pathogenic PRRS cases.

Since 2010, PPRS infection might be less severe due to PRRS vaccination or natural herd immunity. Therefore, mild infection of PRRS might not be accounted for and occurrence of PRRS might have been underestimated.

Compensation payment subsidized by the government for culled pigs was not taken into account in this study because the aim of this study was to quantify the impact of the swine disease outbreaks on farmer's income without considering the impacts of national control measures.

Along with production losses, diseases can have impacts on variations of pig prices determined by supply and demand effects (Zhang et al., 2012). A movement restriction during outbreak can lead to increasing feed cost for finisher production, but disease outbreaks could make the pork price increase due to supply shortage and this price might remain high for a certain period of time even after removal of the movement ban. Therefore, the losses in terms of extra feed costs might be offset by higher pork price after outbreaks. In PRRS outbreak in 2008 and 2010, some interviewed farmers who have experience on PRRS treatment gained some money from buying sick pigs and successfully treating them and selling them with extremely high price after that. In our study, this positive impact was not quantified due to limited data on this type of farmer resilience to an infectious disease outbreak, and this would need further investigation.

Conclusion

Financial impacts of three swine diseases (PRRS, FMD and epidemic diarrhoea) at producer level in Vietnam were estimated as percentage losses of gross margin of pig holdings in different pig farm types. Economic assessment of animal disease impacts is a critical step for the identification of priority diseases for surveillance and control at both national and local level. Estimations of swine disease costs at farm level can help to understand the perception of swine diseases priority for local monitoring as well as farmer's behaviour towards national swine disease surveillance and control strategies.

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Supporting Information

Additional Supporting Information may be found in the online version of this article:

Table S1. Formula for Gross margin estimation.

Table S2. Impacts of swine diseases in provinces.

Figure S1. Farm typology divided into three classes (LF, large farm; FF, fattening farm; SH, smallholder).

