The Economic Impact of Pig-Associated Parasitic Zoonosis in Northern Lao PDR

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Abstract

The parasitic zoonoses human cysticercosis (*Taenia solium*), taeniasis (other *Taenia* species) and trichinellosis (*Trichinella* species) are endemic in the Lao People's Democratic Republic (Lao PDR). This study was designed to quantify the economic burden pig-associated zoonotic disease pose in Lao PDR. In particular, the analysis included estimation of the losses in the pork industry as well as losses due to human illness and lost productivity. A Markov-probability based decision-tree model was

chosen to form the basis of the calculations to estimate the economic and public health impacts of taeniasis, trichinellosis and cysticercosis. Two different decision trees were run simultaneously on the model's human cohort. A third decision tree simulated the potential impacts on pig production. The human capital method was used to estimate productivity loss. The results found varied significantly depending on the rate of hospitalisation due to neurocysticerosis. This study is the first systematic estimate of the economic impact of pig-associated zoonotic diseases in Lao PDR that demonstrates the significance of the diseases in that country.

Keywords: One health; Zoonoses; Lao PDR; Cysticercosis; *Taenia solium;* economic evaluation; Taeniasis; Trichinellosis

The parasitic zoonoses cysticercosis and trichinellosis are endemic in the Lao People's Democratic Republic (Lao PDR) (Carabin et al. 2006a; Conlan et al. 2008, 2011). Socioeconomic factors such as household expenditure on cooking fuel and availability of sanitation facilities contribute directly to the spread of such diseases and are therefore of particular importance in developing nations such as Lao PDR (Fan et al. 1992; Rajshekhar et al. 2003a). *Taenia solium*, the parasite which causes human cysticercosis, is transmitted via the faecal-oral route, primarily as a consequence of poor sanitation and hygiene (Bell 1984; Vázquez-Flores et al. 2001). *Taenia* and *Trichinella* spp., which are the source of taeniasis and trichinellosis respectively, are transmitted via the ingestion of raw or undercooked meat from infected animals (Fan et al. 1992; Takumi et al. 2009).

The Lao People's Democratic Republic is ranked 133 out of the 177 countries listed in the Human Development Index (WHO 2010). It is one of the poorest countries in the Asia Pacific Region with a gross national product per capita (PPP Int. $) of $ 2,597.59 compared to the regional and the global averages of $8,340 and $9,872, respectively (WHO 2010; IMF 2011).

Animal husbandry alone is estimated to form 14.3% of the total contribution of agriculture towards the GDP (Huynh et al. 2006). In addition to the global health priority problems such as malaria,

tuberculosis, maternal health, vaccine preventable illnesses in childhood, Lao PDR has declared zoonotic illnesses as a priority in their National Work Plan for Emerging Infectious Diseases (2007–2010).

Statistically significant estimates of the prevalence and incidence of taeniasis, trichinellosis and cysticercosis are difficult to obtain in Lao PDR. Few studies have estimated the prevalence of swine cysticercosis in Lao PDR and current figures based on inspection data alone range from 0.8 to 1.7% with significant spatial variation (Conlan et al. 2008, 2012). Routine inspection data is unreliable and the maximum likely prevalence estimates range from 2.8 to 4.2% in northern Lao PDR (Conlan et al. 2012).

There have been a limited number of studies designed to assess the economic burden and health impacts of pig-associated zoonotic diseases. This study aims to provide an economic quantification of the burden associated to taeniasis, trichinellosis and cysticercosis in Lao PDR. In particular, focus is given to the estimation of losses occurring in the pork industry, as well as within the human health sector, including lost productivity in the labour market.

Methods

Study Site

The majority of prevalence and raw pork consumption data for this study originates from four provinces of northern Laos: Oudomxay, Luang Prabang, Huaphanh and Xieng Kuang (Fig. 1). Original data collected from these provinces were captured through a human health survey and a pig-abattoir study conducted by Murdoch University and the Department of Prevention and Hygiene, Lao Ministry of Health and the Department of Livestock and Fisheries, Lao Ministry of Agriculture and Forestry (Conlan et al. 2012). A small data set obtained from the Xam Neua District Agriculture and Forestry Office, Huaphan province, was also utilised (DAFO 2008; Conlan et al. 2012).

The human health survey covered 332 households (1,579 individuals) from a total of six randomly selected villages from each of the 4 study regions (Conlan et al. 2012). Data included responses to a questionnaire designed to collect information on the educational and socioeconomic status of respondents and the frequency of raw pork consumption. In addition, the results of testing serum and stool samples for evidence of infection with *Trichinella* and *Taenia* spp. (including *T. solium*) were also available(Conlan et al. 2012).

Surveys of pigs slaughtered at a number of village slaughter points in the four provinces generated information on the prevalence of *Trichinella* and *Taenia* spp. infection and the age (months), weight (kilograms) and origin of the pigs.

Modelling Approach

A Markov-probability based decision-tree model was chosen to estimate the economic and public health impacts of taeniasis, trichinellosis and cysticercosis (Drummond 2005). Two different decision trees were run simultaneously on the model's cohort. The first decision tree (Fig. 2) related to an individual's likelihood of becoming infected with *Taenia* sp. and/or trichinellosis and the subsequent costs associated with treatment. The second decision tree (Fig. 3) related to an individual's likelihood of developing cysticercosis and in some cases neurocysticerosis (NCC) in order to estimate the likelihood of the person incurring hospitalisation costs for seizures.

The costs to the pig industry associated with pig-associated zoonotic diseases were limited to the impact of *T. solium* on saleable carcass and offal. The presence of cysts on either carcass or offal at point of slaughter was assumed to cause a loss in tradeable volume, due to excision of cysts and associated muscle, or condemnation of the carcass outright. A third decision tree was utilised to simulate these potential impacts on pigs in the model (Fig. 4).

Estimates of the input parameters were subject to Parametric Bootstrapping, a form of Monte Carlo simulation. The model was parameterised using Ersatz (Epigear International©, Australia) and 10,000 iterations were run to produce mean estimates of the output variable. Probabilistic sensitivity analysis was performed as part of the standard Monte Carlo routine in Ersatz (Epigear International©,

Australia). In addition, the sensitivity of the model to the proportion of carcasses lost to cysts and the discount rate was assessed by running the model with a range of values for each parameter. The model was automatically cut after 85 years and the surviving members of the cohort presumed to expire at that age.

A full list of variables used in the model and the statistical distributions applied are available in the online appendices.

Input Parameters (Human Health)

The prevalence of infection of humans with *Trichinella* and *Taenia* spp. were derived from human survey data (Conlan et al. 2012). The prevalence estimate for infection with *Taenia* spp. (including *T. saginata*) was derived from the results of microscopic examination of a single faecal sample. It was not possible to determine the species of *Taenia* based on microscopic examination alone. The prevalence of human cysticercosis was estimated from testing serum samples with a *T. solium*-specific ELISA. The prevalence of *Trichinella* antibodies was determined using the excretory-secretory (ES) ELISA (Conlan et al. 2012).

Estimates of the prevalence for each parasite genus (*Taenia* and *Trichinella*) species were derived from the outputs of analysis of raw data using a probit model to generate the estimates for each province that accounted for demographic and behavioural data collected during the survey. Variables included in the probit model ranged from rate of pork consumption, wealth factor score, history of *Taenia* infection and type of toilet facility available (latrine vs. open defecation). The estimated prevalence rates were then incorporated into the economic model. Taeniasis attributable to *T. solium* and *T. saginata* were not disaggregated for the purpose of this study and self-reported cases of taeniasis were not considered (Table 1).

The proportion of people likely to seek treatment for taeniasis and trichinellosis was based on the Human Health Survey (Conlan et al. 2012). It was assumed that in situations where cysticercosis did not progress to NCC, individuals would not seek medical treatment. This assumption was based on

the hypothesis that the associated symptoms of cysticercosis, such as lumps under the skin, were not significant enough to warrant concern in the individual or family and therefore, seek medical advice.

There are no data on the NCC hospitalisation rates in Lao PDR. A varying likelihood of being hospitalised due to NCC was used at probability rates 2, 4, 6, 8%, 10, 20, 30, 40 and 50%.

In the Human Health Survey (Lao PDR), individuals who reported a history of taeniasis were asked whether they sought treatment for their ailment. Of these people (n = 369), 76.9% reported having sought medical care. Time of hospitalisation was estimated as 3 days maximum, due to financial constraints of the patients and their families (Khamlome 2010). Individuals who were not hospitalised were assumed to have sought medical advice from their local pharmacy.

Input Parameters (Pig-Health)

The primary clinical manifestation of *T. solium* in pigs is the formation of internal cysts in muscles and organs that may lead to its partial or complete condemnation at point of slaughter without any significant health impacts for the animal (García et al. 2003). Estimates on carcass condemnation rates were based on a meat inspection data set from the Xam Neua district agricultural office (Huaphanh province) that spanned 21 months (DAFO 2008). 2.15% of the total carcasses were condemned outright due to heavy cyst infection. Carcasses with light cyst infection (1.67% of total carcasses) were actually sold to the public after removal of cysts by the trader. The variation in the quantity of meat and offal lost to this practice was not captured by the meat inspectors providing this data. For the purposes of the model, it was assumed that 50% of the carcass weight and offal weight would have been lost to the removal of cyst contaminated meat.

The size of the pig cohort is based on results from the human survey that indicated that on average, 4.55 pigs were kept by each household (Conlan et al. 2012). The survey also revealed that average age of slaughter was 12.4 months. Therefore, the model was run based on the assumption that every pig that was born in a given year would be slaughtered by the start of the subsequent year.

Economic Parameters

Human health costs are primarily limited to costs incurred for pharmaceutical treatment and hospitalisation due to NCC. Reviewable hospital costs for the country were unavailable. The charges to an individual hospitalised seizure patient were obtained from the Ministry of Health and used to estimate the total direct societal costs due to hospitalisation in Northern Laos. This expert opinion noted that the prices quoted were relatively representative of all hospitals in the country. Medication costs were acquired by Murdoch University staff working in Vientiane city, via phone interviews with seven regional pharmacies (Conlan 2010b). Significant variation in the prices of drugs between regions was found (average: 4833 LAK, Lower 2000 LAK–Upper 10,000). A conversion rate of 8,100 LAK: $USD 1 was used for all estimates.

The Laotian household expenditure and consumption survey (2007/2008) reported 2.5% of long term unemployed individuals cited health reasons as being the barrier to returning to the job market (Lao Department of Statistics 2009). It was also noted that between 40 and 46% of rural and urban workers in Laos had to temporarily stop work due to illness (Lao Department of Statistics 2009). This information was utilised alongside the human capital method (HCM) to estimate socioeconomic impact of cysticercosis alone, due to the lack of data concerning productivity losses caused by taeniasis and trichinellosis. The HCM method was chosen as it incorporates loss of productivity and quality of life. This loss is based on the Disability Adjusted Life Years (DALY) of the disease. DALYs for cysticercosis were assumed to be 9 per 1,000 life years as estimated by Praet et al. (2009b). Although hospitalisation was based on 3 days, a total loss of income was considered for a week, while the loss of productivity from illness was applied through a loss of workable hours per year. In the event of death, productivity losses were applied to the individual for every year they would have lived up to age 65. The model assumes that individuals do not generate economic activity after that age.

The model calculated the hypothetical earnings of the pig cohort should no saleable weight be lost due to full or partial condemnation of the carcass at slaughter. This is based on observations at abattoirs that show carcasses and offal that are laden with a large volume of cysts as being condemned outright

(DAFO 2008). This information was then used to estimate earnings of the cohort that incurred losses attributable to the infections. The difference in earnings is assumed to be loss of potential revenue and therefore the economic loss caused by *Trichinella* and *Taenia*spp. to the pork industry of Lao PDR. The price of meat and offal per kilogram originate from Vientiane pork trading markets (Conlan 2010a). The base case assumes that 50% of carcass and offal weight are lost to light cyst infections. The discount rate is held at 5%.

Results

Prevalence rates as estimated by the probit model are available in Table 2. These estimates were incorporated directly into the Markov model.

The per-person costs of target pig-associated zoonotic diseases as estimated by the model are shown in Fig. 5. Per-person estimates of the costs were calculated to account for the observation that larger populations will generally have larger costs due to higher numbers of affected persons. The direct medical costs incurred by human beings through healthcare expenditure are low. This is likely due to a mixture of the low prevalence, low impactand relatively cheap treatment of taeniasis, trichinellosis and cysticercosis. Hospitalisation costs formed the bulk of human health costs. As an individual had on average a likelihood of 1.96–2.62% probability to acquire cysticercosis, this implied the total likelihood of being hospitalised due to NCC was approximately between 0.04% and 0.06%. However, due to lack of evidence, a rolling estimate of hospitalisation rate due to NCC was used in the model (Table 3).

The model was most sensitive to changes in annual income level followed by proportion of cysts in pigs attributable to *T. solium* and weight of pigs. Proportion of NCC sufferers hospitalised was the fourth most influential parameter. Full results from the sensitivity analysis are presented in the online appendix.

Discussion

Despite the lack of information on the economic burden caused by zoonotic parasites in the pork industry in Lao PDR, it is important to highlight the risk of disease associated to the socio-cultural and dietary practices of the nation as well as the high prevalence of infection in neighbouring regions. The results of this model provide insight into the impact of cysticercosis, taeniasis and trichinellosis in four provinces of Northern Lao. These results show that pig-associated zoonotic diseases have a notable impact on the economy of the selected provinces and deserve policy attention. The confidence intervals for all of the provinces are extremely wide and likely due to the large number of unknowns and assumptions made in the model. As over 60% of healthcare expenditure in Lao PDR is out of pocket, it can be assumed that these diseases have a significant impact on the poorer regions.

The cost attributable to pig-borne zoonosis was significantly higher in Luang Prabang compared to the other three provinces in the study area mately between 0.04% and 0.06%. However, due to lack of evidence, a rolling estimate of hospitalisation rate due to NCC was used in the model (Table 3).

This is likely due to relatively higher proportions of individuals who consume uncooked or partially cooked pork in Luang Prabang compared to other provinces (Conlan et al. 2012). Although Oudomxay presented with higher uncooked pork consumption as compared to Xieng Khouang and Huaphanh; similar total costs of human illness were observed in all three provinces. This is likely due to the provincial population size, as Oudomxay has the second lowest population amongst the study provinces. This hypothesis is supported by Oudomxay having a comparable cost of illness to Huaphanh while having twice the human cost estimation, which is reflected in the higher pork consumption rates.

The results show that Huaphanh has the lowest economic cost per person due to disease. Of the four studied regions, Huaphanh had the lowest proportion of individuals consuming uncooked or partially cooked pork. The heterogeneous dietary habits between various provinces will therefore have a significant impact on variation of the economic burden of the zoonotic diseases evaluated in this study, throughout the nation.

Numerous studies have used the Markov chain model, whereby it allows for the simulation of infectious diseases through the use of probabilities, thereby removing the necessity for complex transmission models and the associated data requirements (Briggs and Sculpher 1998; Majorowski et al. 2005; Carabin et al. 2006b).

Due to the lack of information regarding hospitalisation rates for NCC, varying estimates were used for this variable. Hospitalisation likelihood with a maximum value of 50% was tested by the model. As seen in NCC endemic countries for which information is available, this portrays a realistic scenario (Rajshekhar et al. 2003b). The wide variation in hospitalisation likelihood is also reflective of the difference in the dietary habits of the Lao people, reflecting the varying probability of risk through undercooked pork consumption in the country. Bern et al. (1999) suggests a base underreported NCC prevalence rate in developing countries which ranges from 6 to 10%.

Although the results of this study cannot readily be extrapolated to national levels, it represents a realistic scenario of the economic and health effects on a regional area in Lao PDR due to infection with *Taenia* and *Trichinella* sp. With further information, this model can easily adjust for regional variations in order to produce larger scaled results.

Variations in food consumption patterns, including preferred and accessible meat products, cooking patterns as well as socioeconomic heterogeneity in Laos (World Food Program 2011) mean that exposure levels and ability to prevent and manage the infections will vary, and are visible through the large confidence intervals shown in the model. The financial values presented here were substantially lower than similar studies despite the fact that three diseases were analysed compared to evaluating the impact of Cysticercosis alone. Carabin et al. (2006a) estimated that the annual burden of Cysticercosis is between $US(2004) 18.6–34.2 million in Eastern Cape Province, South Africa, depending on which welfare cost model was used. The main difference to the Lao PDR setting is seen through the variation in the NCC hospitalisation rates, which were based on conservative values.

This study utilised the HCM as opposed to other forms of productivity loss such as the Friction Cost Method (FCM). Though the FCM was considered, its use was rejected by the authors due to the lack

of information regarding average frictional unemployment period. The absence of data in this field also prevented the utility of assumptions as there was a lack of justification behind the parameter selected. The HCM was selected due to its use via assumptions without supplementary data requirements.

Another limitation to the study was found regarding access to individual patient registration data, which is extremely limited outside major cities in Lao PDR. A Peruvian study of the costs per person due to NCC, benefitted from access to records of NCC sufferers registered with the existing national health system (Rajkotia et al. 2007). The authors could then estimate the costs of the pharmaceutical management of seizures. With access to similar data, this study would be able to account for losses in education and recreation time.

The DALY estimate used in this study was derived from data obtained from Cameroon because it is the only published estimate of DALY's for cysticercosis (Praet et al. 2009a). It is possible that this estimate may not be the same in Lao PDR. However, it was important to include an estimate of the DALY in the model because it is the accepted measure of morbidity and mortality. Future studies will benefit from the next iteration of the Global Burden of Disease Study which will contain official global DALY estimates for cysticercosis.

Due to the above-mentioned limitations to data quality, including hospital costs, seizure patient hospitalisation rates, sequelae and the consequences of unemployment, the total societal burden was underestimated.

In the animal model, due to the lack of observational data, the variability in intensity of infection per carcass (swine cysticercosis can range from 1 cyst per carcass to > 80,000 cysts) and distribution of cysts within a carcass, fixed rates of carcass wastage were used.

Although the results of this study cannot be readily extrapolated to national levels, it represents a realistic scenario of the economic and health effects on a regional area in Lao PDR due to infection with *taenia* and *trichinella* parasites. With further information, this model can easily adjust for regional variations in order to produce larger scaled results. In conclusion, this study has been the first

attempt at quantifying the economic impact of pig-associated zoonotic diseases in Lao PDR and demonstrates the significance of the diseases to the nation. This study has shown the importance of pig-associated parasitic zoonosis and emphasises the necessity of increased surveillance especially in raw pork consuming areas of Lao PDR.

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Table 1 Proportion of Consumers Who Eat Pork in Four Provinces of Lao PDR.

Province	**Proportion pork consumption (%)**
Huaphanh	12
Oudomxay	34
Luang Prabang	48
Xieng Khouang	16

Conlan et al. (2012).

Table 2 Prevalence of *Trichinella* spp., *Taenia solium* and Other *Taenia* spp. Infection of People in 4 Provinces of Lao PDR Derived Using a Probit Model (2010).

Province	**Prevalence (%)**		
	***Taenia* sp.**	***Trichinella* sp.**	***T. solium***
Huaphanh	1.65	18.16	1.98
Oudomxay	4.03	18.76	2.62
Luang Prabang	3.56	18.84	2.05
Xieng Khouang	1.81	18.06	1.96

Data derived from Conlan et al. (2012).

Table 3 Annual Economic Cost to Society Due to Pig-Associated Zoonotic Diseases, by Region and Likelihood of Hospitalisation Due to Neurocysticercosis.

Region	**Likelihood of adverse health outcome resulting in hospitalisation due to NCC**								
	2%	**4%**	**6%**	**8%**	**10%**	**20%**	**30%**	**40%**	**50%**
Huaphan	$376,737	$385,936	$396,222	$405,712	$415,778	$465,270	$513,019	$562,627	$609,411
Oudomxay	$501,512	$513,074	$525,086	$536,980	$549,949	$610,917	$671,718	$734,467	$792,898
Luang Prabang	$1,208,825	$1,222,737	$1,237,908	$1,253,834	$1,269,096	$1,342,422	$1,414,795	$1,487,553	$1,562,292
Xieng Khuang	$461,468	$469,179	$477,335	$484,471	$492,878	$533,245	$570,534	$611,285	$651,059

Figure 1 Map of Lao PDR with emphasis on provinces evaluated in present study.

Figure 2 Decision tree for estimating the economic burden of *Taenia* and *Trichinella* spp. in humans.

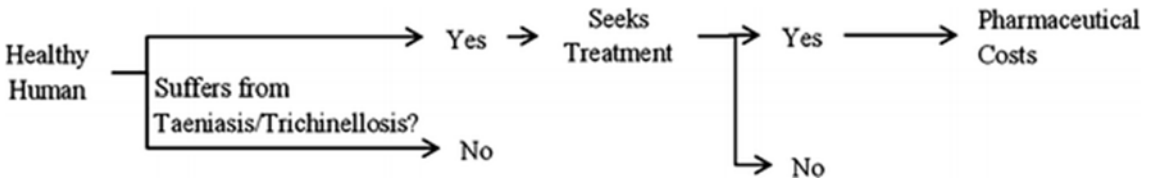

Figure 3 Decision tree for estimating the economic burden of neurocysticercosis in humans.

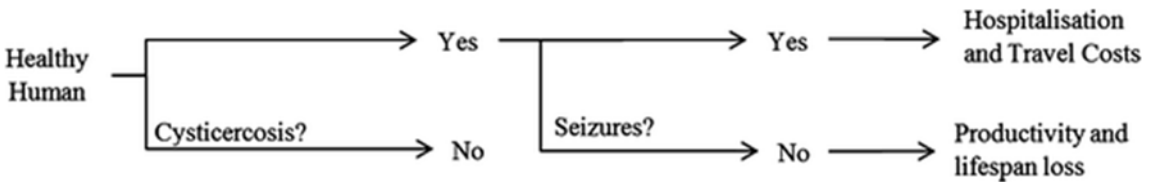

Figure 4 Decision tree for estimating the economic burden of *T. solium* in pigs.

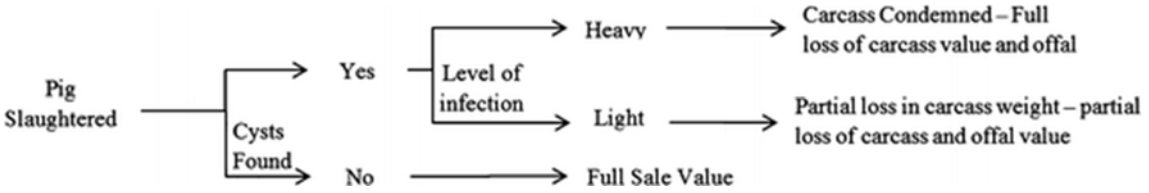

Figure 5 Annual per-person costs due to pig-associated parasitic zoonoses by % likelihood of NCC sufferers seeking hospitalisation, by region.