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African swine fever outbreaks in China led to GDP and economic losses

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Abstract: African swine fever (ASF) is a fatal and highly infectious haemorrhagic disease that has spread to all provinces in China – the world's largest producer and consumer of pork. Here, we use an input-output (I-O) model, partial equilibrium theory and a substitution indicator approach for handling missing data to develop a systematic valuation framework for assessing economic losses caused by ASF outbreaks in China between August 2018 and July 2019. We show that the total economic loss accounts for 0.78% of China's GDP in 2019, with impacts experienced in almost all economic sectors through links to the pork industry and a substantial decrease in consumer surplus. Scenario analyses demonstrate the worst cases of pig production reduction and price increase would trigger 1.4% and 2.07% declines in GDP, respectively. These findings demonstrate an urgent need for rapid ASF containment and prevention measures to avoid future outbreaks and economic declines.

Keywords: African Swine Fever; economic loss evaluation; IO model; substitution indicator estimation; consumer surplus.

Introduction

African Swine Fever (ASF) is classified by the World Organization for Animal Health (OIE) as a List A disease, with mortality up to 100%[1-3]. The latest large outbreak of ASF was reported in China, the world's biggest producer and consumer of pork, in August 2018 and have killed millions of pigs [4]. Due to the absence of effective vaccines and treatment and proper sanitary and hygiene practices, it has been a great challenge to eradicate the disease[5,6]. Particularly in China, a large proportion of pigs are kept on small-sized farms which lack the capacity for infection prevention and the control of pig diseases. This makes ASF very difficult to eradicate in China. Since the outbreak occurs, huge efforts have been made to prevent and control the fast spread of the disease, including a strict stamping-out policy, the delineating of quarantine zones of infected areas, and the rigorous culling of infected herds[7-9]. These measures inevitably induce large economic losses and affect many people and related industries[10,11].

This study, therefore, aims to propose a valuation framework for assessing the extent of both the direct and indirect financial losses caused by the ASF outbreaks in China over the period from August 2018 to July 2019. Although this ASF epidemic has not completely ended in China when we revised the paper (July 2021), we chose to look at this one-year period as an estimation interval based on the following consideration: the novel coronavirus (COVID-19) was identified in Wuhan, China at the end of 2019 and has since then spread rapidly across the whole of China and the world. The COVID-19 pandemic is not only a public health crisis but has also severely affected the Chinese economy. Thus, only examining the period before the outbreak of the coronavirus allows us to focus on the impact of the ASF epidemic, and our findings will help further studies to disentangle the economic impacts of these two overlapping epidemics.

We then develop an economic loss assessment framework of animal epidemics, which integrates substitution indicator estimation, the input-output (IO) model and partial equilibrium theory. We estimate the direct economic losses to China's swine industry from three aspects: the financial losses from the culling and removal of infected carcasses, the financial losses from damaged reproductive capacity due to the losses of breeding pigs, and the financial losses from supply disruptions caused by the abandonment of farming and other factors, such as underreporting. We also evaluate the economic losses to all sectors in China using the IO model. Furthermore, the loss in consumer surplus caused by the outbreaks of ASF and the costs incurred by the state and local governments in relation to the prevention and control of the epidemic are assessed and discussed. Finally, we provide a scenario analysis based on different assumptions regarding the reduction in pig production and price increase caused by ASF. Our findings can help Chinese policy makers to better understand the financial losses of the ASF epidemic and evaluate the effectiveness of related policies, and also provides a scientific decision-making reference for countries affected by animal diseases, to help them formulate tailored epidemic prevention and control measures, and livelihood and food safety policies.

Results

Official figures being understated

Since August 2018, ASF has been detected in Shenyang in Liaoning province, China, and then spread to all mainland provinces. As of July 2019, there were a total of 162 ASF outbreaks in all parts of China. Fig. 1 shows the numbers of ASF outbreaks and pig deaths during the first year of the ASF pandemic. According to official data, by mid-2019, 13,355 pigs had died due to the ASF virus infection, and 1,204,281 pigs had been culled to halt the virus's spread. The epidemic has caused significant economic losses to the Chinese animal husbandry industry, and has even led to a sharp disruption in the livestock supply chain and meat consumption structure.

According to China Statistical Yearbook, from 2010 to 2018, the number of pigs slaughtered and the herd size of pigs in China remained at the levels of about 700 million and 450 million heads per year. The officially released data on culling and deaths caused by the ASF accounts for less than 0.2% of the yearly number of slaughtered (healthy) pigs[12]. This figure is much smaller than some industry estimates (150-200 million)[13], indicating that the official data may not reflect the true scale of the ASF outbreak. There are several reasons we believe the official figures may be under-reported. First, in China, small and medium-sized farmers (with less than 500 heads) account for more than 95% of the pig farming industry. It is a common practice for those small and medium-sized farmers to feed untreated swill to pigs. The waste management and sanitary conditions are relatively poor, and little is invested in the prevention and control of infectious swine disease. Therefore, once a pig disease begins to circulate, those small farms will often be almost totally destroyed. A complete and accurate picture of slaughter and on-farm death figures on small and medium-sized farms is difficult to obtain. Second, due to the lack of efficient treatments and vaccines against the ASF virus, and the insufficient funds and compensations available for farmers to help them to resume breeding, most of them have decided to quit farming pigs (i.e. abandonment), at least in the short to medium term, to avoid further financial losses. This impact in terms of future shortages in the pig supply market will not be captured by the culling and death data.

It is worth noting that, from 2015, the Chinese government started to introduce non-livestock production regions (NLPRs) and pig-reallocation policies to prevent the pollution of major water sources and odour caused by agricultural activity. The implementation of those policies has caused a decrease in the number of slaughtered pigs over time. Specifically, compared with the year 2014 (i.e. 749.51 million heads), slaughtered pigs decreased by 25.36 million heads in 2015, 48.78 million in 2016, 47.49 million in 2017 and 55.69 million in 2018[14,15], suggesting that the policies have had a lasting impact on pork production. Therefore, the shrinking supply in the pig market since the outbreak of ASF has been caused by two major factors: the remaining effect of the ban on breeding of pigs policy, which we estimate to have resulted in 46 million fewer pigs being slaughtered over our sample period, and the ramifications of the ASF epidemic.

We estimate 43.46 million pigs died due to either ASF virus infection, being culled to stamp out the virus, or other ASF-related impacts during the first year of the ASF outbreaks, accounting for 6.3% of the total number of pigs slaughtered in 2018 (i.e. 693.824 million). According to the China Animal Husbandry and Veterinary Statistics (2019), we assume that the average weight of a slaughtered pig is 120.76 kg and the average dressing percentage of pigs is 70%[16]. The total economic loss caused by the ASF outbreak is estimated to be about US$111.2 billion, which accounts for 0.78% of China's GDP in 2019. The total economic loss consists of the direct economic loss to the swine industry, the indirect economic loss to all sectors of the economy, the decrease in consumer surplus, and the government loss (excluding costs for non-affected areas).

Direct economic losses

Across the Chinese provinces, the average direct financial loss due to mortality and culling was US$8.7 million per province, and almost half of the provinces suffered more than US$4.5 million in financial losses. The province of Liaoning was the most severely damaged by ASF, with a direct financial loss that amounted to US$55 million (Fig. 2). Moreover, based on official data from the Ministry of Agriculture and Rural Affairs of the People's Republic of China and the Asian Infrastructure Investment Bank (AIIB)[17,18], the financial loss from decreased reproduction due to the deaths and culling of breeding pigs is estimated to have been US$681 million. The financial loss caused by abandonment and other reasons is estimated to have been US$10 billion (Supplementary Table S1).

Indirect economic losses

The total indirect economic losses to producers in all sectors of the Chinese economy (149 sectors) are estimated to have been US$14.5 billion. Across the different provinces in China, this varies from US$2.2 billion in Guangdong province to US$1.4 million in Qinghai province. The average indirect economic losses of producers per province were US$467.8 million and 18 provinces suffered losses of between US$100 and US$900 million (Fig. 3). The provinces with high economic losses for producers are mainly located in the eastern coastal, central and southern parts of China. These findings suggest that the ASF epidemic has not only directly hit the swine industry, but almost all economic sectors through its links, leading to considerable economic losses.

Decrease in consumer surplus and government loss

The decrease in consumer surplus caused by the outbreaks of ASF is estimated to be US$84.9 billion. This is more than three times the total production losses (i.e. US$25.9 billion), suggesting the economic losses have mainly come from the decrease in consumer surplus. Finally, the government loss associated with ASF is about US$364 million (see Supplementary Table S2 for the explanation of government costs calculation). Relative to the other economic losses, the government loss is very low (Supplementary Table S3). This suggests that increases in expenditure and investment in the prevention and control of ASF may help to reduce the economic losses for producers and consumers.

Scenario analysis

To explore a broad range of future uncertainties and corresponding realities, and shed light on the economic losses likely to be associated with future ASF outbreaks, we conduct a series of sensitivity analyses based on different scenarios. First, taking the estimated case of a 6.3% reduction in China's pig production as a reference scenario (S^{0}), five other scenarios are analyzed, in which the reduction in pig production is scaled down by 20%, or scaled up by 20%, 40%, 60%, and 80% (S^{-20}, S^{20}, S^{40}, S^{60} and S^{80}). Moreover, we also explore five scenarios of pork prices where the pig carcases and pork prices either remained constant, fell by 20% or increased by 20%, 40% or 60% and 80% (SP^{-20}, SP^{20}, SP^{40}, SP^{60} and SP^{80}). We apply the same method as before to estimate the total economic loss and its components for each scenario, and the estimated results are presented in Tables 1 and 2.

From the best-case (S^{-20}) to the worst-case (S^{80}) ASF scenario, the direct financial loss to the swine industry ranges from US$9.1 billion to US$20.6 billion, and the total economic loss ranges from US$89.5 billion to US$196.2 billion, accounting for between 0.6% and 1.4% of Chinese GDP in 2019. China has the largest hog herd in the world and accounts for roughly 45% of global pork production[19]. A considerable reduction in the pig population would result in a serious shortage of pork supply, an increase in the demand for and prices of substitute commodities and feed ingredients, and even a change in the diet culture in China, and the impairment of calorie availability and nutrition intake in some underdeveloped areas in the world[13].

The worst scenarios (S^{40}, S^{60} and S^{80}) would trigger a loss of more than 1% of GDP, which would exert a significant socio-economic impact on China. Thus, the government should prepare policies to avoid these worst-case situations by implementing strong measures to effectively prevent and control the spread of the epidemic.

The ASF outbreaks are still ongoing in China and impose lots of uncertainty on pork prices which directly affect pork production and consumer welfare. Our sensitivity analysis on the pork prices shows that from the best-case (SP^{-20}) to the worst-case (SP^{80}) ASF scenario, the total economic loss ranges from US 60.6 billion to US 296.9 billion, accounting for between 0.42% and 2.07 % of Chinese GDP in 2019. The price changes mainly impact the consumer surplus and the worst-case could result in a decrease of US211.18 billion in consumer surplus, 2.9 times higher than the reference point.

Discussion

The impact of ASF on people's livelihoods and health and food security is potentially equally disastrous. In 2019, during several important national holidays, the Chinese government repeatedly released 10,000 to 30,000 tonnes of pork from state reserves to secure the meat supply. However, relative to the estimated reduction in pork supply due to ASF (3.67 million tonnes), these released frozen pork reserves represent a negligible amount. A reasonable estimate of the animal-sourced food reserve is essential to improve food safety and consumer welfare, and mitigate disease risks from livestock. In addition, to prevent the introduction of the ASF virus from and to other countries, strict compliance with regulations on the export and import of pork is important. Moreover, people's meat-consumption attitudes and behaviours have undergone some changes since the outbreak of ASF. Some people have begun avoiding eating pork because of a lack of correct understanding of the transmission of ASF virus that does not pose a hazard or a risk to humans. Thus, the government has a responsibility to educate the public and help people to face and understand animal diseases.

A lack of crucial data is one of the main challenges we faced in this research. Missing data can reduce the statistical power of a study and cause biased estimates, leading to invalid conclusions. Thus, this study uses a substitution indicator approach for handling incomplete/missing data. There is a large gap between the officially stated and actual data on the number of pigs that have died or been culled because of ASF. Estimations should be based on data and information that adequately reflect the true picture. We believe the data gap mainly comes from the following sources: the impaired reproductive capacity due to the reduction in the number of breeding pigs due to deaths and culls; the significant drop in the hog herd supply caused by farmers stopping breeding pigs, and under-reporting in official data collection. The substitution indicator estimation considers and integrates information closely related to the number of slaughtered pigs. Pig feed production is closely related to the number of pigs. Therefore, we use the information on swine feed production reduction and average feed intake for a pig to construct a substitution indicator to proxy for the actual reduction in the number of pigs. This substitution indicator estimation approach will address the incomplete/missing data problem and be very useful for other similar economic evaluations.

Methods

Economic loss evaluation system

In the study, economic losses caused by ASF are evaluated from four aspects: the direct economic losses to the swine industry, the indirect economic losses to all sectors of China’s economy, the decrease in consumer surplus and the government loss. The schematic diagram of the proposed evaluation system is shown in Supplementary Fig. S1.

The swine industry's direct economic loss includes three components: the economic loss from the culling and removal of infected carcasses, the economic loss due to impaired reproductive capacity caused by the reduced number of breeders, and the economic loss due to the shrinking of the pig supply market. A deterministic calculation and a substitution indicator are applied to estimate the above losses. The industrial structure and food consumption vary across provinces in China. To consider the possible impact of such geographic differences and achieve a more accurate estimation, we estimate each type of economic loss at the province level. These estimations can also provide a scientific decision-making reference for each province to use to make tailored control and prevention policies.

The indirect economic loss to all sectors of the economy is estimated based on complete consumption coefficients obtained from the 2017 IO table published by the National Bureau of Statistics of China[20]. A complete consumption coefficient refers to the amounts of products or services of each sector that need to be consumed directly and indirectly (that is, completely consumed) in order for each unit of the final product provided by a specific sector to be produced. See Supplementary Fig. S2 for the indirect influence coefficients of the swine industry on each industry.

We then estimate the decrease in consumer surplus, which refers to the change of consumer welfare under the pork market's partial equilibrium before and after the outbreaks of ASF. Finally, we assess the government loss, which refers to the government's emergency expenditure on controlling and extinguishing the epidemic, including investments and expenses related to culling and disposal, culling compensation, disinfection, movement restrictions in epidemic-affected areas, protective materials, emergency command and supervision, investigation and monitoring, and propaganda and training.

Economic loss from removal of swine

In this study, the direct economic loss associated with dead and culled pigs is estimated by the following equation:

$$L_0 = \left(n_d + n_k\right) \cdot w_0 \cdot v_0 \quad (1)$$

where L_0 is direct economic losses from the death and culling of pigs caused by ASF, n_d and n_k (heads) are the number of dead pigs due to ASF directly, and the number of pigs culled in the efforts to prevent the virus's spread, respectively, w_0 is the average weight of the slaughtered pigs (kg/head), and v_0 (dollars/kg) is the market price of pig carcases in each province when the ASF outbreaks occurred.

Damaged reproductive capacity

The economic loss caused by the reduction in the number of breeding pigs is denoted by L_1 and estimated by the following equation:

$$L_1 = R_b \cdot \left(n_d + n_k\right) \cdot n_b \cdot w_0 \cdot v_1 \quad (2)$$

where R_b is the ratio of the number of breeding pigs to the total number of fattening pigs at the end of each year (pig inventory) (Supplementary Table S4). n_b (head/head) is the average annual reproductive capacity of each breeding pig, and v_1 (dollars/kg) is the average market price of pig carcase during January 2019 and July 2019 in each province (see Supplementary Table S5).

Abandonment of farming and other factors

Due to the lack of the required official data on abandoned pigs, this study uses an innovative approach for handling incomplete/missing data. As we discussed previously, the actual reduction in the number of pigs due to ASF is unclear. Therefore, we use the difference between swine feed production before and that after the ASF outbreak (i.e yearly feed production reduction) divided by the average yearly feed intake per pig, as the substitution indicator for the total reduction in the number of slaughtered pigs in the estimation interval. The related calculations are as follows:

Total reduction of slaughtered pigs = reduction due to the NLPRs and pig-reallocation policies + reduction due to ASF

where the reduction in the number of slaughtered pigs due to the prohibition of pig breeding policy over the estimation period is estimated at 46 million heads, and the reduction due to ASF is equal to the official death and culling data plus the reduction in reproduction capability due to the reduction in the number of breeding pigs plus the shrinking of the future pig supply market due to the stoping of farming and other factors.

Indirect economic loss to all sectors of the economy

The input-output economic models are widely used in assessing the impact of shocks such as the COVID-19 outbreak, disasters and contagious diseases[21-23]. Based on the IO table, the IO model establishes corresponding linear equations to describe the chain relationship between production and consumption among economic sectors. Although the IO model can effectively evaluate the impact of a disruption on one sector of an economy, as well as the associated loss assessment for other sectors[24,25], one of weaknesses of the IO model is that it does not consider the impact of changes in prices. The correlation of industries in the IO table of the static IO model is expressed as follows: $AX + Y = X$, i.e. $\sum_{i,j=1}^{n} a_{ij} X_j + Y_j = X_i$, where a_{ij} is the direct consumption coefficient, A is the direct-consumption coefficient matrix, X_i is the total output of sector i, Y_i is the demand, and $X = (I - A)^{-1} Y$ is obtained. The indirect input loss is represented by the reduction of intermediate input as $\Delta X - \Delta Y$.

Since $\Delta X - \Delta Y = \left[(I - A)^{-1} - I \right] \Delta Y$, B is a complete coefficient consumption matrix, such that $B = (I - A)^{-1} - I$ [26,27].

Assume sector i suffers the loss ΔY_i:

$$\begin{pmatrix} \Delta X_1 \\ \Delta X_2 \\ \vdots \\ \Delta X_n \end{pmatrix} = \begin{pmatrix} b_{1i}\Delta Y_i \\ b_{2i}\Delta Y_i \\ \vdots \\ b_{ni}\Delta Y_i \end{pmatrix} + \begin{pmatrix} 0 \\ \vdots \\ \Delta Y_i \\ \vdots \\ 0 \end{pmatrix} \quad (3)$$

Thus, the total production loss of sector i is given by $\Delta X_i = b_{ii}\Delta Y_i + \Delta Y_i$ and the loss of the other sectors is given by $\Delta X_n = b_{ni}\Delta Y_i, (n \neq i)$.

Change in consumer surplus

In this study, we use a partial equilibrium model to evaluate the change in consumer surplus[13]. Under the partial equilibrium conditions of a perfectly competitive market, the demand curve and the supply curve jointly determine the local equilibrium point of the market. The partial equilibrium of the pork market is shown in Supplementary Fig. S3. For simplification purposes, we assume that the supply (S) and the demand (D) curves are straight lines. It is worth noting here that the curves are ideally estimated using supply and demand elasticities, which would give the actual slope and overall shape of the curves. However, our simplified linear approximation still can give a useful sense of potential impact on the consumers and provide a good estimation.

At the beginning of the period, the intersection of the supply curve S_1 and the demand curve D determines the equilibrium E of the pork market, where the equilibrium price and quantity are P_1 and Q_1, respectively. The total consumer surplus is the sum of areas A and B. Since 2015, the Chinese government has gradually implemented the ban on breeding of pigs policy in designated regions to address environmental pollution problems. Jointly with the outbreak of ASF, they caused a sharp drop in pork supply during our estimation period. Thus, assuming other conditions remain unchanged, at the end of the period, the supply curve S_1 shifts to the left, remaining parallel, to become the new supply curve S_2, and the demand curve D remains unchanged, forming an equilibrium F. The equilibrium price and quantity are P_2 and Q_2, respectively, and consumer surplus is adjusted to area A. Therefore, the change of consumer surplus jointly caused by ASF and the ban on pig breeding policy in our evaluation period is area B. The equilibrium points E and F could determine the demand curve D. In this study, we only focus on evaluating the economic impact of ASF. So after removing the effect of the ban policy, we get the supply curve S_3 and the new equilibrium H that would occur under the impact of ASF alone, with equilibrium price and quantity P_3 and Q_3, respectively. Therefore, the change of consumer surplus caused by the ASF epidemic is defined as:

$$L_2 = \frac{1}{2} \cdot (Q_3 + Q_1) \cdot (P_3 - P_1) \quad (4)$$

where P_1 is the average price of pork at the beginning of the period, P_3 is the average price of pork under the impact of the ASF epidemic alone (see Supplementary Table S6), Q_1 is the average pork consumption at the beginning of the period, and Q_3 is the average pork consumption when reduced by the ASF epidemic.

Government loss

The direct government losses (costs) associated with the ASF is estimated by the following equation:

$$L_g = (n_d + n_k) \cdot c_g + n_k \cdot c_c \quad (5)$$

Where L_g is direct government loss associated with the death and culling of pigs caused by the ASF. c_g is the average government expenditure per dead or culled pig, calculated by the sum of average costs of culling and disposal, cleaning and disinfection, movement restrictions for ASF affected areas, protective materials, emergency command and supervision, investigation and monitoring, and propaganda and training.

c_c is the average compensation for culled pigs. Information on those average costs is collected from a survey conducted by the China Animal Health and Epidemiology Center in the ASF affected areas in 2019 (internal database). Based on the government official data, the total dead and culled pigs caused by the ASF from August 2018 to July 2019 are 13,355 (n_d) and 1,204,281(n_k), respectively. See Supplementary Table S2 for details.

Statistics & Reproducibility

The results of this research can be reproduced and verified based on the information and data provided in the Supplementary Information and Supplementary data files. In this research, no statistical method was used to predetermine sample size and no data were excluded from the analyses.

Data Availablity

The data that support the findings and of this study are available from Supplementary information and Source Data Files

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Author Contributions Statement

S.Y. and B.S. conceptualized and designed the research. T.L. and Y.D. drafted the paper. T.L., M.Z., X.Z., B.W., Y.W., J.L. and X.W. acquired and analyzed the data. All authors interpreted the data. Y.D., S.Y., M.Z. and B.S.substantively revised the paper. All authors reviewed and approved the final version and agreed to be personally accountable for their own contributions.

Competing Interests Statement

The authors declare that they have no competing interests.

Tables

Table 1: Changes in the economic loss by different scenarios. This table shows the total economic losses based on different scenarios. The scenarios are set to under a range of severity of ASF epidemic. We take the main estimation - a 6.3% reduction in China's pig production caused by ASF as a reference scenario. The five other scenarios are analyzed, in which the reduction in pig production is scaled down by 20%, or scaled up by 20%, 40%, 60%, and 80%. The numbers in parentheses indicate the percentage of GDP of China in 2019.

Table 2: The economic losses by different price scenarios. This table shows the total economic losses based on different scenarios. The scenarios are set to under a range of price changes in the pig carcases and pork. We set the pig carcases and pork prices either remain constant as a reference scenario. The five other scenarios are analyzed, in which pig carcases and pork prices are scaled down by 20%, or scaled up by 20%, 40%, 60%, and 80%. The numbers in parentheses indicate the percentage of GDP of China in 2019.

Figure Legends/Captions

Fig. 1: Monthly distribution of number of outbreaks and deaths of pigs. This figure shows the numbers of ASF outbreaks and pig culling and deaths during the first year of the ASF pandemic in China. The left axis shows the monthly number of ASF outbreaks and the right axis shows the monthly number of pigs died or culled due to the ASF outbreaks. In September and October of 2018, the ASF epidemic reached its peak.

Fig. 2：The direct economic loss of each province. This figure shows the levels of economic loss across provinces in mainland China. The bright colors represent low levels of direct economic loss, while the dark colors represent high levels of direct economic loss. The number in parentheses indicates the number of provinces whose direct economic loss is within the range. The box on the right-hand side represents the South Sea Islands of China.

Fig. 3: The indirect economic loss of each province. This figure shows the levels of indirect economic loss across provinces in mainland China. The losses are estimated through the IO model. The bright colors represent low levels of indirect economic losses, while the dark colors represent high levels of indirect economic loss. The

number in parentheses indicates the number of provinces whose indirect economic loss is within the range. The box on the right-hand side represents the South Sea Islands of China.

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