Modelling the global economic consequences of a major African swine fever outbreak in China

Daniel Mason-D'Croz[1], Jessica R. Bogard[1], Mario Herrero[1], Sherman Robinson[2], Timothy B. Sulser[2], Keith Wiebe[2], Dirk Willenbockel[3], H. Charles J. Godfray[4,5]

[1]CSIRO Agriculture and Food, Commonwealth Scientific and Industrial Research Organisation, St Lucia, Queensland, Australia

[2]Environment and Production Technology Division, International Food Policy Research Institute (IFPRI), Washington, DC, USA.

[3]Institute of Development Studies at the University of Sussex, Brighton, UK

[4]Oxford Martin School & Department of Zoology, University of Oxford, Oxford, UK

[4]Author for correspondence (charles.godfray@oxfordmartin.ox.ac.uk)

ORCIDs: DM-D'C: 0000-0003-0673-2301; JRB: 0000-0001-5503-5284; MH 0000-0002-7741-5090; TBS: 0000-0001-7128-5283; KW: 0000-0001-6035-620X; DW: 0000-0002-6840-0954; HCJG: 0000-0001-8859-7232.

Abstract

African swine fever (ASF) is a deadly porcine disease that has spread into East Asia where it is having a detrimental effect on pork production. However, the implications of ASF on the global pork market are poorly explored. Two linked global economic models are used to explore the consequences of different scales of the epidemic on pork prices and on the prices of other food types and animal feeds. The models project global pork prices increasing by 17-85% and unmet demand driving price increases of other meats. This price rise reduces the quantity of pork demanded but also spurs production in other parts of the world, and imports make up half the Chinese losses. Demand for, and prices of, food types such as beef and poultry rise, while prices for maize and soybean used in feed decline. There is a slight decline in average per capita calorie availability in China, indicating the importance of assuring the dietary needs of low-income populations. Outside of China, projections for calorie availability are mixed, reflecting the direct and indirect effects of the ASF epidemic on food and feed markets.

Introduction

African swine fever (ASF) is a virulent disease of pigs that originated in Africa and has been reported in other continents from the 1950s[1]. It has recently spread into Eastern Asia and was recorded for the first time in China in August 2018. At the time of revising the paper (February 2020) the disease has spread to all mainland provinces and several million pigs have been culled in an effort to halt its spread[2,3]. Industry estimates suggest 150-200 million pigs (30% of the Chinese population) have been infected by mid-2019[3], while some press reports indicate that once under-recording is considered the figure may be as high as 50-70%[4,5].

ASF is a notifiable haemorrhagic disease caused by an Iridovirus (Asfarviridae)[6]. Its natural hosts in Africa are wild members of the pig family where it is transmitted by soft ticks and does not cause clinical disease[7-9]. Different strains of the virus strike farmed and feral pigs and their European wild boar relatives, with the strain present in China being particularly virulent and causing nearly 100% mortality[10]. Disease control consists of culling infected herds and imposing strict quarantine procedures; there is no current vaccine or treatment[11-13]. The disease is spread by contaminated products and by the animals themselves. The presence of wild boar populations or free-roaming feral pigs, as found in many areas of China, and the common practice in China of feeding untreated swill to pigs, are particular risk factors[8]. There is no direct biological risk to humans from ASF.

It is important to explore the potential consequences of a major epidemic in China and to consider potential ramifications as it spreads. The repercussions could potentially affect not only pork consumption and the incomes of pork producers, but also feed markets, the demand for pork alternatives or substitutes[5,14] and the diets of consumers in areas directly and indirectly affected by the disease.

This study uses economic modelling of the global food system to examine some of the potential consequences of a significant disruption of pig production in China. The modelling approach first considers the direct and a number of indirect consequences of the disruption of the supply of pork to the prices of pork and other food types. Second, the model is used to explore the sensitivity of the results to different assumptions about supply and demand responses. Five scenarios, where pig production in China remains constant (S^0) or is reduced by 20, 40, 60 or 80% (S^{20} etc.), are explored.

When we conceived this project, these scenarios spanned the possible range of epidemic severities. At the time of revising this paper (February 2020), it appears the last two scenarios best match the unfolding outbreak, but we present results from the full range of scenarios because these provide information about the effects of possible future less-serious epidemics.

Results

Effects on Pork prices, demand, production, and trade

China currently (2018) produces about 55 Mt (million metric tonnes) of pork per year, from more than 700 million slaughtered pigs[15]. Our simulations assume a reduction of pigs that lead to a decline in pork production in China of between 10-40 Mt in the four scenarios representing increasingly severe ASF epidemics (Figure 1A). This represents cuts of 9-34% in global production (120 Mt in 2018) compared to a reference scenario without an ASF epidemic. This decline in production would lead to increases in global pork prices of 17-85% (Figure 1B; Supplementary Table 1). For S^{60} and S^{80}, pork prices rise above beef prices, a major inversion of past price trends for the two commodities last observed in 1996[16], when Bovine spongiform encephalopathy (BSE) was linked to Creutzfeldt-Jacob disease and led to a sharp decline in beef demand[17,18].

Higher pork prices drive down pork demand in all regions, with average global per capita demand declining by 0.7-2.4 kg y^{-1} (4-16%) (Figure 1C; Supplementary Table 2). In China, the percentage reduction is slightly smaller than the global average (3-13%) though the actual drop in demand (1.4-5.3 kg y^{-1}) is above the global average. Much of the global decline (60%) happens outside of China with the greatest effects (for S^{80}) observed in Europe (7.9 kg y^{-1}), with significant drops in North America (4.5 kg y^{-1}), Latin America (2.4 kg y^{-1}), and the rest of East Asia and Pacific (2.2 kg y^{-1}).

Higher pork prices spur more production (5-22 Mt) in regions outside of China. This response makes up for about half of the losses in China so that overall global production falls by only 5-18 Mt (4–16%). Europe, the rest of East Asia and Pacific, North America, and Latin America are the regions that contribute the most in this global response with increases in pork production of 6.6, 4.4, 4.2, and 3.1 Mt respectively.

The reference scenario assumes own-price elasticities based on historical trends and which vary from country to country. To explore uncertainty in how sensitive consumers would be to changes in pork prices we implemented all scenarios under elasticities half and double the reference assumption. Global pork production and pork prices are negatively correlated with this elasticity (Supplementary Figures 1 & 2), effects that would be stronger if the changes were applied globally, not just in China.

China is the world's largest pork importer and has seen steady growth in imports over the past decade[19]. Currently, China imports account for about 5% of domestic demand[15], as China has tended to encourage feed imports to achieve greater self-sufficiency of meat production[19,20]. The changes described in Figure 1 suggest that trade will play an important buffering role in reducing the shock to Chinese consumers, albeit at the expense of pork consumers elsewhere. Pork imports into China increase by 8-32 Mt. The regions highlighted in Figure 1 that see the largest increases in production as well as declines in per capita demand are the primary sources of China's additional imports, as pork in these markets gets reallocated to respond to the shock in China.

Knock-on effects on other commodities

Higher pork prices will not only impact consumers and producers of pork. It will also have secondary effects as consumers substitute pork with relatively cheaper alternative food types (for example, other meats, and plant-based alternatives). Changes in food prices also spur the reallocation of resources in the agricultural sector in response to changing demand patterns. Key inputs to the pork sector in China are reallocated to other uses, whereas the pork sector in other regions takes a larger share of feed inputs as they expand to respond to increased demand for imports into China. This could impact the historical preference for grain imports over meat imports[19,20], at least in the short run until livestock value chains adjust and recover.

As consumers shift to pork substitutes, global production increases to meet this demand (Figure 2A). However, their prices are projected to rise which reflects limitations in animal value chains to quickly increase production. Note that these price changes are significantly smaller than those observed for pork (Figure 1), with beef and poultry seeing price rises of 1.5-6.0% and 1.6-6.7% respectively; global production increases by up to 0.1 Mt for beef and 0.4 Mt or poultry (mostly in North and South America) in the case of the most severe epidemic. The ASF epidemic in China causes significant disruption to livestock value chains in China and abroad, forcing feed markets to adjust. Figure 2B & 2C summarizes these spillover effects for key pork substitutes and feed inputs to the livestock sector in China and globally. Changes in feed inputs may negatively or positively affect productivity but we do not model these indirect effects here.

Larger disruptions are seen in feed markets than are observed in global food demand (Figure 2A) as lower pork production in China reduces the demand for feed crops used in the pig meat industry. Globally, this reduction is partially offset by increased pork production in other regions and increased beef and poultry production both in China and abroad. Nevertheless, the price declines observed for key feed inputs (maize, soybean meal, and sweet potatoes) are similar in size to the increases for meat substitutes. In the worst scenario (S^{80}), maize and soybean meal prices decline by 5% and 2% respectively. Sweet potatoes, another important feed input into the pork sector[21], see the largest price declines of nearly 15% in S^{80}, in part due to increased exports from China into a relatively thin international market. These price rises, may be ameliorated if other uses for sweet potato such as bioethanol production emerge in China. The increase in production of livestock products outside of China leads to a significant reallocation of feed globally. Demand for maize for feed in China declines by as much as 47 Mt compared to the reference scenario. Globally for the same scenario, maize feed demand only declines by 11 Mt, with the majority of maize previously destined to the Chinese livestock sector being reallocated to livestock production in other countries. Soybean meal sees a similar trend, whereas the deficit in sweet potato demand is not as readily absorbed by increased livestock production in other regions, explaining the much larger price declines. Price rises for other globally important feeds (wheat and barley) are also observed. These price rises are driven by increased demand for both throughout the world, but particularly in Europe where wheat and barley are disproportionately used in the livestock sector.

The changes in demand for different feedstocks are reflected in shifts in agricultural trade patterns. The most dramatic is a marked decrease in exports of maize from North America. This maize is redirected to support livestock sectors in North America, though there is also an increase in maize exports to Africa (and of sweet potato from China) which affects welfare as discussed below.

Effects on food and nutrition security

We estimate the sum of the spillover effects on different components of people's diets and their effects on calorie consumption. Higher prices for meat and those cereals that serve as animal feeds (e.g. wheat) lead to declines in calorie availability in most regions (**Error! Reference source not found.**A). The projected changes in food prices increase food expenditure in China (as a share of average income in the reference scenario) by as much as 9% in the most severe scenario. This increase leads to the average per capita calorie availability in China declining by more than 50 kilocalories per day or 1.6% of the reference scenario. Aside from China, we see many countries in East and Southeast Asia as well as Europe with declines in calorie availability of more than 1%. In high-income countries where baseline calorie availability is already high, such declines will tend not to have negative health impacts. However, in middle-income countries in Southern and Eastern Europe (e.g. Poland and Romania), rising food prices may be of greater concern (**Error! Reference source not found.**B). In East and Southeast Asia, a similar pattern can be seen with higher-income East Asian countries able to absorb the reduction in calories, while lower-income countries like Vietnam and the Philippines are of greater concern. The largest absolute change in hunger is found in India (more than 2 million additional people at risk of hunger) and are driven primarily by the secondary price impacts, particularly the increase in price of wheat which is an important food staple.

Several countries, particularly in Eastern and Southern Africa and Central America, see an increase in calorie availability. In these countries, maize is a dietary staple and they benefit from the lower prices caused by reduced demand for maize as an animal feed. However, this picture is complicated by the preference of consumers in these countries for white rather than yellow maize, which while not uniform across the whole region can be observed by price premiums for white maize[22,23]. Internationally and domestically, white and yellow maize prices tend to track each other; nevertheless, there is evidence that local and global markets are not well integrated, and that transmission of world prices locally is muted and often with a time lag[24,25]. Eastern and Southern Africa also consume a considerable amount of sweet potatoes and obtain a further benefit from the large price declines in this crop. Like maize price transmissions, there is reason to be skeptical of these gains, given shallow international sweet potato markets. Nevertheless, both China and Africa are net exporters to Europe[15], and increased availability of sweet potatoes for export could displace some African exports, increasing domestic supply in the region. Overall, the number of people at risk of hunger in Sub-Saharan Africa may decline by more than 1 million people in the most severe ASF scenario. However, while countries such as the DRC and Tanzania are beneficiaries, those such as Mozambique and Ethiopia would see increases in the population at risk of hunger (**Error! Reference source not found.**B). These projections of varying effects on different countries should be treated as indicative – further analysis considering the national dietary and cultural context, as well as integration between local, regional, and international markets, is warranted.

The ASF epidemic may also affect dietary diversity and nutrient intake, with negative health implications (Table 1). Further details are given in the Supplementary Notes but, in particular, the model projects possible reductions in the B vitamins and zinc. Among macronutrients, the projections show a relatively large reduction in total and saturated fat consumption, which may in some people affect their intake of critical fat-soluble vitamins.

Demand for food is relatively inelastic, so the production shock in Chinese pig production tends to increase global food expenditures. In the absence of any countervailing intervention by governments, consumers will be relatively worse off, especially in countries and regions where pork is a major part of the diet. Because IMPACT is a partial equilibrium model, it cannot be used to explore the effect of this increase in food expenditure on overall household income. To begin to investigate the effect on household incomes and changes in welfare we use the output from IMPACT as input to GLOBE (described above). We found that household welfare in China declined by between 0.12-0.78% for S^{20} to S^{80}, with household income declining by 0.3-1.8% respectively (see also Supplementary Table 3). For the worst-case ASF scenario, this is a socio-economically significant and perhaps politically relevant decline.

Outside of China, we find that only a few regions benefit from increased commodity prices (**Error! Reference source not found.**). These are major meat exporting regions, with the largest gains 0.01-0.09% observed in high income countries in Oceania (Australia and New Zealand). Most other regions see small declines in welfare. In all cases, these shifts are many orders smaller than those observed in China.

Discussion

Approximately half of global pig production occurs in China. The presence of a disease as deadly as ASF in East Asia will have major ramifications for the global food system and food security[6]. Our projections of the effects of a major production shock in the Chinese pig industry using a global partial equilibrium economic model of the food sector provide an indication of the capacity of the national and global food system to absorb the perturbation without large effects on prices and consumption. This resilience comes about through international trade and consumers switching to non-pork foods. The effects of an ASF outbreak in China are not limited to China, but are experienced in other countries and affect other food types. Whilst we modelled a shock and a response that occurred within a year, delays in restocking and an epidemic that lasts for a greater period of time are likely to lead to more severe effects.

Recent data on pork prices in China show increases of the order of 50% during 2019 (Figure 4), which may have contributed to inflation in China recently exceeding Government targets. These are consistent with our projections, though we think it is too early to do a formal comparison and validation of the model. There is still considerable uncertainty about the extent of the epidemic, and some of the economic data is still preliminary.

It is important to explore whether this conclusion is a consequence of model assumptions that may not reflect real-world food systems accurately. Models such as IMPACT assume that markets regularly equilibrate. If there are frictions or disruptions, so that markets clear more slowly or trading flows adjust less rapidly, then the initial effects of the outbreak may be larger and more spatially contained. IMPACT also tends to overestimate the degree to which domestic markets in low income countries are tied to world markets and hence some of the effects of the ASF outbreaks on sub-Saharan countries may be less than projected[24-26]. In addition, IMPACT uses data from FAO and these are based on national statistics, which have been found in some studies to be inconsistent, particularly with respect to pork[27].

Several aspects of real food systems may influence the effects of an ASF outbreak. First, the release of frozen meat in 2019 is thought to have tempered pork price rises in China[5], and this approach could be taken again. Such policy decisions would likely be captured by a simple reduction in the size of the production shock in proportion to the amount of stocks released. Pork production and consumption varies across the country[28]. Per capita consumption is lowest in the north and east and highest in the south and west: the region with least consumption is the western province of Xinjiang (3.8 kg y^{-1}), with its large Muslim population, and highest in the southern provinces of Sichuan & Chongqing (>30 kg y^{-1}). Since the outbreak began, the Chinese authorities have introduced and sometimes relaxed different regulations about inter-province pig trade that will have affected price transmission and local prices, but these are not modelled here.

Second, it is possible that the presence of ASF affects not only supply but also demand. In previous outbreaks of livestock diseases, demand of affected commodities was reduced in part due to a loss in trust in the quality and safety of the commodities[29,30]. There is evidence of this already occurring in China[5]. This impact can linger beyond the initial outbreak and can take some time (a decade or more) before consumers fully return to previous levels.

Third, governments often respond to production shocks by imposing tariffs or export restrictions. These policies are typically motivated by a wish to protect local producers or consumers (or a political imperative to be seen to be doing something), with their effectiveness depending on trading partners. Import restrictions on live animals or animal products are likely to be introduced as quarantine measures. In general, trade restrictions will tend to reduce the capacity of the global food system to buffer production shocks, though genuine quarantine measures can help contain the disease.

Finally, the current ASF outbreak is occurring at a time of tension in global trading relationships, especially between China and a major source of pork imports, the United States. Tariffs on US pork imports into China have recently increased from 12% to 62%, though this has not disincentivised some major purchases[31]. In July 2019, net tariffs were at 81%, though the politics are fluid, which adds an additional layer of geopolitical uncertainty to the way the global food system will be affected by the disease outbreak. The outbreak of the coronavirus (covid-19) that is developing as we revise the paper (February 2020), and which affects humans (and conceivably pigs), adds another level of uncertainty that is as yet impossible to assess, though possibly it may have reversed a small decline in pork prices at the end of 2019 (Figure 4).

Since the beginning of the project, the outbreak has expanded rapidly to other countries. ASF has now been recorded in 2019 from Mongolia (January), Vietnam (February), Cambodia (April), North Korea (May), Laos (June), Philippines (July), Myanmar (August), Timor-Leste (September), South Korea (November) and may be in Indonesia (November). Further modelling of a broader epidemic in Asia would be informative, as well as in Europe, which has suffered a number of smaller-scale outbreaks. In Europe, the pig industry is more intensive and more vertically integrated[32], in part due to challenges from other diseases, and containment should be easier compared to Asia with its large smallholder sector[33]. Nevertheless, the disease is causing major concern in Europe, with Denmark building a fence along its southern border to prevent wild boar entering from Germany. A serious ASF outbreak in Europe could undermine the Common Agricultural Policy and "dramatically shake European identity and cohesion"[34].

An ASF outbreak will have both macroeconomic and welfare economic consequences. Agriculture currently makes up 7-8% of Chinese GDP[35] with the pork sector contributing 10-15% of gross agricultural value added[15]. The pork sector is probably worth more than $US 100B and the worst outbreaks we simulated would reduce Chinese GDP by approximately 1%. For context, this reduction is a little less than the effect of the 2008 Sichuan earthquake, but of the order of 20 times greater than recent avian flu outbreaks or the SARS outbreak centred on southern China in 2002-3. In the same regions, the early 2000s avian flu outbreak depressed Vietnam GDP by 0.3-1.5% ($0.1-0.6B)[36]. Further analysis of the costs of the epidemic, in particular of mass culling, and of alternative mitigation strategies would be welcome.

Though analysis with the GLOBE model suggests average household incomes will decline by less than 2% in the worst case, predominantly smallholder farmers in the lower deciles of the income distribution will be affected by ASF [37]. Some farmers will be insured against epidemic risk, but the majority will have no or inadequate insurance. Thus, it is likely that government would need to provide income support. Additionally, farmer and farmer family mental health impacts are likely to be substantial.

China will likely import more pork and less pig feed with consequences for trading partners. Pork producers in exporting countries will benefit, though consumers will experience higher prices in domestic markets. Feed producers will look for new markets, resulting in increased exports of commodities such as maize and sweet potato to emerging economies in sub-Saharan Africa and elsewhere. In this case, there is a risk that local agriculture may be undermined, especially if exports are supported by direct and indirect subsidies and other market distortions.

In the longer term, the current ASF outbreak will spur investment in research and innovation with the possibility of vaccine development [13]. A less optimistic possibility is that the disease becomes endemic with periodic resurgences buffeting the food system. This possibility would reduce the attractiveness of pig production for investment and tend to increase food prices. Consumers could respond by switching to meat substitutes, chicken or ruminant meats. Given the different consequences for human health and the environment of the production and consumption of these different food types, there are possibilities for both positive and negative indirect effects of continuing ASF outbreaks.

Methods

Model

We studied the effect of ASF in China on food system dynamics using two linked global models: the International Model for Policy Analysis of Agricultural Commodities and Trade (IMPACT) developed by the International Food Policy Research Institute (IFPRI)[38,39], and a dynamic version of the GLOBE computable general equilibrium model[40]. These two models were used to assess the potential effects on the broader global economy and average incomes across regions and countries that are linked to China through international trade. The IMPACT model has been used to explore other supply shock scenarios, for example, the effects of a major disease of rice in South-east Asia[41] and extreme weather events affecting particular regions[42] or the global food system[43].

Briefly (See Supplementary Materials for fuller explanation), IMPACT is a partial equilibrium economic model that represents the production and consumption of 62 agricultural commodities in 158 political units (which are composed of one or more sub-regions where political units encompass several water basins). Consumer diets are determined by income and food prices summarised by functions (with constant price elasticities) describing how they affect demand; while producer behaviour is determined analogously by commodity prices and input costs. Population and income are treated as exogenous, with crop yield growth rates having both exogenous and endogenous components. IMPACT is linked to crop and hydrological models (that can themselves be driven by global climate models) to determine changing yield patterns. Different countries are linked by international trade and IMPACT simulates the operation of the global economy, finding world prices for all included commodities that clear international markets. IMPACT does not directly project future diets, but dietary patterns and calorie intake can be estimated under different scenarios and compared with WHO guidelines for a healthy diet (assumed to be ~2500 Kcal for men and ~2000 Kcal for women) as was done in Springmann, et al. [44].

The IMPACT model only includes agricultural goods and markets and does not incorporate links between agriculture and the rest of the economy. To capture these links, we use a separate global model (GLOBE) that operates at the level of national economies, incorporating production and demand for all commodities, and trade between countries. This model simulates the operation of commodity and factor markets in all countries and finds equilibrium commodity prices and wages of factors of production that clear both domestic and world markets together. This dynamic computable general equilibrium (CGE) model is calibrated with a global data set maintained by the Global Trade Analysis Project (GTAP) at Purdue University [45].

In our analysis, the IMPACT model is used to determine the effects of a shock on the agricultural sectors. The results are then "soft linked" to the GLOBE CGE model[46], which is used to analyze the effects of the changes in agriculture on the rest of the economy, tracing the direct and indirect links between the agricultural and non-agricultural sectors. The CGE model captures links between commodity markets and factor markets, showing how a shock in agriculture affects incomes, supply, demand, and prices across the economy.

Scenarios

Our main analysis is a comparison of a reference scenario with a series of alternative scenarios in which we assume that the number of pigs in China is reduced by 20, 40, 60 and 80% in a single year. In the face of great uncertainty (at the time the project was conceived) about the possible severity of an epidemic we choose these five alternatives to span a full range of possibilities. The reduction includes pigs killed by the disease and those slaughtered (but not consumed) to prevent the spread of the epidemic. Pork prices in China cycle with a period of approximately four years[47] which seems to be associated with inaccurate expectations about future profits. We think it likely that the appearance of the epidemic reset profit expectations and we make no attempt to model the cycle. There has been a reduction in China's pig herd (though less, only 2%, in pigs slaughtered) since about 2013 due to tightening environmental regulations, but this has been relatively gradual and very different from the dramatic declines beginning in 2018.

The assumed income elasticity is 0.18, which is broadly consistent with income elasticities estimated by the USDA[48] (0.24 for urban and 0.13 for rural households). IMPACT's default own-price elasticity of demand for pork is -0.23. This is within the range of price elasticities reviewed by Chen et al [49] though on the inelastic side as IMPACT elasticities are calibrated for long-run as opposed to short-run behaviour. This elasticity represents an average Chinese consumer and is a simplification of the diversity of demand outcomes (preferences, incomes, available food budgets, prices) within the country. This simplification allows us to estimate average changes but will not allow us to capture some of the potential distributional and compositional effects that might occur from production and price shocks that would impact different consumers to varying extents. We explore the sensitivity of the results to the value of the own-price elasticity for pork by halving or doubling the assumed value, which we expect to include the likely range of uncertainty about that parameter.

Data availability

Full documentation of IMPACT and GLOBE are available at http://ebrary.ifpri.org/cdm/ref/collection/p15738coll2/id/129825 and http://ebrary.ifpri.org/cdm/ref/collection/p15738coll2/id/132757, respectively. Model output from this study can be found in the Mendeley Data repository at: http://dx.doi.org/10.17632/zgrngg5hp5 .

Tables

Table 1 Changes in selected macro and micronutrients in China

	Nutrients	China AR[1]	RNS[2]	% change in nutrient intake in 2020 under the four ASF Scenarios: 20%	40%	60%	80%
B Vitamins	Folate (B9, mcg [3])	1.1	403	0	-0.1	-0.1	-0.1
	Niacin (B3, mg [4])	1.8	27	-0.4	-0.8	-1.3	-1.6
	Riboflavin (B2, mg)	1.4	2	-0.3	-0.7	-1	-1.3
	Thiamin (B1, mg)	1.8	2	-0.6	-1.2	-1.8	-2.3
	Vitamin B12 (mcg)	0.8	2	-0.8	-1.5	-2.3	-2.9
	Vitamin B6 (mg)	2.6	3	-0.3	-0.6	-0.8	-1.1
Minerals	Iron (mg)	1	21	-0.1	-0.2	-0.4	-0.5
	Phosphorus (mg)	2.6	1925	-0.2	-0.5	-0.7	-0.9
	Potassium (g)	1	5	-0.1	-0.2	-0.4	-0.5
	Zinc (mg)	1.2	17	-0.4	-0.8	-1.1	-1.5
Fat	Total Fat (g)		91	-0.7	-1.3	-1.9	-2.5
	Saturated Fat (g)		27	-0.8	-1.6	-2.4	-3.1
Fat Soluble Vitamins	Vitamin A (mcg [5])	1.9	1330	0.2	0.3	0.5	0.7
	Vitamin D (mcg [6])	0.5	1	0.1	0.2	0.2	0.3
	Vitamin E (mg [7])	0.7	11	0	-0.1	-0.1	-0.1
	Vitamin K (mcg)	4.5	299	0	-0.1	-0.1	-0.1

[1] Adequacy Ratios in the absence of ASF; the ratio of average daily availability of a nutrient to the requirement for a representative consumer. Data from https://impactnutrients.ifpri.org/nutrientModeling/

[2] Reference Nutrient Supply: average nutrient supply in reference scenario (units) /person/day

[3] mcg dietary folate equivalents

[4] mg niacin equivalents

[5] mcg retinol activity equivalents

[6] Does not account for vitamin synthesised in the presence of sunlight

[7] mg α-tocopherol

Table 2. Percentage change in average household welfare by region and scenario. The heat chart uses two colour schemes reflecting the fact that the impacts in China are 10 times higher than in other regions. Changes in China are in red and range from 0 (white) to -1% (red). A different scale is used for other regions where blue reflects welfare improvements (up to 0.1%) and orange reflects welfare reductions (up to -0.1%)

		ASF20	ASF40	ASF60	ASF80
East Asia and Pacific	China	-0.12	-0.28	-0.49	-0.78
	Other East Asia	0.00	0.00	-0.01	-0.01
	High Income Asia	0.00	-0.01	-0.01	-0.02
	High Income Oceania	0.01	0.03	0.06	0.09
South Asia	India	0.00	0.00	0.00	0.00
	Other South Asia	0.00	0.00	0.00	0.00
Latin American and Caribbean	Central America	0.00	0.00	0.00	-0.01
	South America	0.00	0.00	0.00	0.00
Sub-Saharan Africa	West Africa	0.00	-0.01	-0.01	-0.02
	East Africa	0.00	-0.01	-0.01	-0.02
	Southern Africa	0.00	0.00	0.00	0.01
Middle East and North Africa		0.00	-0.01	-0.01	-0.02
Europe		0.00	0.00	0.00	0.00
North America		0.00	0.00	0.00	0.01
Former Soviet Union		0.00	-0.01	-0.01	-0.02

Figure Legends

Figure 1. Changes in Chinese and selected regions pork production (Mt) (A) world pork prices (% change) (B) and average per capita food demand (kg/person/yr) in China and selected regions (C)

Figure 2. Changes in selected commodity prices (% change) (A) and household food demand (Mt) (B) and animal feed demand (Mt) (C).

Figure 3. Effect of ASF epidemic on calorie availability and risk of hunger. (A) Percent change from reference scenario in calorie availability in S^{80}. (B) Changes in the population at risk of hunger in absolute (million) and relative terms (%)by region and selected countries in S^{80} compared to reference.

Figure 4. Changes in Chinese pork prices from 31 Dec 2017 to 6 Feb 2020 (data from the Professional Pig Community; https://www.pig333.com/).

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Contributions

The project was conceived by HCJG, SR & DM-D'C; all authors contributed to its execution and write up with DM-D'C leading on the IMPACT analysis, DW on the GLOBE analyses, JRB on the nutrition aspects and HCJG & DM-D'C on writing the paper.

Competing Interests

The authors declare no competing interests.

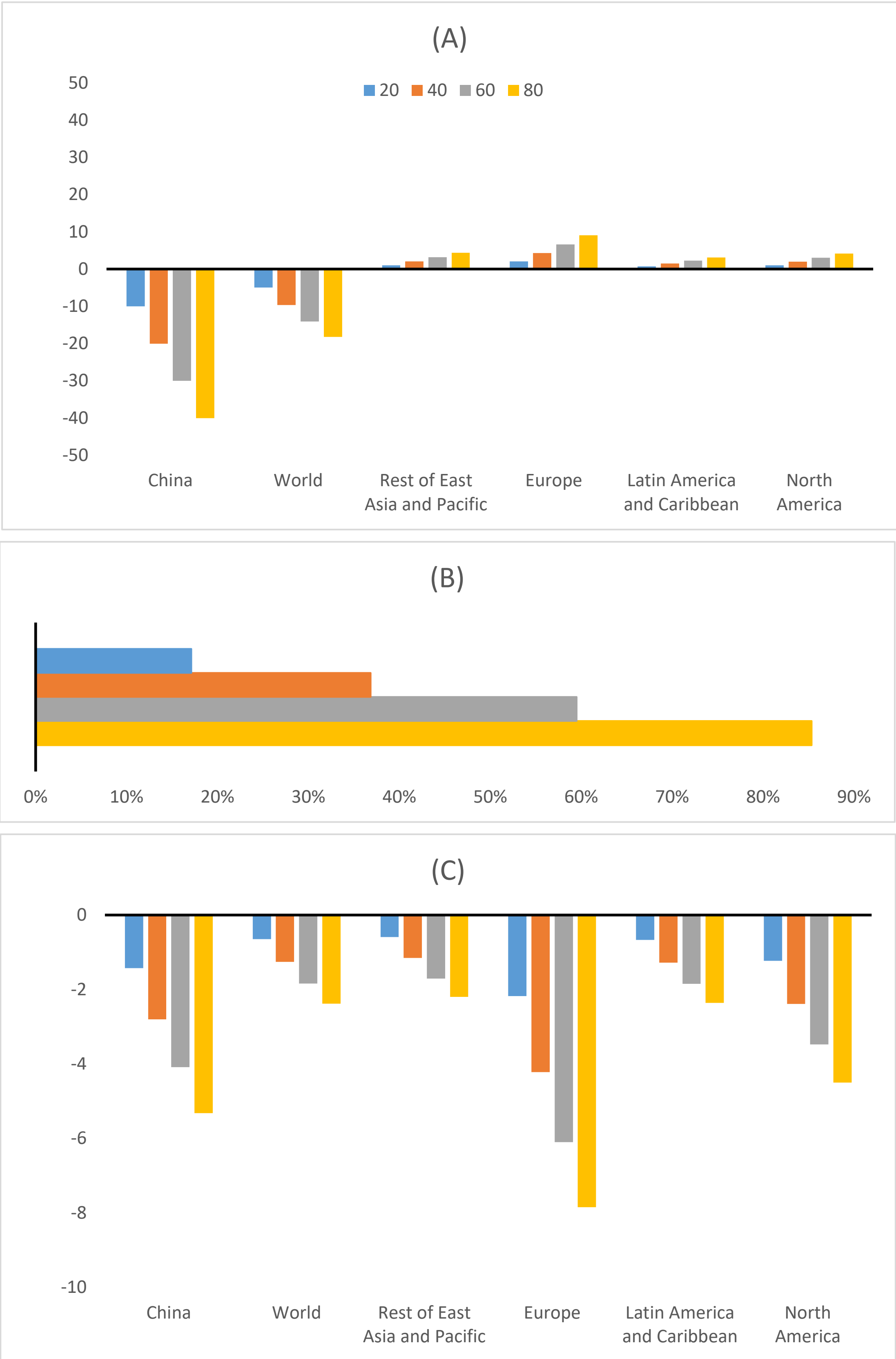

Figure 1. Changes in Chinese and selected regions pork production (Mt) (A) world pork prices (% change) (B) and average per capita food demand (kg/person/yr) in China and selected regions (C)

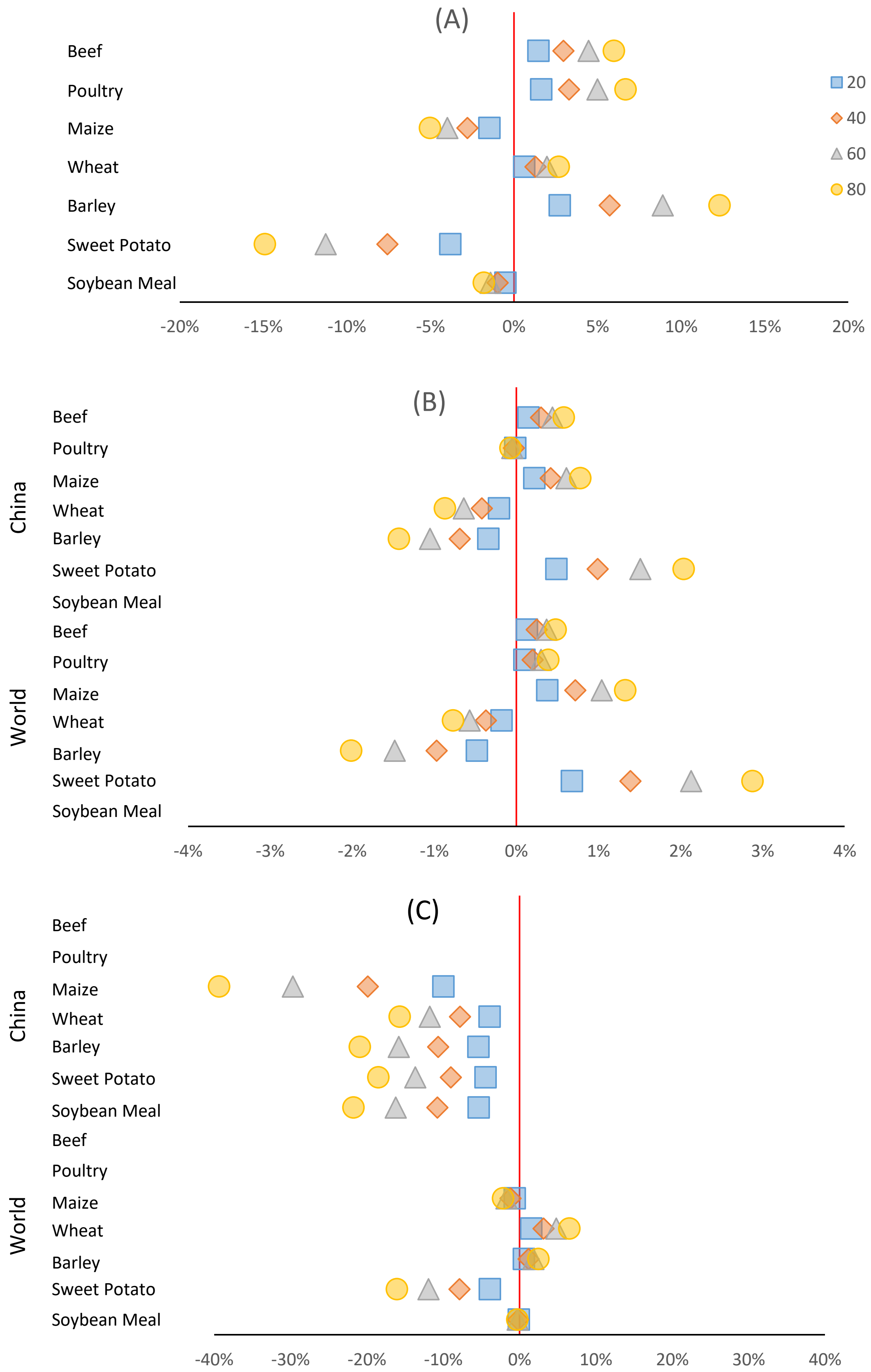

Figure 2. Changes in selected commodity prices (% change) (A) and household food demand (Mt) (B) and animal feed demand (Mt) (C).

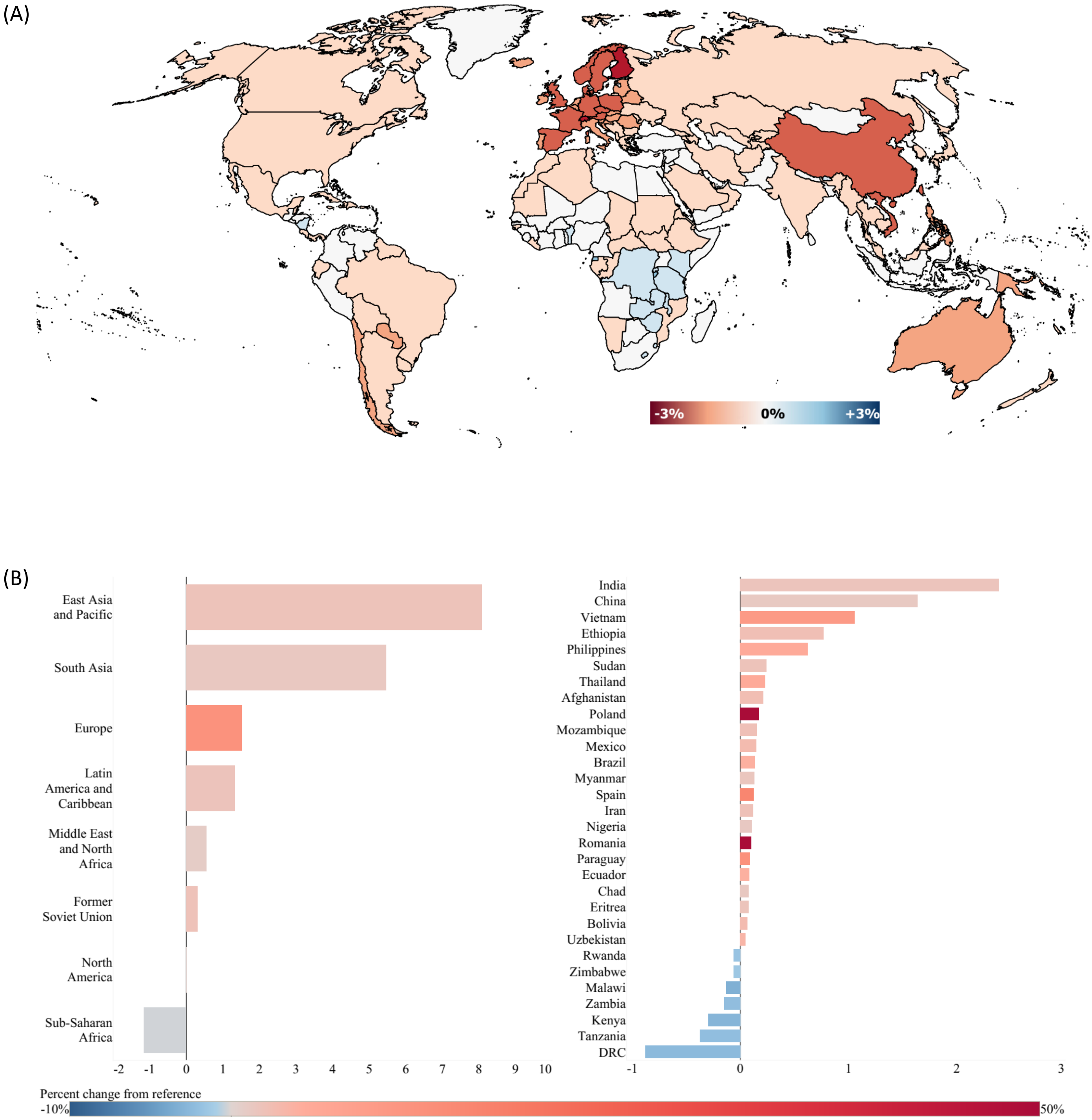

Figure 3. Effect of ASF epidemic on calorie availability and risk of hunger. (A) Percent change from reference scenario in calorie availability in S^{80}. (B) Changes in the population at risk of hunger in absolute (million) and relative terms (%) by region and selected countries in S^{80} compared to reference.

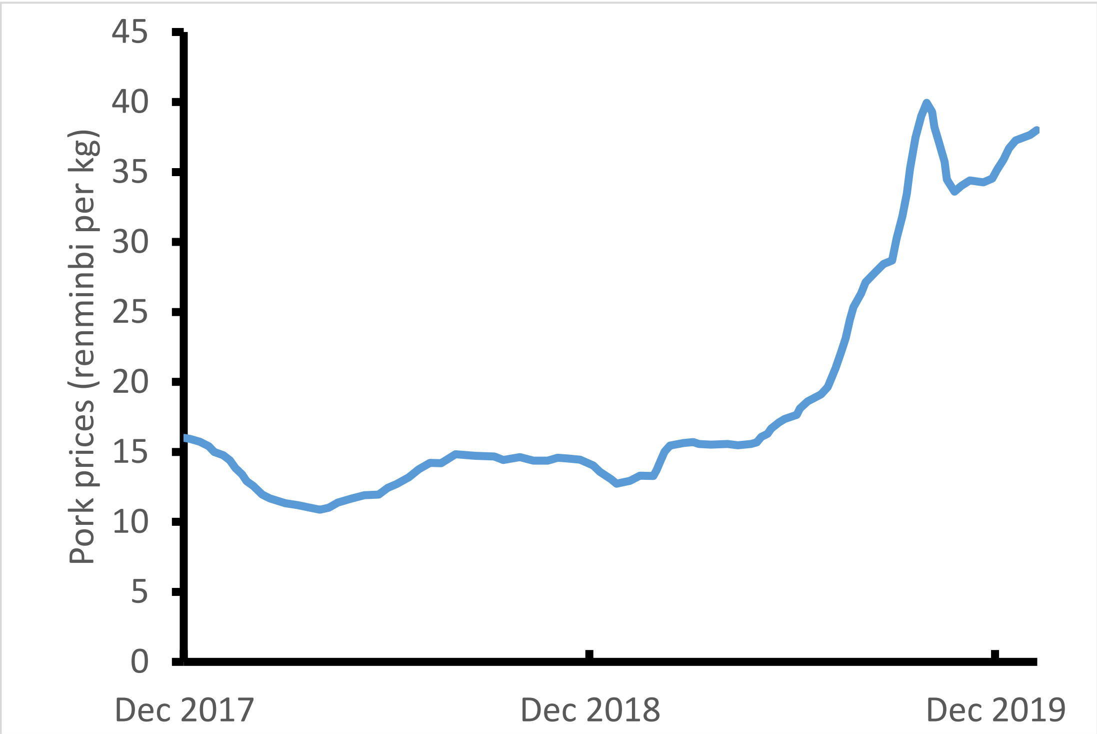

Figure 4. Changes in Chinese pork prices from 31 Dec 2017 to 6 Feb 2020 (data from the Professional Pig Community; https://www.pig333.com/).