African Swine Fever in China: Shocks, Responses, and Implications

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Abstract

African Swine Fever broke out in China in late 2018 and has caused substantial loss to China's hog industry. Pork is the dominant meat in Chinese's diet with its price being a critical component of China's Consumer Price Index. In 2019, a large increase in the pork price caused by the sharp reduction in pork supply incentivized the government to help recover pork production by subsidizing large-scale hog farms. This policy, however, may not be the most effective or efficient for achieving short-run price reductions. Based on the new estimation of China's meat demand, we show that subsidizing the production of chicken, which is a major substitute for pork and currently counts for a small share of meat consumption, can bring down the pork price faster and at lower government costs. We discuss price dynamics and consumer surplus of alternative subsidy plans over a 30-month window. Simulation outcomes suggest that subsidizing chicken farms in addition to hog farm is likely to bring various benefits to consumers, producers, and the government.

Keywords: African Swine Fever, China, Meat demand, Flexibility, Production recovery, Subsidies.

JEL Codes: Q11, Q17, Q18

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1. Introduction

China, the world's largest producer and consumer of pork, reported the first case of African Swine Fever (ASF) in one of its Northeastern provinces on August 3, 2018 (USDA, 2019a). Since then, the disease has spread to all of China's mainland provinces and caused substantial loss to its hog industry (USDA, 2019b). Substantial loss has been caused within a year. By August 2019, the stock of hogs decreased from 320.8 million to 190.9 million, a loss of 40.5%, while the stock of sows fell from 31.3 million to 19.0 million, or 39.3% (see figure 1).

It did not take long for the devastating loss of hogs to translate into a drop in the pork supply, which has been reflected by the rapidly increasing wholesale and retail prices of pork. The real wholesale price, according to data reported by the Chinese Ministry of Agriculture and Rural Affairs, has more than doubled the pre-ASF level by the end of October 2019, reaching a historical record of 51 RMB per kilogram.[1] In the meantime, the retail price climbed all the way up from 25 RMB per kilogram to over 60.

With pork being the dominant meat in Chinese diet, the sharp price increase has made headlines on major news media and put the Chinese government under pressure of keeping pork prices down to a "reasonable range", especially during late 2019 awaiting for the peak demand season approaching the Chinese New Year in February 2020.[2] Both the central and provincial governments have announced a series of supporting policies, almost all aiming at boosting the hog production within a relatively short period of time.

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[1] Prices are reported in 2018 real RMB throughout this article.

[2] News article titled "summary of the State Council's executive meeting on November 6, 2019." Available in Chinese at: http://www.gov.cn/premier/2019-11/07/content_5449896.htm

However, China's domestic supply of pork may not be brought up quickly due to the long biological cycle of hog production. With ten months needed from an embryo to a finished hog in China, even in an ideal situation where ASF were extinguished and millions of piglets were added to the current stock, the supply of pork might not be able to recover anywhere near the pre-ASF level until the end of 2020. Worse still, the disease remains far from being eliminated, and achieving such a large increase of piglet supply is unlikely after a two-fifths reduction in the domestic stock of sows as of December 2019. Besides trying to increase domestic hog production, China has increased pork imports during 2019 to two million metric tons, nearly 70% up from the previous year. However, imported pork may not increase the domestic supply in any significant way, because it only contributes 1-2% of yearly domestic consumption before 2019 and 4.7% in 2019 (see figure 3).

Alternatively, we argue that an effective and efficient policy potentially helping suppress pork price in the short-run is to increase the supply of ASF-resistant substitute meats with shorter production cycles. Chicken tends to be an ideal candidate. So far, chicken only accounts for about 12-13% of meat consumption in China or less than one third of the pork share. This share is much lower than the world average of 41%, that for most western countries of 44%, and even that for other Asian countries with similar food cultures.[3] It suggests considerable room left for China to further expand its chicken consumption.

In order to examine the evolvement of China's meat markets under alternative policy options of the Chinese government, we study the short-run pork price responses to alternative policies. Specifically, we use Chinese meat consumption and price data, including pork, beef,

[3] Meat consumption data from OECD. https://data.oecd.org/agroutput/meat-consumption.htm

mutton, poultry and aquatic products, from 1980 to 2018 to estimate own-quantity flexibility (i.e., percent change in price of a good over one percent change in quantity supplied) of pork and its cross-price flexibilities against other meats. The first-difference Inverse Almost Ideal Demand System (IAIDS) model, a model that is more appropriate for perishable commodities than the commonly used AIDS model (Eales and Unnevehr, 1993; Eales and Unnevehr, 1994) is employed. We also allow for structural breaks based on the Maximum Likelihood Estimation (Moschini and Meilke, 1989).

Using the estimates of quantity flexibilities from the IAIDS model, we characterize a simulation model to evaluate price effects of alternative domestic policies on meats. We estimate the total amount of subsidies needed to increase the output of pork for target price reductions specified by the government. Alternatively, we estimate the subsidies needed to increase the output of chicken for the same price reductions. With a few additional assumptions, we compare price dynamics under various subsidy allocations to hog and chicken farms from June 2019 to December 2021. Subsidizing chicken farms in addition to subsidizing hog farms, as we show, can bring down the pork price a few months easier and reduce government expenditure considerably.

Our study makes mainly two contributions to the literature. One, we are the first to model China's meat demand over a four-decade window and provide updated estimates of price-quantity relationships for four major meats. Allowing for a structural change gives our study another advantage over prior ones. Second, we contribute a first policy discussion regarding the recovery of the world's largest hog industry after the heavy hit by ASF. Insights of this article may also benefit other countries which suffer from sever livestock production loss due to animal epidemics.

We describe the ASF situation and policy alternatives in China in the next section, where both the government's responses and our proposed alternative policies are discussed. The third section provides our econometrics model of meat demand in China as a foundation for the quantitative policy analysis. Economic impacts of each alternative policy will be derived and compared from simulated results in the fourth section. Section 5 gives the concluding remarks.

2. Supply Shock and Alternative Policy Responses

ASF has caused substantial decreases in the stock of hogs and sows in China, and large price increases follow. Because pork price accounts for 9% of China's Consumer Price Index (CPI), keeping pork prices reasonably low help stabilize CPI at a relatively low level (Zhang et al., 2018). As a result, the Chinese governments, at the central and provincial levels, have launched a series of policies to support the recovery from the loss and increase hog output within a short period.

In this section, we first discuss the changes in hog stocks and pork prices since the outbreak of ASF. We summarize the policies by surveying news reports and discuss the limitation of current policy responses. Next, we propose an alternative policy response and discuss its advantages in bringing down pork prices.

2.1 Declining Hog Inventory and Rising Prices

ASF heavily struck China's hog industry starting in August 2018 and throughout 2019. As shown in figure 1, the month-end inventory of hogs and sows both experienced sharp and rapid declines and have only shown limited evidence of recovering. By February 2020, the stock of hogs is as low as 60% of that in July 2018, while the stock of sows is only 66% of its pre-ASF level. Not surprisingly, the production of pork in 2019 declined by 21.3% compared with that in 2018.

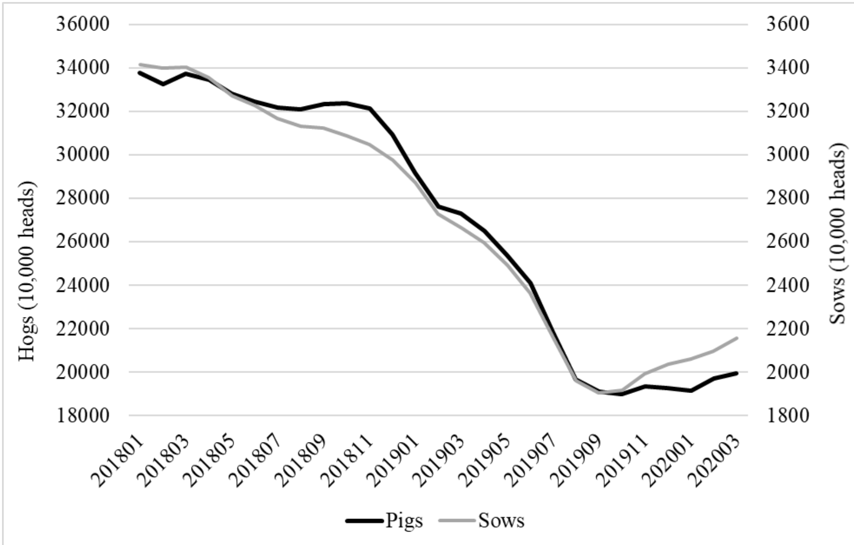

Figure 1. Stock of Pigs and Sows in China

Source: Ministry of Agriculture and Rural Affairs of China

Notes: Unit is 10,000 heads. Horizontal axis indicates year and month. For example, 202002 refers to the 2nd month of 2020, namely, February 2020.

The price of hog and the price of pork both go up and break their historical records starting from mid-2019. Weekly national average prices are reported in figure 2. Both prices more than double from the outbreak of ASF to the end of 2019. With pork being the dominant meat in Chinese diet (Ortega et al., 2015), the pressure for the government to keep pork prices at a relatively low level, not surprisingly, grows and becomes quite considerable.[4] Real prices of other meats remain relatively stable during the same period (see appendix 2).

[4] News article titled "behind the CPI increase of 3.8% in October 2019." Available in Chinese at: http://www.gov.cn/xinwen/2019-11/09/content_5450485.htm

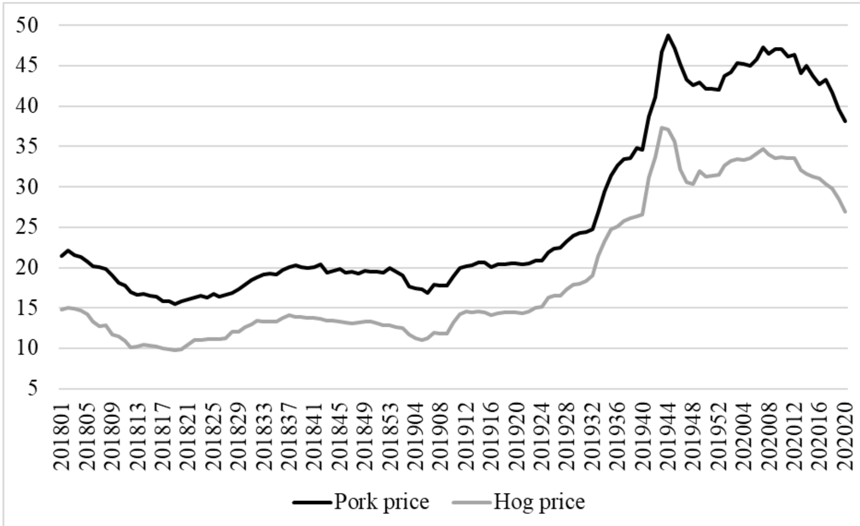

Figure 2. Nation-Level Weekly Hog Price and Pork Wholesale Price

Source: http://zhujiage.com.cn/ Data are subscribed from the website and cleaned by authors.

Notes: Real prices are reported in the unit of RMB per kilogram with January 2018 RMB as the baseline. Hog price is the average price received by slaughtering firms, and pork price is the average price in pork wholesale markets. Horizontal axis indicates year and week. For example, 202020 refers to the 20th week of 2020.

2.2 Current Policy Responses

Since late 2019, the governments have launched financial supporting programs to help large-scale hog farms restore the production and largely increase hog outputs in 2020 and 2021. As shown in table 1, all major producing provinces have announced their recovery plans and corresponding financial supports on large-scale hog farms. Billions of RMB have been or will be put into those recovery programs.

The overall recovery target set by the central government was announced in March 2020, aiming at bringing the annual hog production close to the pre-ASF level by the end of 2020 and back to the level by the end of 2021. This is an ambitious goal, given that the annual hog production in 2019 is 150 million heads down from the 2018 level and the stocks of sows by the end of 2019 is only 60% of its pre-ASF level. To increase the hog output by such a large portion requires first increasing the stock of sows by a large portion. Given the biological lags, achieving the large increases is difficult if not impossible within such a short period. The fact that pork prices stay at a high level until June 2020 is evidence of the biological lags (see figure 2). We revisit the biological cycle of hog production in section 4.2.

Table 1. Supporting Policies to Hog Production after the African Swine Fever

Date of news released	Provinces	Types of support	Amount (10 mil RMB)	Targeted deadline	Targeted increase (mil heads)
04/19/2019	Guangdong	1, 2, 3	--	12/2020	3.6
09/07/2019	Hebei	3	66.8	--	--
09/30/2019	Fujian	2	--	12/2020	3.2
10/17/2019	Zhejiang	1, 2, 3	>54	12/2021	5.4
10/17/2019	Hubei	3	42	12/2022	11.7
10/24/2019	Henan	3	<6	12/2022	
11/18/2019	Chongqing	2, 3	66.5	--	--
11/23/2019	Jiangsu	3	39.6	--	--
11/25/2019	Liaoning	2	4.1	07/2019	--
11/25/2019	Anhui	3	13	--	--
11/26/2019	Tianjin	3	5.2	--	--
12/04/2019	Jilin	2	1.8	12/2020	--
03/11/2020	Hunan	1	27.8	--	--
03/19/2020	All	2	>44.4	12/2021	>150
03/26/2020	Heilongjiang	1, 2, 3	>3	12/2020	4.0
04/24/2020	Shandong	1	7.9	--	--
05/06/2020	Sichuan	3	15	12/2020	11.5

Source: Links to the news are reported in appendix 1. All news is in Chinese.

Notes: *Types of support* is a categorical variable with 1 meaning access to credits, 2: discounts on loan interests, and 3: direct payments. Only a few policies set specific targets for production recovery by the deadlines. Most policies only claim to aim at "helping the recovery". 7 RMB is worth about 1 USD.

Besides, China has increased the import of pork over the past year. Figure 3 shows a considerable increase in pork import as well as import of beef, mutton, and fish since the outbreak of ASF. By the end of 2019, the monthly quantity of pork imported more than double the average monthly quantity during 2017 and 2018. Total quantity of pork imported in 2019 is 68% higher than that in 2018. Even with such a sharp increase, however, the imported pork counts for less than 5% of total pork consumed in 2019.

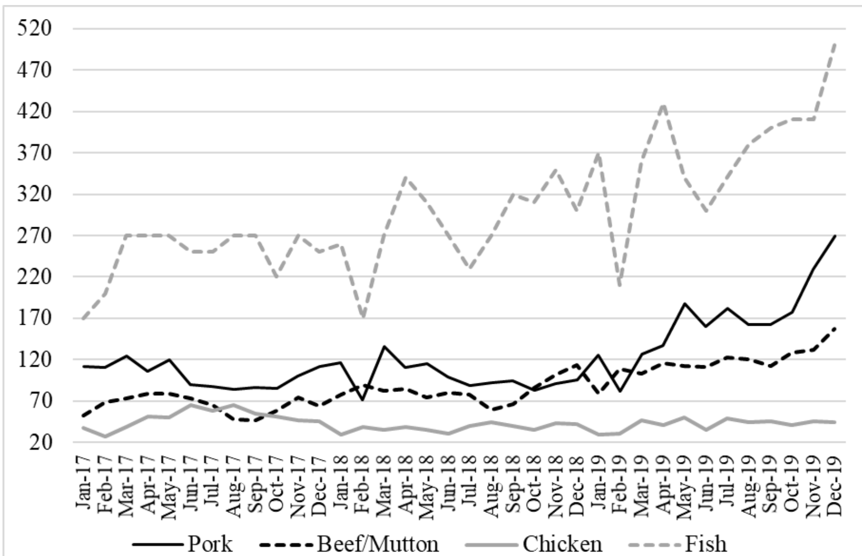

Figure 3. China's Monthly Import of Meats

Source: General Administration of Customs of China.

Notes: Unit of weight is 1,000 MT.

2.3 A Potential Alternative Policy Response

Prior studies show that chicken and beef, especially chicken, are substitutes for pork in China (Gould and Villarreal, 2006; Liu et al., 2009), though cross-price elasticities are estimated using relatively dated data. Compared with the production of hog, the production of cattle takes an even longer cycle and is more land intensive (Peters et al., 2014). In the international agricultural market, China has no comparative advantage in producing cattle and has been importing large quantities of beef in recent years to meet the domestic demand (Liu and Xiao, 2016).

Chicken, on the other hand, has a much shorter cycle to produce. As detailed in section 4.2, the production of chicken only takes about one quarter of the time that hog production needs. Additionally, the production of chicken is less environment, land, and labor intensive. We argue that the goal of bringing down pork prices can also be achieved and achieved within a potentially shorter period of time by expanding the production of chicken. The fact that chicken only accounts for about 12-13% of meat consumption in China also suggests considerable room to further increase chicken consumption.

3. Demand Estimation

Meat demand in China has experienced significant changes in recent years. Existing studies that estimate meat demand only use data up to 2011 (Chen et al., 2016). In order to estimate outcomes of alternative policy responses to the ASF, we need updated estimation of price-quality relationships. Thus, our first task is to update data of meat consumption and prices in China to 2018 and estimate the demand of meats. Relying on an augmented AIDS model, we identify a structural break in the meat demand using maximum likelihood tests. Estimation outcomes suggest that chicken is the major substitute for pork in recent years.

3.1 Data

We collect meat data for a long period from 1980 to 2018. During the period, China has experienced substantial economic growth and real income increase. The consumption of food has experienced significant changes, too. We consider four meats: pork, poultry, beef and mutton, and fish. Because chicken is the dominant poultry meat in China, we use the price of chicken for poultry in this article.[5] The consumptions of beef and mutton are added up, because each is small relative to other meats. Throughout this article, fish refers to all aquatic meats, including sea and freshwater fish as well as shellfish.

As summarized in figure 4, pork price roughly doubles from 1980 to 2018, with most of the increase happening after 2007. Price of beef and mutton has gone up by 300% over the period. Similarly, the increase becomes substantial after 2007. Chicken price falls slightly from about 16 RMB per kilogram to 10 RMB per kilogram. This is probably driven by the cost reduction due to the transformation from backyard to industrialized production (Ke and Han, 2007; Xin et al., 2016). Fish price has stayed relatively stable.

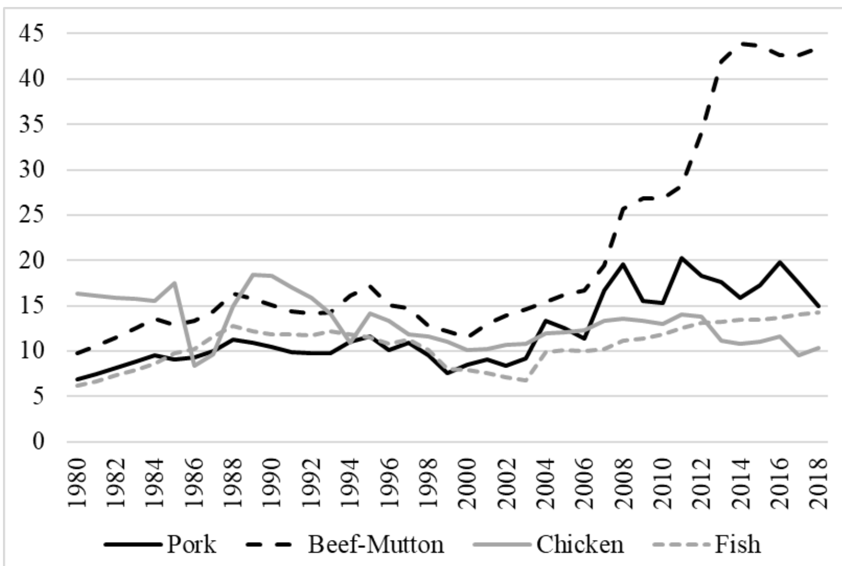

Figure 4. Real Retail Prices of Meats in China

Source: FAO, National Bureau of Statistics of China, and Ministry of Commerce of China.

Notes: Real prices are reported in the unit of RMB per kilogram with 2000 RMB as the baseline. The price reported for beef-mutton is the average of the beef price and the mutton price weighted by their consumption shares.

[5] Chicken counts for the dominant share of poultry consumption. https://xueqiu.com/9582690951/136501897 Information of duck and other poultry prices are difficult to obtain.

To visualize trends of apparent meat consumption per capita (i.e., production minus net export), we plot the data in figure 5. From 1980 to 2018, total meat consumption per capita in China increases from 19 kilograms to 109 kilograms, an increase of more than 450%. Per capita consumption of pork is the highest until 2014, growing by almost 300% since 1980. Fish becomes the most consumed animal protein, not counting dairy or eggs, since 2015 with an 800% growth since 1980. Increases in the consumption of the other three meats are also considerable, though they still count for relatively small shares of the total consumption.

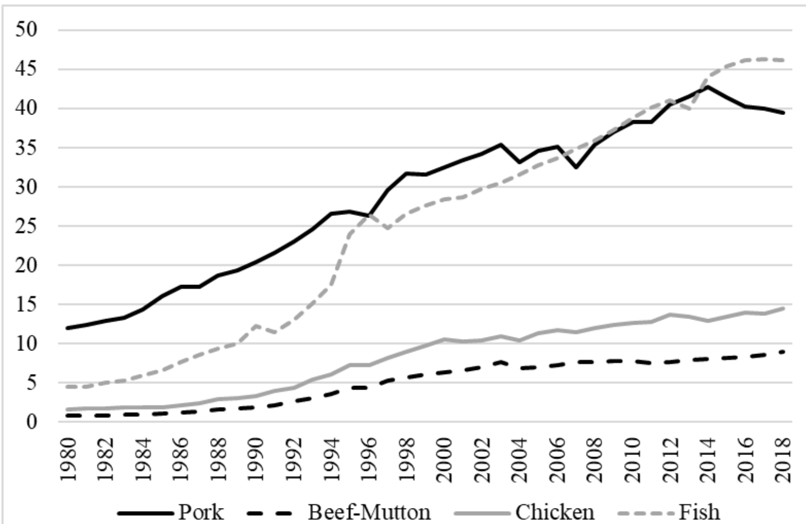

Figure 5. Per Capita Consumption of Meats in China

Source: FAO, National Bureau of Statistics of China, and Ministry of Commerce of China.

Notes: The unit is kilogram per capita per year.

3.2 Estimation Strategy

The AIDS model has been widely used for estimating demand elasticities of prices for its solid theoretical basis and simplicity, which fits our need in investigating the Chinese hog market and analyzing policy scenarios. It has been adopted by many earlier studies on meat demand in many economies (Eales and Unnevehr, 1988; Moschini and Meilk, 1989) and specific for China (Ortega et al., 2009).

The standard AIDS model describes consumption response to exogenous prices, which relies on the assumption of predetermined market prices. This assumption may not be appropriate in some context. In particular, for perishable commodities whose production is subjective to biological lags, it may be more appropriate to assume that the quantity supplied to the market is predetermined and consumer demand is reflected by prices to clear the market. The inverse AIDS (IAIDS) model developed later tends to better characterize the demand of meat than the AIDS model, because meat is mostly consumed as perishable commodities (Eales and Unnevehr, 1994; Eales et al., 1997).

We employ the first-differenced IAIDS model, which is developed from the distance function approach of duality consumption theory (Cornes, 1992; Eales et al., 1997; Holt, 2002; Rangkakulnuwat et al., 2007). Similar as in the AIDS model, adding up, homogeneity, and symmetry constraints are imposed. In our context of four meats, there are hence three equations under the adding-up constraint.

Let w_i be the budget share of meat i, c_i is a meat-specific constant, q_j the per capita consumption of meat j, t is the meat-specific time trend, and $\ln(Q) = \sum_{j=1}^{4} w_j \ln(q_j)$ is the Stone quantity index. The equation in the system is expressed as:

$$w_i = c_i + \sum_{j=1}^{4} \gamma_{ji} \ln(q_j) + \beta_i \ln(Q) + a_i t.$$

Taking the first difference to take care of the dynamic behavior of time-series data (Holt and Balagtas, 2009), we can rewrite the first-difference IAIDS system as:

$$dw_i = a_i + \sum_{j=1}^{4} \gamma_{ji} \, \mathrm{dln}(q_j) + \beta_i \, \mathrm{dln}(Q), \quad (1)$$

where $\mathrm{dln}(q_j)$ is the first-differenced log quantity and $d\ln(Q) = \sum_{j=1}^{4} w_j \mathrm{dln}(q_j)$.

Then we are able to compute the Marshallian own-quantity, cross-quantity, and expenditure flexibilities in a similar way as the own-price, cross-price, and expenditure elasticities computed in an AIDS model. The flexibility measures the percentage change in consumption of a commodity that leads to a 1% increase in the marginal value of the commodity (i.e., its market price). Formulas for price and expenditure flexibilities are, respectively:

$$f_{ij} = -\Delta_{ij} + \frac{\gamma_{ji} + \beta_i\left(w_j - \beta_j \ln(Q)\right)}{w_i},$$

where $\Delta_{ij} = 1$ for $i = j$ and zero otherwise.

$$f_{im} = -1 + \frac{\beta_i}{w_i}.$$

Interpretation of flexibilities are similar to that of elasticities. A key difference, though, is that commodities are termed gross price substitutes if their cross-price elasticity is positive, but are termed gross quantity substitutes if their cross-quantity flexibility is negative (Cornes, 1992). Similarly, the expenditure flexibility is -1 if the commodity is a normal good, while the corresponding price elasticity would be 1. The flexibility of -1 implies that by expanding consumption of all commodities by 1%, the expenditure would also increase by 1% to achieve this new bundle of consumptions. The normalized prices, prices divided by expenditures, would hence decrease by 1%.

3.3 Structural Change

As discussed in section 2.1, meat consumption in China has experienced substantial changes over the past four decades. We would expect some structural change in the demand due to changes in consumer preferences driven by factors that are documented in studies on the long-term meat demand (Eales and Unnevehr, 1993; Hovhannisyan and Gould, 2014). For example, as health and environmental concerns prevail, consumers, especially in developed economies, tend to substitute read meat for white meat or even vegetarian-meat products (Haley, 2001; Janssen et al., 2016). Similar preference changes may occur in China as well.

To identify a potential structural change in meat demand, we follow the widely used model developed by Moschini and Meilke (1989). It specifies a time path h_t which captures a potential break in coefficients in (1) over time. We can re-write (1) as

$$dw_i = (a_i + \delta_{0i}h_t) + \sum_{j=1}^{4}\left(\gamma_{ji} + \delta_{ji}h_t\right)\mathrm{dln}\left(q_j\right) + (\beta_i + \delta_{5i}h_t)\,\mathrm{dln}(Q), \quad (2)$$

The model characterizes the path by a linear function. Letting 1980 be $t = 1$, for one structural change starting at $t = \tau_1$ and ending at $t = \tau_2$, the path in equation (2) is specified as:

$$h_t = 0, for\ t = 1, \dots, \tau_1;$$

$$h_t = \frac{t - \tau_1}{\tau_2 - \tau_1}, for\ t = \tau_1 + 1, \dots, \tau_2;$$

$$h_t = 1, for\ t = \tau_2 + 1, \dots, T.$$

The specification allows us to calculate the Maximum Likelihood Estimation (MLE) for all possible τ_1 and τ_2 the range of 1984 to 2018, and search for the τ_1 and τ_2 giving the largest likelihood ratio.

Summary statistics of the data used for the estimation are provided in appendix 3. MLE outcomes suggest that the optimal parameter estimates are $\tau_1 = 21$ and $\tau_2 = 38$. The two parameters imply a structural change starting in 2001, gradually evolving, and ends in 2017. Timing of this change agrees with the general economic development path of China, when significant growth takes place after 2000. In particular, China joined the World Trade Organization in 2001, which has brought profound impacts to many aspects of the Chinese economy (Huang and Rozelle, 2003; Carter et al., 2009). All these changes may influence Chinese consumers' demand structures for food, including meats.

To confirm the significance of this structural change, we report likelihood ratio tests for the hypothesis of constancy of the parameter vector over time in the appendix 4. The hypothesis of no structural change in the full set of parameters is rejected at the 1% significance level, suggesting that a set of time-invariant parameters cannot characterize demand within the assumed model. A structural change over the period needs to be considered. Further, we group the parameters into three subsets, one for each set of explanatory variables, to examine the nature of this structural change. As shown in table A3, the intercepts of the equations are not subject to this change. However, the hypotheses of constant quantity and expenditure parameters are rejected, implying significant changes in own- and cross-quantity flexibilities during the period.

3.4 Estimation Outcomes of Flexibilities

The estimates of flexibilities are presented in table 2. With three equations to estimate, we effectively have 117 observations for a panel of 39 years. The Durbin-Watson statistics suggest no evidence of autocorrelations in the residuals after taking the first difference.

In the upper panel, we report estimates of flexibilities before the structural change takes place. Standard deviations of 21 estimated flexibilities are displayed in the parentheses. In the lower panel, we report estimates after the structural change is finished, namely, flexibilities in 2018. Per capita real income is included as a control variable in the estimation. Besides, we add a dummy variable indicating if the observation is after 2003 as another control variable. This control variable is included to take care of the fact that our consumption and price data come from different sources before and after 2003.

The estimates suggest that own-quantity flexibility of pork is -3.6, and chicken is the major substitute of pork with the cross-quantity flexibility being -0.9. Beef, mutton, and fish are also substitutes with smaller cross-quantity flexibility than chicken. Adding more controls of demand changes, such as percentage of senior populations, urbanization rate, and so on, the cross-quantity flexibilities remain statistically indifferent.

Table 2. Estimated Flexibilities from the IAIDS Model

	Pork	B&M	Chicken	Fish	Expenditure
1980-2000					
Pork	-0.43	-0.09	-0.24	-0.52	-1.28
	(0.12)	(0.02)	(0.04)	(0.10)	(0.05)
B&M	-0.46	-0.02	-0.18	-0.32	-0.98
	(0.11)	(0.24)	(0.04)	(0.08)	(0.004)
Chicken	-0.63	-0.08	0.19	-0.18	-0.70
	(0.17)	(0.03)	(0.34)	(0.06)	(0.09)
Fish	-0.54	-0.06	-0.07	0.001	-0.67
	(0.10)	(0.02)	(0.02)	(0.21)	(0.07)
2018					
Pork	-3.61	-0.83	-0.89	-0.30	-5.63
B&M	2.05	3.18	-0.34	-0.50	4.38
Chicken	0.76	-0.27	3.98	2.73	7.20
Fish	0.98	-1.64	-0.14	-1.06	-1.85

Source: Data are summarized in appendix 2.

Notes: B&M stands for beef and mutton. Standard deviations are in the parentheses. Adding urbanization ration and percentages of senior and male population do not change the estimates in any significant ways. Outcomes of robustness tests are available upon request.

4. Simulated Policy Outcomes

Given the estimates of meat demand in China, we need information of production cycles of pork and chicken to make predictions of outcomes under the alternative policies within the target period of time. This section starts with a comparison of production cycles of the two animals. Policy outcomes are then simulated and discussed.

4.1 Production Cycle of Pork and Chicken

Current policies supporting the production of hogs direct all subsidies to large-scale hog producers. As summarized in table 3, targeted large-scale farmers need to build large-scale pig sheds first, which takes 6-10 months in China. From gestation to the finishing of hogs, there is another window of about 300 days. In contrast, from eggs to chickens, the cycle takes only about 80 days. Building chicken houses takes much less time, too.

The total cost of hog production for large-scale farms is 1747 RMB per head in 2017, including overhead costs (CARS, 2019). The total cost of chicken production is about 15-16 RMB per head. After slaughtering, each hog produces 77.5-78.2 kilograms of pork, while a slaughtered chicken weighs 1.3-1.5 kilograms. Thus, every 52-53 chickens provide the same amount of meat that one hog provides, suggesting that the effective cost difference between hog and chicken is not as wide as it might seem by comparing the per head production costs.

Table 3. Production Cycle and Costs of Hog and Chicken

	Hog		Chicken	
Item	Time (days)	Cost (RMB/head)	Time (days)	Cost (RMB/head)
House construction	180-300	150	72-120	0.4
Gestation	114	648	--	--
Farrowing/Hatching feed	21	75	22	2-3
Nursery feed	42-56	202	28-35	1.3
Growing/Finishing	115-120	388	21-28	8.4
Labor		165/109		1.0
Other costs		90		2.4
Total, excl. house	292-311	1568/1512	71-85	15.1-16.1

Source: https://www.htfc.com/wz_upload/png_upload/20180413/1523602567467fb62bf.pdf, (CARS, 2019), and http://www.czeps.cn/yangjijishu/79495.html

Notes: Housing cost is computed assuming a large basic pig shed can be used for 15 years and host 10,000 pigs, and chicken shed for 100,000 head per year. Other costs include veterinary drugs and vaccination, water, electricity, and loss due to natural mortality.

4.2 Policy Comparison

The actual pork market price of the second half of 2019 reached 44.9 RMB per kilogram. We consider a policy goal of bringing it down to its pre-ASF level eventually by the end of 2021 (i.e., about 22.4 RMB per kilogram), with the price down to 32.0 RMB per kilogram or lower by the end of 2020. These two levels are set based on the goals stated by the central government in March 2020 (see table 1), that the pork market will be brought "largely back to normal by the end of 2020" and "normal by the end of 2021". Interpreting the two targets by price, we argue, reflects the essential goals of recovering pork supply, because the actual pressure on the government comes from rising pork prices and the increasing CPI index. Consumers would not care whether the actual production of pork has increased, as long as the price stays at a low level.

The government's subsidies to the hog industry have been offered since mid-2019. To achieve the stated goals and given the biological patterns in production, the annual production of pork would have to increase by 4.0% in 2020 and by another 8.3% in 2021 based on our estimated own-quantity flexibility of -3.6 (see table 2). Correspondingly, China needs to produce 19.4 million more hogs in 2020 than in 2019 and an additional 42.2 million increase in hog production in 2021.[6] Because the government plans to exclusively promote large-scale hog farms, we assume that the additional hogs all come from large farms that produce 50,000 hogs per year and can compute the number of new farms to be established. Also according to the news, governments subsidize hog farms at 100-300 RMB per hog produced per year. We hence find the total amount of subsidies needed to support new hog farms, assuming that the government pays 7.5 million RMB per farm. The subsidies, though looking considerable, is only worth about 5% of total construction costs.

Alternatively, we consider a policy that achieves the same pork price reductions by exclusively subsidizing chicken farms and increasing the supply of chicken meat. The cross-quantity flexibility of pork with respect to chicken is -0.9. To achieve the same price reductions, the increase of chicken output has to be 31.9% and 33.3% for 2020 and 2021, respectively. If subsidies are limited to large-scale chicken farms, we find the number of new chicken farms by dividing the increase of chicken heads by the number of birds that one large farm produces per

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[6] Strictly speaking, we are ignoring the growth of population in the following estimation, given that flexibilities from the IAIDS model are computed based on per capital consumption. Population growth in China is slow in recent years with an annual increase of about 0.4%. The base population is that of 2019.

year. Parameters used in the simulation are listed in appendix 5, and the detailed simulation procedure is in appendix 6.

It turns out that subsidies needed to increase hog farms are considerably higher than subsidies needed to increase chicken farms for the same pork price reductions. Further, due to longer biological lags and more time needed to construct hog farms, a particular price reduction brought by increasing pork supply would come at least half a year later than that brought by an increase in the supply of chicken.

In the long-run, of course, the production of hogs needs to be restored from the loss caused by ASF, even if not necessarily at the full level. Bringing the pork price down by exclusively boosting chicken production would not be optimal, although subsidizing chicken farms is relatively cheap and fast to manifest impacts. On the other hand, bringing pork price down by exclusively increasing pork production would not be optimal or even feasible, because of the long biological lags and the substantial loss of sows. Specifically, to increase hog production by over 19 million heads in 2020, at least 1 million more sows are needed. Increasing the number of sows by one million in a year *per se* is a challenge if not impossible.

Thus, a more relevant policy question would be: what is the optimal mix of subsidies to hog and chicken farms to achieve the target price reductions? There is a tradeoff: spending more subsidies on chicken farms would bring down price faster in the short-run, while spending more on hog farms would ensure supply of pork in the long-run.

To compare various policy designs, we assume that the government subsidies start in the third quarter of 2019 and last to the end of 2021. We choose a few splits of the government subsidy budget in the 30-month horizon. For simplicity, we assume that the 2021 budget may only be allocated on hog farms to ensure the increase of pork supply in the long-run, while the split of the budget in 2019 and 2020 is flexible. We then simulate pork prices for each quarter under alternative splits (figure 6).

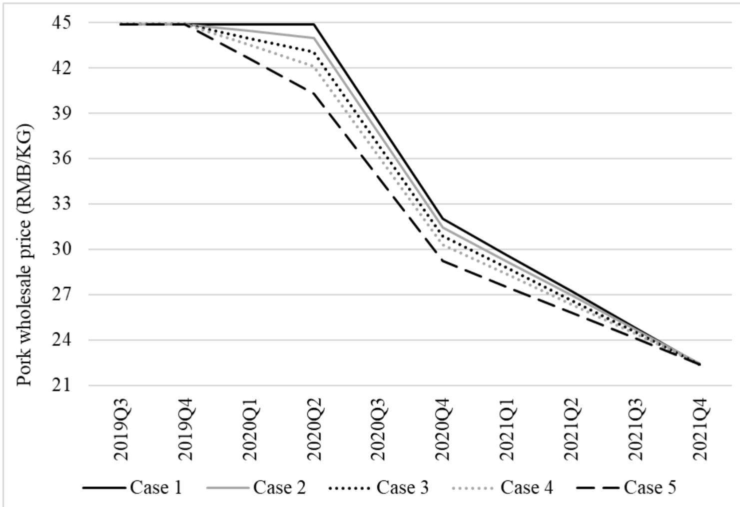

Figure 6. Reactions of the Pork Price to Alternative Policies

Source: Authors' calculation.

Notes: Real prices are reported in the unit of RMB per kilogram with 2000 RMB as the baseline. Price reductions are evenly spread over quarters in a given year, reflecting the fact that subsidies roll out gradually to farms. Case 1: all subsidies are spent on hog farms to achieve the two target price reductions. Case 2: 90% of 2020 subsidies are spent on hog farm and the rest on chicken farms. Similarly, Case 3: 80% of 2020 subsidies are spent on hog farm, Case 4: 70%, and Case 5: 50%. Horizontal axis indicates the year and the quarter. For example, 2021Q4 means the fourth quarter of 2021.

Figure 6 shows that spending a higher portion of the budget on chicken farms in the first 1.5 years would bring down the pork price faster, so that consumers can benefit from lower prices earlier. This is because the substitutability between pork and chicken, and consumers voluntarily consume more chicken due to lowered chicken price with increased supply and less pork, causing the pork price drop. In addition, boosting chicken supply reduces the total government expenditure needed to achieve the goal by the end of 2021. For example, in case 1, all subsidies go to hog farms. No price reduction happens until the third quarter of 2020. In case 2, if the government first spends 10% of the budget on chicken farms, the price will start dropping in the first quarter of 2020. Plus, the total expenditure would be 3.3% lower than the total expenditure if only subsidizing hog farms (i.e., 9.2 billion RMB). If 50% of the subsidies in 2019 and 2020 is allocated to chicken farms as in case 5, it would save as much as 15.2% of the total expenditure, or 1.4 billion RMB. These simulation outcomes stay robust if inputting different parameter values.

As explained in appendix 6, we can follow the price dynamics to compute consumer welfare changes under alternative policies. Focusing on the consumer surplus (CS) of pork, we find that cases 2 to 5 all increase CS from the base case 1. Specifically, case 2 increases CS by 1% of case 1, and case 5 increases CS by 3.1%. Given the substantial population size of China, even a 3% increase in CS is likely to be considerable. Indeed, this is only a lower bound of CS increase due to subsidizing chicken farms, because we use yearly prices and quantities to estimate the CS relying on the IAIDS estimates displayed in section 4.3. The value of pushing down the price of pork half a year earlier is not incorporated, when estimating the CS for cases 2 to 5.

In addition to increasing the CS, the structure of meat consumption in China tends to be improved by increasing chicken supply from the perspective of health. Before 2019, the share of chicken out of meat consumption in China is 12-13%. The percentage can be pushed up to 16.4% in case 2 and to 18.2% in case 5 by the end of 2021. As consumers substitute expensive pork for relatively cheap chicken in the short-run, their diet preferences reinforced by the food processing and food service industries' adaption may change towards white meat in the long-run and become more in line with diets in advanced economies (Holt and Balagtas, 2009) that pursue healthy lifestyle.

Replacing hog farms by chicken farms also has environmental and resource benefits, because chicken production causes less environmental pollution and has much higher feed conversion rate. Looking back, the environmental damage of hog farms was exactly the reason that many local governments prohibited the construction of new hog farms and removed a number of existing hog farms pre-ASF, which might have aggravated the fall in pork supply in 2019 (Gu and Mason, 2017; Patton and Gu, 2020). Limiting the increase of large-scale hog farms in a short period can help pressure down environmental costs.

4.3 Further Discussion

Although increasing pork import can also help alleviate the short-run high pork price in the domestic market, its effects may be quite limited for several reasons. First, given China's domestic pork consumption is huge and the ASF caused production loss of over 21%, the world market has no extra source of this scale. Chinese imports have historically counted for small shares, ranging from 1-2%. Even doubling or tripling the pre-ASF imports of pork would only marginally make up the lost domestic supply of pork. Second, trade policies and biosafety measurements may add uncertainties and impediment imports. For example, the ASF virus itself has been spreading outside China. Importing from certain countries hence are of high risk to the domestic hog industry. Another concern is the ongoing trade war between US and China that Chinese pork import from the US is sometimes levied a very high tariff and other times none.

Furthermore, the oversea shipment of pork is mostly frozen and end up in food processing and/or food service sectors. In retail markets in China, frozen pork and fresh pork have a low degree of substitutability and are sold at highly different prices. Finally, the pork import is likely to be impeded by the spread of COVID-19 during 2020. For example, the cargos have experienced extra-long time at the port due to reduced workforce at many logistic sections (AJOT, 2020; WPSP,

2020) and additional inspection and quarantine procedures. Processing plants in exporting countries like the U.S., Brazil and the Germany, also face reduced capacity due to virus-sickened workforce (Lakhani 2020; The Pig Site 2020; Noryskiewicz, 2020).

The long-run dynamics of pork prices are not explicitly incorporated in our simulation model. It is important, however, to consider the price cycles for pork in China which lasts for 3-4 years in recent decades (Chavas and Pan, 2020). A critical down side of building a large number of new hog farms within 2 years is increasing the risk of pushing the price *too* low in later years – such that the hog farmers would experience losses in a longer horizon. Historical data suggest that experiencing losses during low-price periods of the hog cycles is not uncommon for Chinese hog farmers (CARS, 2019). If hundreds of large-scale hog farms are built within a relatively short period of time, and some existing farmers also increase production capacity at the scale outside the government subsidy, a market overshooting may occur.

5. Concluding Remarks

In this article, we discuss policy responses to the sharp decline in hog inventory due to the 2018-2019 ASF outbreak in China – the world's largest producer and consumer of pork. The reduction of hog production and inventory has resulted in substantial price jumps in 2019, which pushes the government to announce and carry out a series of subsidizing programs to hog farms, aiming at restoring hog inventory and boosting pork production within a 2-3-year window.

To evaluate effectiveness and efficiency of the current recovery policy, we first employ 1980-2018 meat consumption and price data to estimate meat demand of China, discovering a structural change which gradually evolves from 2001 to 2017. Based on updated own and cross-quantity flexibilities of pork, we estimate the price dynamics given alternative subsidies on hog and chicken farms.

We find that allocating even a small portion of the subsidies to chicken farms may significantly accelerate price reductions and save government expenditure. For example, if putting half of the initial pork-exclusive budget on chicken farms, the government could save more than 15% of the expenditure over a 30-month window to achieve the same reductions of the pork price. Besides benefiting consumers and the government, allocating some of the subsidies to chicken farms also avoids expanding hog production too much and too rapidly. China’s hog industry has experienced strong price cycles in recent years. Increasing hog production at a relatively low speed helps mitigate the risk of sharp drops of hog prices and protect hog producers in the long-run. Our findings encourage a reallocation of government budget on China’s hog industry and ensuring meat consumption and are of relevance to other countries that suffer from the ASF.

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Appendix 1. List of News about Policy Responses to the African Swine Fever in China

Table A1. List of News of Policy Responses

Date of news	Provinces	Web links
04/19/2019	Guangdong	https://news.163.com/19/0725/21/EKVB5HBN0001875N.html
09/07/2019	Hebei	http://www.gov.cn/xinwen/2019-09/07/content_5428110.htm
09/30/2019	Fujian	https://finance.sina.cn/2019-09-30/detail-iicezzrq9445237.d.html?from=wap
10/17/2019	Zhejiang	http://news.cctv.com/2019/10/03/ARTIbA7moPAbU4Hoeuuo6LR6191003.shtml
10/17/2019	Hubei	http://www.chinapig.cn/html/n2/1/2019/10/17/2019/10/1710423406.shtml
10/24/2019	Henan	http://www.ketaijituan.com/ktc_5/20191024171649348.htm
11/18/2019	Chongqing	http://www.gov.cn/xinwen/2019-11/18/content_5453063.htm
11/19/2019	Jiangxi	http://paper.people.com.cn/rmrb/html/2019-11/19/nw.D110000renmrb_20191119_7-02.htm
11/23/2019	Jiangsu	http://www.gov.cn/xinwen/2019-11/23/content_5454893.htm
11/25/2019	Liaoning	https://m.chinanews.com/wap/detail/zw/sh/2019/11-25/9016400.shtml
11/25/2019	Anhui	https://m.chinanews.com/wap/detail/zw/sh/2019/11-25/9016400.shtml
11/26/2019	Tianjin	http://www.chinapig.cn/html/n2/1/2019/11/26/2019/11/269475906.shtml
12/04/2019	Jilin	http://www.xinhuanet.com/2019-12/04/c_1125308647.htm
12/06/2019	Shanxi	http://www.sx.xinhuanet.com/2020-01/09/c_1125439567.htm
03/11/2020	Hunan	https://kuaibao.qq.com/s/20200311A0PCRE00?refer=spider
03/19/2020	All	https://news.ifeng.com/c/7uyQX5VC8FE
03/26/2020	Heilongjiang	http://www.caaa.cn/show/newsarticle.php?ID=404419
04/24/2020	Shandong	http://finance.eastmoney.com/a/202004241466402848.html
05/06/2020	Sichuan	http://finance.eastmoney.com/a/202005061474943927.html

Notes: All news articles are in Chinese.

Appendix 2. Weekly Prices of Meats from January 2018 to May 2020

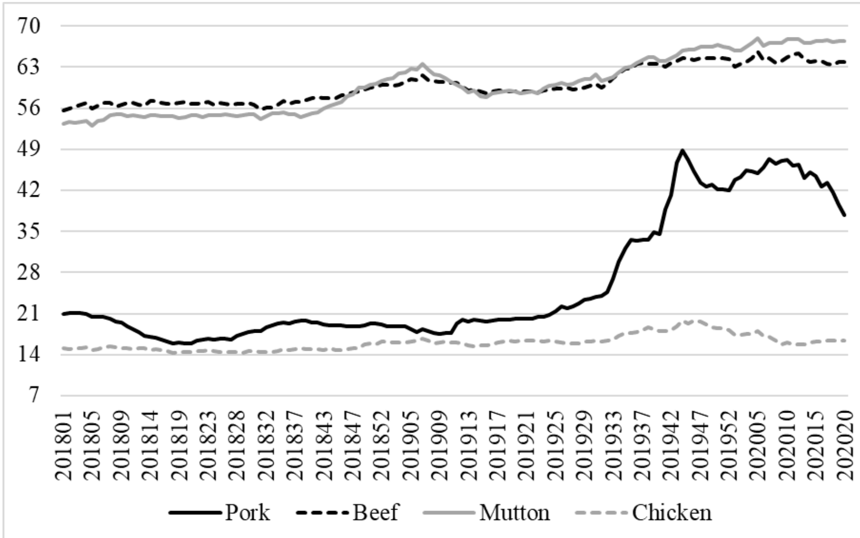

Figure A1. Weekly Real Wholesale Prices of Meats

Source: Ministry of Agriculture and Rural Affairs of China.

Notes: Real prices are reported in the unit of RMB per kilogram with January 2018 RMB as the baseline. Horizontal axis indicates year and week. For example, 202020 refers to the 20th week of 2020.

Appendix 3. Summary Statistics of Data Used in the IAIDS Model

Table A2. Summary Statistics of Dependent and Explanatory Variables

Variables	Mean	Std. dev.	Min	Max
Pork price	12.13	3.89	6.92	20.29
Beef-mutton price	20.67	11.08	9.76	44.94
Chicken price	13.10	2.62	8.33	18.44
Fish price	10.67	2.27	6.19	14.24
Pork consumption per capita	28.74	9.74	11.97	42.79
Beef-mutton consumption per capita	5.02	2.90	0.81	8.99
Chicken consumption per capita	8.12	4.51	1.68	14.49
Fish consumption per capita	25.07	14.19	4.53	46.23
Yearly income per capita	5928.54	5340.13	997.79	18816.08
Other control variables				
Urbanization ratio (%)	37.17	12.41	21.10	59.58
Senior population (%)	7.26	1.96	4.65	11.94
Male population (%)	51.37	0.21	50.82	51.70

Notes: The number of observations is 39. Unit for prices is real RMB/kilogram and for per capita consumption is kilogram. Unit for income per capita is also real RMB. The real RMB is computed using 2000 as the base year.

Appendix 4. Likelihood Ratios for Structural Change Tests

Table A3. Parameter Consistency in the IAIDS Model

Hypothesis	#Restrictions	Likelihood ratio	Prob > χ^2
No structural change in:			
All parameters	18	20.41	0.001
Intercept parameters	3	0.28	0.595
Expenditure parameters	3	9.47	0.002
Quantity parameters	12	4.06	0.040

Notes: The econometric specification is the same as that used for table 2.

Appendix 5. Parameters for the Policy Simulation

Table A4. Simulation Parameters

Parameter	Value	Unit
Year-end pork consumption 2019	4444.3	10,000 MT
Year-end chicken consumption 2019	2307.2	10,000 MT
Second half-year pork consumption 2019	1898.9	10,000 MT
Second half-year pork price	44.9	RMB per kilogram
Target pork price by Dec 2020	32.0	RMB per kilogram
Target pork price by Dec 2021	22.4	RMB per kilogram
Yearly output per hog farm subsidized	50,000	heads
Yearly output per chicken farm subsidized	600,000	heads
Subsidies per new hog farm	7.5	Million RMB
Subsidies per new chicken farm	0.25	Million RMB
Carcass weight per hog	78	Kilograms
Carcass weight per chicken	1.5	Kilograms

Source: Same as the source of table 3.

Notes: The subsidy on chicken farms is assumed to be worth 5% of the total construction cost. This ratio is the same as the assumed subsidy ratio for hog farms.

Appendix 6. Simulation Procedure

For year 2020, the baseline year is 2019. The annual consumption of pork is 44.4 million tons, and the consumption of the second half of 2019 is 19.0 million tons. To bring the price down to 32 RMB per kilogram from 44.9 RMB per kilogram by the end of 2020, the percentage drop in price is $\frac{44.9-32.0}{44.9} \times 100\% = 28.7\%$. Because the own-price flexibility of pork is -3.6, the supply of pork has to increase by $\frac{28.7\%}{3.6} = 8.0\%$.

Yet given that pork supply may only increase starting June 2020 due to the biological lag, China effectively only has to increase the supply of the second half of 2020 by 8% to push year-end price down to 32.0. Thus, the 2020 year-end price is achieved by increasing the output of hogs of the second half of 2020 by 8.0%:

$$\frac{19.0\ mil\ ton \times 8.0\%}{78\ kg} = 19.4\ mil\ heads.$$

If the government supports large-scale farms to produce the 19.4 million hogs and each farm produces 50 thousand hogs a year, $\frac{19.4\ mil}{50{,}000} \approx 389$ farms need to be built. For each farm, let the government subsidize 5% of the construction cost, the budget for 2020 would be

$$389 \times 7.5\ mil\ RMB = 2.9\ bil\ RMB.$$

Following a similar procedure, one can figure out the number of chicken farms to build and the budget for subsidizing those chicken farms. Also, by replacing the baseline consumption of pork for 2021 by the year-end consumption of pork in 2020, one can figure out the budget for 2021, given a specific 2020 budget plan and the target price reduction.

Because we assume that the subsidies reach farms in waves, the annual price reduction is assumed to be manifested evenly over a few quarters. For example, when spending all the 2020 subsidies on hog farms, we assume that the first batch of incremental pork enters the market 10 months after the subsidies are first distributed in quarter 3 of 2019.[7] Hence, the first price drop takes place in the third quarter of 2020 and the second drop in the four quarter. For the price effect to manifest evenly, we let the price of quarter 3 to fall to 38.5 RMB per kilogram and to 32.0 RMB per kilogram in the next quarter.

Similarly, if spending half of the 2020 budget on chicken farms, the first batch of incremental chicken meat arrives in the market 6 months after quarter 3 of 2019. The first increment of pork supply enters the market in quarter 3 of 2020. Knowing the total price reduction caused by incremental chicken and by incremental pork, we again break the price reduction evenly over the quarters. Thus, the price of 2020 quarter 1 falls to 42.6 RMB per kilogram, to 40.3 in the second quarter, to 34.8 in the third quarter, and 29.2 in the fourth quarter (see figure 6).

Fixing the ultimate goal of pressing price down to 22.4 RMB per kilogram and given a specific year-end price for 2020, we find the 2021 budget that is needed under a particular split of 2020 budget. For example, if spending 50% of the 2020 budget on chicken farms, the price of pork already falls to 29.2 RMB per kilogram by the end of 2020. Thus, only 78% of original 2021 budget on hog farms, the budget allocating no subsidies on chicken farms in 2020, is needed to further push the price down to 22.4 RMB per kilogram by the end of 2021. As much as 15.2% of total expenditure can be saved over the 30-month window as a result.

Correspondingly, we can compute consumer surplus (CS) from pork based on the IAIDS model. Given that $w_i = c_i + \sum_{j=1}^{4} \gamma_{ji} \ln\left(q_j\right) + \beta_i \ln(Q) + a_i t$, we can write price i as a function of quantities:

[7] To be conservative, we assume that the gestation can be done together with the construction of hog houses. Otherwise, the first price reduction would happen in the fourth quarter of 2020.

$$p_i = \frac{E}{q_i}\left(c_i + \sum_{j=1}^{4} \gamma_{ji} \ln(q_j) + \beta_i \ln(Q) + a_i t\right).$$

Taking the expenditure and $\ln(Q)$ as given (Cornes, 1992), we can express CS by taking the integration of price *i* over quantity *i* where superscript * indicates an equilibrium value and superscript ^ refers to the estimated coefficients.

$$CS = \int_0^{q_i^*} p_i(q_i) dq_i - p_i^* q_i^*$$

$$= \left[\ln(q_i) E\left(\widehat{c_i} + \sum_{j \neq i}^{4} \widehat{\gamma_{ji}} \ln(q_j) + \widehat{\beta_i} \ln(Q) + \widehat{a_i} t\right) + \frac{(\ln(q_t))^2}{2} E\widehat{\gamma_{ii}}\right] - p_i^* q_i^*.$$

By fixing the coefficients at values estimated from the IAIDS model, we find prices and quantities for alternative policies and compute CS for pork consumers in 2020 and 2021. Note that we only consider annual average prices and quantities in computing CS. By assuming that flexibilities are fixed at their 2018 values (see table 2), we can keep E and $\ln(Q)$ updated as alternative policies bring changes to quantities of pork and chicken. Thus, the estimated CS does not incorporate the value of enjoying price reduction earlier in cases 2-5: the estimated CS increases are lower bounds. Detailed computation steps are available upon request.