2020

Quantifying the U.S. Market Response to the African Swine Fever Outbreak in China

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Disciplines

Agricultural and Resource Economics | Agriculture | International Economics

Comments

This is a Selected Paper prepared for presentation at the 2020 Agricultural & Applied Economics Association Annual Meeting, Kansas City, MO July 26-28, 2020

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June 29, 2020

Abstract

China reported its first outbreak of African swine fever in August 2018. The devastation caused to the Chinese hog herd has had far-reaching implications for the international pork market. The protein deficit caused by the African swine fever outbreak in China and elsewhere in Southeast Asia continues to create opportunities for exporting countries to fill the void and provides openings for back-filling other partner country's demand needs. At the same time, increased prevalence of ASF has fueled concerns regarding the spread into disease-free regions, including the United States. Given the position of both China and the United States in the international pork market, of interest is how the U.S. pork market has responded. A structural break test identifies up to five structural breaks in a constructed series of "year-out" implied volatilities calculated from CME lean hog options. We calculate changes in the market-perceived probability of a catastrophic price decrease occurring in the CME lean hog market, with results indicating that the probability has increased substantially. The average market-perceived probability of a 30% price decrease during August 27, 2018, to March 13, 2019, increased by 165% compared to the period November 11, 2017, to August 26, 2018. Hog producers, government entities, and allied industries could all leverage this information in many of their business decisions, risk analyses, and contingency planning.

Introduction

China reported its first outbreak of African swine fever (ASF) on August 3, 2018 (FAO 2020). Cases have since been reported in at least 32 Chinese provinces, and many other countries in the region (FAO 2020). Data published by the Chinese government indicates that hog (sow) inventories in the country dropped 41% (38%) from October 2018 to October 2019 (Bloomberg News 2019). China is far and away the world's largest producer and consumer of pork (USDA-FAS 2019a), so the disease situation there has far-reaching implications for international pork supply and demand.

The United States ranks only behind China and the European Union in worldwide pork production (USDA-FAS 2019a). With this being the case, the pork industry in the United States could benefit greatly from decreased pork supplies worldwide resulting from the ASF outbreak in China and Southeast Asia, especially since the United States is the second largest pork exporter in the world (USDA-FAS 2019b). In fact, the United States exported nearly 23% of its total pork production in 2019 (USDA-FAS 2019a, 2019b). On the other hand, increased prevalence of ASF internationally has led to heightened concerns that the disease may continue to spread into disease-free regions, including the United States (Sundberg 2019).

When it comes to the likelihood of an ASF outbreak in the United States, we are unaware of any known probability. Changes in the ASF status in a country (i.e., never reported, absent, suspected, present, limited to one or more zones, or current event) likely impact the possibility of an outbreak in another country. However, U.S. Department of Agriculture (USDA) highlights there is high uncertainty regarding the possible pathway through feed and fomites and emphasizes the role of more research and data collection to reduce the uncertainty (USDA-APHIS-VS-CEAH 2019).

This study utilizes data from Chicago Mercantile Exchange Group (CME) lean hog futures and options contracts to measure the market response to the recent ASF outbreak abroad. The lean hog futures market is central to the U.S. hog industry. A large fraction of the U.S. hog industry uses the hog futures market for hedging purposes and some producers use marketing contracts tied to futures prices (Lawrence and Grimes 2007). Results from structural break tests, that choose break dates endogenously, indicate there have been up to five structural breaks since January 2017 in a constructed time series of implied volatilities calculated from lean hog options contracts. In a subsequent analysis, the futures and options data is utilized to calculate several measures of the perceived probability of a catastrophic price decrease in the CME lean hog futures market. These metrics demonstrate that this probability has increased substantially at various periods corresponding with ASF-related events. Many stakeholders in the U.S. swine industry could benefit from these market-based measures, from hog producers making risk management decisions (purchasing catastrophic loss insurance, buying put options, etc.) to government entities designing indemnity provisions and even financial institutions performing stress tests in regard to their swine-industry related holdings.

Background

A documented case of ASF in the United States would be economically disastrous. An ASF outbreak in the United States would cause all movement of hogs to completely halt immediately, and U.S. pork exports could cease for an indefinite period of time (Crawford 2019; Pudenz, Schulz, and Tonsor 2019). A study by Hayes et al. (2011) estimates that an outbreak of classical swine fever in the United States could lead to a 45% decrease in barrow and gilt prices due to lost export markets. The USDA Animal and Plant Health Inspection Service (USDA-APHIS) classifies ASF as a Tier 1 disease along with classical swine fever and foot and mouth disease. Tier 1 diseases are those that have the highest risks and consequences and therefore present the most significant threat to animal agriculture in the United States (USDA-APHIS-VS 2013). Lusk (2019) predicts that an ASF outbreak in the United States could lead to U.S. producers and consumers alike experiencing welfare losses ranging from $1 billion per year to nearly $8 billion per year depending on model assumptions.

The United States has never had a documented case of ASF (USDA-APHIS-VS 2019), but the potential for such losses has led to serious responses by U.S. stakeholders and allied industries. Referencing recent research that identifies imported feed and feed ingredients as a potential ASF entry pathway, the National Pork Board recommends holding high-risk feed and ingredients for long periods of time (National Pork Board 2020). USDA-APHIS and the

Department of Homeland Security's U.S. Customs and Border Protection (CBP) have strengthened efforts to prevent ASF from entering the United States. Such efforts include the use of the now-famous "Beagle Brigade" to prevent entry of illegal agricultural products at U.S. ports of entry such as airports (USDA 2018). Notably, concerns about ASF led U.S. CBP to confiscate 1 million pounds of illegally imported food products (initially reported as 1 million pounds of pork) from China in March 2019 (Polansek 2019b). Additionally, some private insurance companies in the United States and around the world have developed and offered policies to producers to insure against losses from an outbreak of ASF.

The CME lean hog futures and options market has likewise responded quite strongly to international developments regarding ASF. Figure 1 shows lean hog futures prices for the June 2019 futures contract and depicts what is likely a market response to the ASF outbreak in China. Daily settlement prices rose from $72.30/cwt on August 3, 2018, to $78.75/cwt on August 31 of that month. Another large price change for the June 2019 contract occurred in March 2019. This price increase parallels two back-to-back U.S. federal government announcements made during that month. First, on March 14, USDA published data showing that China had purchased nearly 24,000 metric tons (i.e., more than 50 million pounds) of U.S. pork in the week ending March 7 (Polansek 2019a). Second, on the very next day, U.S. CBP announced the seizure of 1 million pounds of illegally imported food products from China in March 2019 (Polansek 2019b). These events certainly contributed to the price increases observed on those dates.

The CME lean hog options market also provides insight into the ASF market impact. As described concisely by Hayes et al. (2011), options premiums tell us a lot about how markets expect futures prices to change since "(t)he more experts are willing to pay for options the greater the likelihood of major price movements" (pg. 24). Specifically, a Black-Scholes option pricing model (Black and Scholes 1973) can be used in conjunction with lean hog options premiums to calculate implied volatilities of lean hog futures contract prices. Assuming the Black-Scholes framework, these volatilities are those that are implied by the options premiums observed in the lean hog market (Hull 2018). Figure 2 shows implied volatilities for the June 2019 lean hog futures contract calculated by Barchart.com using the Black-Scholes methodology. The implied volatilities rose from 18.98% on August 3 to 24.55% on August 31. The implied volatility also increased in March 2019, which corresponds with the two U.S. government announcements and subsequent popular press media coverage.

Visual inspection of figures 1 and 2 does not definitively establish a lean hog market response to ASF. Identifying with statistical tests that there have been one or more structural breaks in a time series from this market that correspond with meaningful developments in the ASF situation would. If such evidence is found, there would be justification for calculating the ASF-induced change in the perceived probability of a catastrophic lean hog price decrease in the United States. Furthermore, using reasonable assumptions, the market-perceived probability of a price decline could be interpreted as the perceived probability of an ASF outbreak occurring in the United States. Such a probability could then be used in a variety of applications.

Literature Review

The literature concerning the likelihood of an ASF outbreak in the United States is remarkably limited. One relevant assessment is a study by USDA-APHIS in 2019 that details a qualitative analysis of the probability of ASF entering the United States (USDA-APHIS-CEAH 2019). The study classifies eight transboundary pathways for ASF (live pigs, swine products and by-products, etc.) according to likelihood rating (negligible, low, moderate, high, very high) and uncertainty level (low, moderate, high). The study also considers both legal and illegal entrance via these pathways. For example, the probability of ASF entering the United States via *legally* imported swine products and by-product is determined to be “negligible to low” with a “moderate” level of uncertainty. At the same time, the likelihood of ASF getting into the United States through *illegally* imported swine products and by-products is deemed to be “high” with a “low” uncertainty level. These ratings were assigned according to criteria such as total volume of potentially contaminated imports and effort dedicated to inspection and efficiency of detection. This analysis does not make claims regarding the likelihood of these transboundary pathways leading to an ASF outbreak, however, since pig exposure pathways or the likelihood exposure leads to infection are not studied (USDA-APHIS-VS-CEAH 2019).

Two recent studies calculate quantitative probabilities related to the spread of ASF. The first, published by Jurado et al. (2019), connects to the USDA-APHIS study in that it estimates the probability of the special case of ASF entering the United States through illegally imported pork products. Specifically, Jurado et al. (2019) estimate the likelihood of ASF entering the United States through illegally imported pork in passenger luggage using a quantitative stochastic model and data regarding U.S airport passenger arrivals as well as records of pork confiscated at U.S. airports by U.S. CBP. Model results demonstrate the mean annual probability of pork products entering the United States via this channel to be 0.11%. This estimate is small in magnitude but is more than 180% higher than the corresponding estimate for data before the international ASF developments of 2018 and 2019 (Jurado et al. 2019). Such information is definitely useful for agents concerned with that particular transboundary route, a route that was given a “high” likelihood rating by USDA-APHIS. That said, the broader applicability of such a measure is likely limited, especially since as with the USDA-APHIS study exposure pathways are not considered. The second recent study is by Taylor et al. (2020), who use a general risk assessment framework to measure the likelihood of one or more infections occurring in boars or pigs through three specified transmission pathways. While this methodology is able to assign probabilities of at least one case of ASF occurring at the 100 square kilometer level in Europe in 2019, the approach requires a lot of data (volume of legal live pig trade, ASF prevalence in pigs and boars, wild boar populations, etc.) and only concerns the European Union where the disease is already present (Taylor et al. 2020).

Hayes et al. (2011) use a market-based approach to model the probability of a catastrophic animal disease outbreak. They utilize a single CME lean hog futures price (i.e., the December 2012 lean hog futures price on November 15, 2011) and the corresponding implied volatility from the CME lean hog options market to parameterize a lognormal price distribution from which they draw simulated prices. The authors subsequently calculate the proportion of simulated prices that represent 40% and 50% price decreases in comparison to the futures price on November 15, 2011. Making the assumption that such catastrophic price decreases could only be caused by an animal disease event that leads to the loss of export markets for U.S. pork and live hog products, the authors subsequently call their proportions the probability of a major disease event (Hayes et al. 2011). Importantly, this novel approach represents an entirely different methodology than other work. The Hayes et al. (2011) analysis and validity of results are predicated on the efficient market hypothesis. Concisely, "asset prices reflect all available information" relevant at any given time (Fama 2013, pg. 365).[1] This assumption is not trivial, but it does ultimately allow for calculation of quantitative metrics of the probability of an ASF

[1] A more vigorous discussion regarding efficient markets appears in Fama (1965): "In an efficient market, competition among the many intelligent participants leads to a situation where, at any point in time, actual prices of individual securities already reflect the effects of information based both on events that have already occurred and on events which, as of now, the market expects to take place in the future. In other words, in an efficient market at any point in time the actual price of a security will be a good estimate of its intrinsic value" (pg. 56).

outbreak in the United States that require relatively little data and are free of qualifications such as specifications of entrance pathway. Furthermore, unlike other modeling techniques, this approach can be easily applied to many dates over a long period of time and can be updated in real-time to give a sense of how the modeled probability has changed over time.

Methodology

The Bai-Perron test is utilized to test for structural breaks in time series of the lean hog market corresponding to recent ASF outbreaks abroad and related actions taken by global market participants and governments. Several studies have successfully applied Bai-Perron tests in assessments of market data (Boetel and Liu 2010; Ortez and Tonsor 2016; Rude, Felt, and Twine 2016; Twine, Rude, and Unterschultz 2016; Tonsor and Mollohan 2017; Mullally and Lusk 2018). The Bai-Perron method estimates break dates of unknown structural breaks in a time series while allowing for testing of the null hypothesis that there are l structural breaks versus the alternative that there are $l + 1$ breaks (Bai and Perron 1998). The test is performed with heteroskedasticity and autocorrelation consistent (HAC) standard errors, with options selected that—in the calculation of the covariance matrix—allow for both regressors and errors to have heterogeneous distributions across the various regimes of the time series determined by the estimated structural breaks. The tests are performed for trimming rates of both 15% and 10%, with the trimming rate being the minimum proportion of observations required in each regime. A trimming rate of 15% allows at most five breaks while 10% allows up to eight breaks. A smaller trimming rate allows for the identification of structural breaks that are closer together (Bai and Perron 2003). While a smaller trimming rate is more likely to lead to test size distortions, concerns regarding size distortions are mitigated by our very large sample size (Bai and Perron

2003). Both trimming rates are considered valid, but results for both are presented for completeness.

We follow the approach of Hayes et al. (2011) but apply it to a continuous series of daily data covering a three-year window beginning in January 2017 to model the market-perceived probability of a catastrophic price decrease in a year's time. For each trading day in that time frame, MATLAB is used to make 10,000 draws from a standard normal distribution. These draws are then converted into (cumulative) probabilities which are used to draw prices from a lognormal distribution using the "logninv" function in MATLAB. For each lognormal distribution generated using this function, the mean of the logarithmic values is parameterized as the natural logarithm of the settlement "year-out" futures price, and the standard deviation of the logarithmic values is the "year-out" implied volatility for that date. In this way, a simulated distribution of 10,000 lognormal prices is generated for each trading day for which there was an observation on Barchart.com for the year-out price and implied volatility.

The Hayes et al. (2011) analysis is further extended in several important ways. The proportion of simulated prices representing price decreases of at least a certain percentage in a year are calculated, but in our case these price decreases range from 10% to 50% by increments of 10%. This "percent drop" metric does not provide a lot of information not already contained in the "year-out" implied volatility time series, but it has the value of converting changes in implied volatilities into something that is readily interpretable. We also include a calculation of the proportion of simulated prices dropping below various "floor" prices of $50/cwt, $40/cwt, and $30/cwt. This "price floor" metric has the advantage of more directly taking price levels into account, but doing so does cause price seasonality to have a stronger impact.

There are several modeling assumptions that are critical for contending that our methodology is appropriate for identifying the probability of a catastrophic price decrease in the U.S. lean hog market. First, assuming that the efficient market hypothesis holds for the CME lean hog futures and options markets is key. If futures prices and option premiums reflect all relevant and available information, then they embody information about the potential for a catastrophic price decrease. If this is the case, then we can learn something about a catastrophic price decrease from studying these prices and premiums. The second crucial assumption is that, like Hayes et al. (2011), price distributions are reasonably modeled as a log normal distribution. This is a foundational assumption of the Black-Scholes option pricing model (Black and Scholes 1973) and has been maintained in other agricultural economics studies (e.g., Hart, Hayes, and Babcock 2006).

A third assumption that is required if the probability of a catastrophic price decrease is to be interpreted as the probability of an ASF outbreak in the United States is to assume that during the period of study market participants thought a catastrophic price decrease in the CME lean hog market could only be caused by an ASF outbreak on U.S. soil. Lusk (2019) presents several hypothetical scenarios, grounded in economic theory, in which U.S. exports completely cease and supply losses are low to moderate, leading to dramatic lean hog price decreases as a result of an ASF outbreak in the United States. For 2017 to 2019, it is difficult to pinpoint any other major events and/or market fundamentals perceived by market participants that could have caused lean hog prices as low as $30/cwt or a 50% decrease in lean hog prices. This assumption regarding market participants pricing in catastrophic price decreases only due to a major animal disease event follows the assumption made by Hayes et al. (2011), but it is not exactly vital for the present analysis. Where the assumption would be more critical, however, is in an application where the probability of a catastrophic disease event like an ASF outbreak has to be separated from a similarly disastrous non-disease event.

Data

Daily CME lean hog futures prices and implied volatilities calculated using the Black-Scholes option pricing model were obtained from Barchart.com. Futures prices and implied volatilities for lean hog contracts for all eight contract months (February, April, May, June, July, August, October, and December) were downloaded, but data for May and July were dropped due to lack of implied volatility data available on Barchart.com for the time frame of study. Data for the six even month contracts are used to construct a single rolling “year-out” futures price time series and a single rolling “year-out” implied volatility time series. For instance, on January 1, 2018, the most recently expired futures contract is that for December 2017 and the “nearby” futures contract is that for February 2018. As such, for January 1, 2018, the year-out futures price is taken to be the January 1, 2018, futures price for the December 2018 futures contract. In the same way, the year-out futures price is the December 2018 futures price for all dates for which February 2018 is the nearby futures contract. Figures 3 and 4 provide these time series for January 2017 through December 2019 period. Notably, in 2019 the “year-out” price series reached its highest levels of the three-year period, as did implied volatilities.

Results

Structural Break Estimation

Bai-Perron tests are performed on the lean hog implied volatility time series for January 2017 to December 2019. When the trimming rate is set to 15%, the test finds three structural breaks at the dates July 18, 2017, August 27, 2018, and March 14, 2019. When the trimming rate is reduced to 10%, the test indicates the presence of two additional breaks at dates November 15, 2017, and September 13, 2019. All five structural breaks are depicted by the vertical lines in figure 5 labeled according to date, with the black lines representing the breaks identified with a 15% trimming rate while the grey lines represent the additional breaks identified with the 10% trimming rate. Structural breaks on August 27, 2018 and March 14, 2019, have clear intuitive explanations, with August 27, 2018, corresponding to the period directly after the first cases of ASF reported in China and March 14, 2019, coinciding exactly with the two U.S. government announcements about Chinese imports of U.S. pork and seizure of illegally imported food products from China. These two structural breaks demonstrate market responses due to these ASF events, namely that the volatility in lean hog prices implied by options premiums experienced significant increases. From a price risk management perspective, this equates to a substantial cost increase of using lean hog options following these ASF-related events.

The three remaining breaks likewise have useful interpretations. Structural breaks at July 18, 2017, and November 15, 2017, serve as beginning bounds for the time period of interest for trimming rates of 15% and 10%, respectively. Finally, the presence of a break at September 13, 2019, indicates that the volatility in the lean hog market declined after a period of extreme volatility in the wake of the March 2019 events.

Catastrophic Price Decrease Probabilities

Results for the probability of a catastrophic price decrease in the U.S lean hog futures market are reported in figures 5 and 6. For illustrative purposes, consider the light grey line in figure 5 that represents the probability of a 30% drop in prices in a year's time. This probability is well less than 10% until March 2019, after which the probability spikes to nearly 20% before falling to between 10% and 15% at the end of 2019. These probabilities look similar to the "year-out" implied volatility time series, but presenting results as percent decreases eases interpretation. Table 1 reports means and standard deviations for the catastrophic price decreases by regime identified by the structural break tests. For instance, Regime 2 starts on November 15, 2017, and continues until August 27, 2018. As shown in table 1, the average market-perceived probability of a 30% price drop more than doubles from Regime 2 to Regime 3, and then doubles again from Regime 3 to Regime 4.

The lines in figure 6 provide a different shape that more strongly reflects seasonal pricing trends. This metric more directly takes the price level into consideration in addition to the implied volatility. Interestingly, the $40/cwt price floor measure shows that the perceived probability of a price decrease had essentially no immediate reaction to the initial news of the outbreak in China in August 2018. There was, however, an immediate increase in this measure of the perceived probability following the March 2019 announcements. Average market-perceived probabilities tell a different story. Table 2 shows that the average market-perceived probability of prices decreasing to $40/cwt increased more than 500% from Regime 2 to Regime 3, although this probability remains essentially the same for Regime 4.

Conclusion

This study utilizes CME lean hog futures and options data to demonstrate the market response to the ASF outbreak in China. We first establish the presence of up to five structural breaks in a "year-out" lean hog implied volatility time series. Then, year-out prices are simulated that allow for the calculation of metrics of the market-perceived likelihood of a catastrophic price decrease. Both measures indicate that market participants believe that the probability of a catastrophic price decrease in the lean hog futures market increased substantially in the wake of the 2018 Chinese ASF outbreak, with some notable increases corresponding to the timing of subsequent major ASF-related events. This can be interpreted as evidence of an increase in the market-perceived likelihood of an ASF outbreak in the United States.

Our results—particularly those that relate to the market-perceived probability of a catastrophic price decrease—provide hog producers, government entities, and allied industries such as the financial sector hard evidence to assess or benchmark how they perceive the risk of ASF and possibly change behavior or propose policy to mitigate the risk. This increased risk of a disastrous price decrease may mean that catastrophic loss insurance premiums are more palatable to hog producers, or that using price risk management methods such as hedging or options are more advisable than ever. Similarly, government agencies could use probability measures such as these in construction of indemnity policy for animal disease events or in cost-share programs for disease prevention measures. At the very least, demonstrating that a catastrophic price decrease is more likely could encourage the private and public sectors to dedicate more resources towards foreign animal disease mitigation efforts.

Future work could take several directions. One avenue would be to use methodology provided in the finance and agricultural finance literatures to make use of volatility information. Statistical methods similar to those in Hart, Hayes, and Babcock (2006) could be employed to incorporate information from all lean hog futures contracts that expire in the next year instead of just the "year-out" contract, or tools developed since Black-Scholes could be used to estimate volatility in the lean hog market. Future work could also examine a long time series of prices and volatilities. Doing so would put the probability of price decrease estimates in a historical context of previous changes in market fundamentals (animal diseases, policy interventions, etc.) that led to drastic changes in price decrease probabilities. This may help parse out how much of the probability is directly attributable to ASF, which could be important for leveraging results in business decisions, risk analyses, and contingency planning.

Acknowledgements

This work is/was supported by the USDA National Institute of Food and Agriculture, under award number 2015-69004-23273. The contents are solely the responsibility of the authors and do not necessarily represent the official views of the USDA or NIFA.

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Table 1. Means (Standard Deviations) of Percent Price Drop Probabilities by Regime, January 2017 to December 2019

Regime	Start Date	N	10% Drop	20% Drop	30% Drop	40% Drop	50% Drop
0	1/1/2017	135	0.292855 (0.00848)	0.124326 (0.009721)	0.032773 (0.005408)	0.00431 (0.001428)	0.000179 (0.000174)
1	7/18/2017	85	0.272301 (0.009299)	0.099076 (0.009576)	0.020095 (0.004191)	0.001707 (0.000735)	0.000044 (0.000066)
2	11/15/2017	195	0.282923 (0.011949)	0.113095 (0.013364)	0.026924 (0.006602)	0.003041 (0.001351)	0.000111 (0.000135)
3	8/27/2018	137	0.332667 (0.009555)	0.179318 (0.014084)	0.07131 (0.011636)	0.018354 (0.005572)	0.002463 (0.001297)
4	3/14/2019	127	0.38182 (0.008549)	0.262055 (0.014785)	0.154728 (0.016704)	0.073092 (0.01384)	0.024909 (0.007963)
5	9/13/2019	76	0.366854 (0.006918)	0.235987 (0.009419)	0.125332 (0.009179)	0.049867 (0.006255)	0.012793 (0.002672)

Table 2. Means (Standard Deviations) of Price Floor Probabilities by Regime, January 2017 to December 2019

Regime	Start Date	N	$50/cwt Floor	$40/cwt Floor	$30/cwt Floor
0	1/1/2017	135	0.068238 (0.035774)	0.004496 (0.003145)	0.000021 (0.000056)
1	7/18/2017	85	0.013164 (0.014067)	0.0003 (0.000436)	0.000001 (0.000011)
2	11/15/2017	195	0.054151 (0.030538)	0.003011 (0.002759)	0.000011 (0.000035)
3	8/27/2018	137	0.107543 (0.058952)	0.018254 (0.015069)	0.000774 (0.001016)
4	3/14/2019	127	0.068617 (0.022811)	0.017561 (0.008305)	0.00189 (0.001436)
5	9/13/2019	76	0.084993 (0.042818)	0.019713 (0.012427)	0.001678 (0.001352)

Figure 1: CME June 2019 lean hog futures contracts, prices (in $/cwt), May 2018 to June 2019

Figure 2: CME June 2019 lean hog futures contracts, implied volatilities (in %), May 2018 to June 2019

Figure 3: CME rolling "year-out" lean hog futures contracts, price (in $/cwt), January 2017 to December 2019

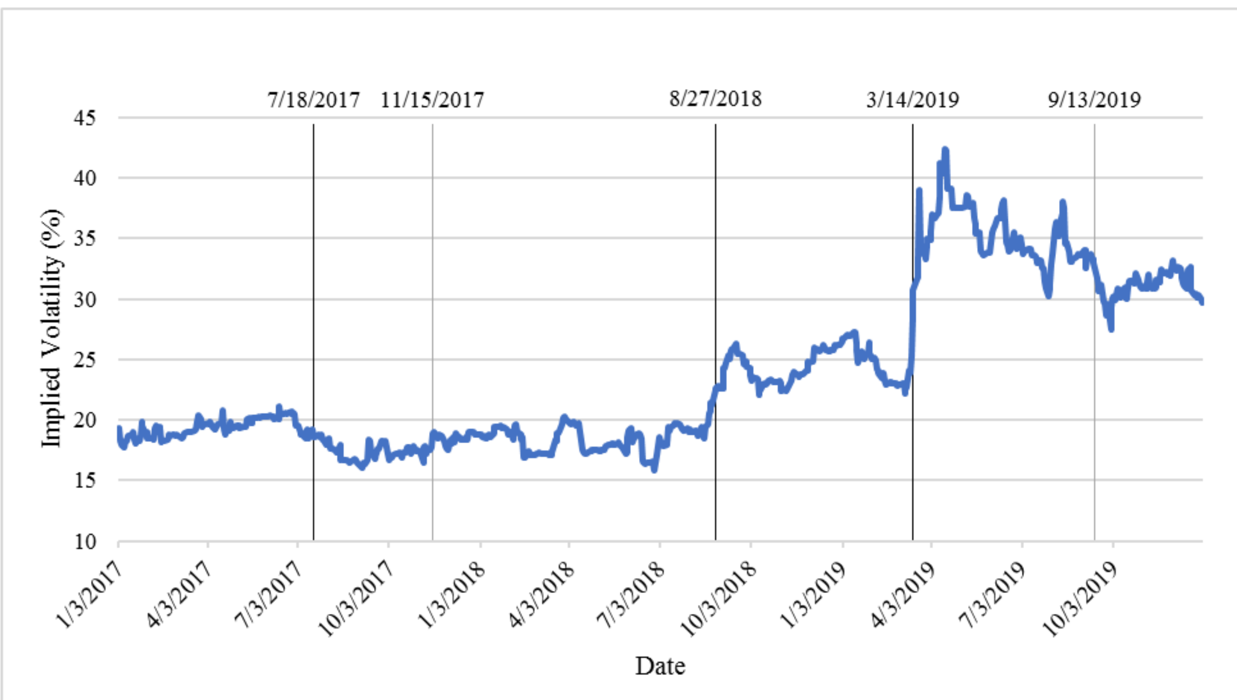

Figure 4: CME rolling "year-out" lean hog futures contracts, implied volatilities (in %), January 2017 to December 2019

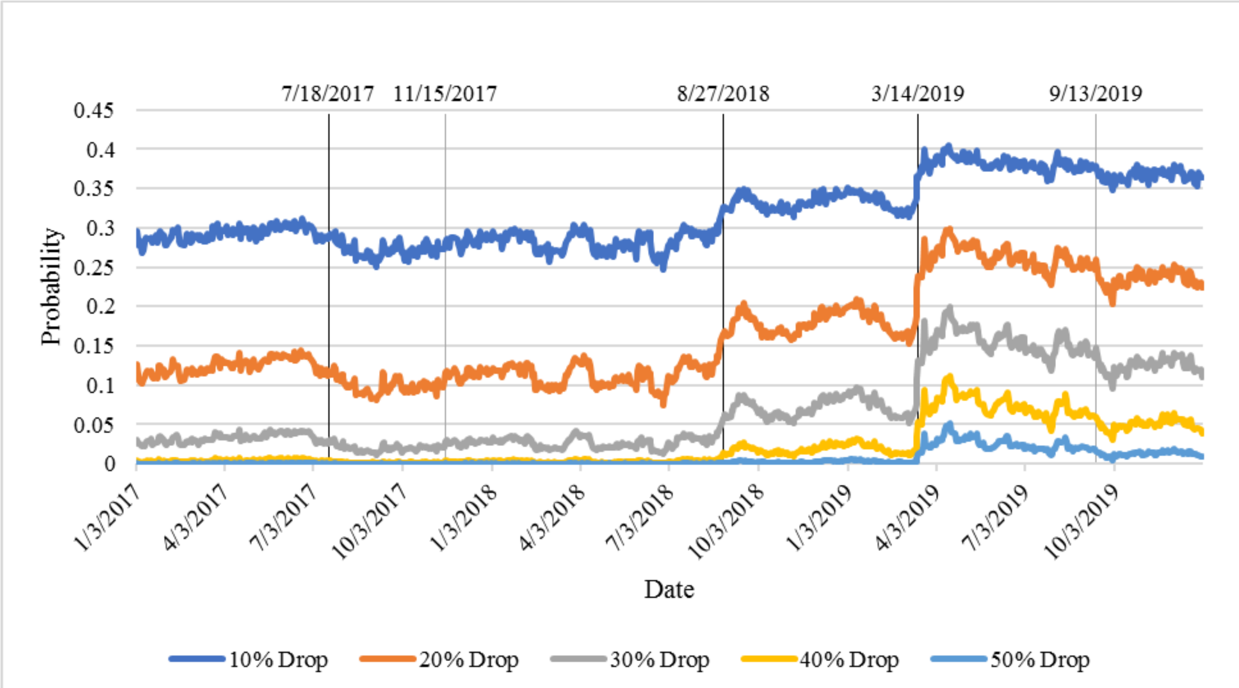

Figure 5: Probability of a catastrophic disease event, percent drop method

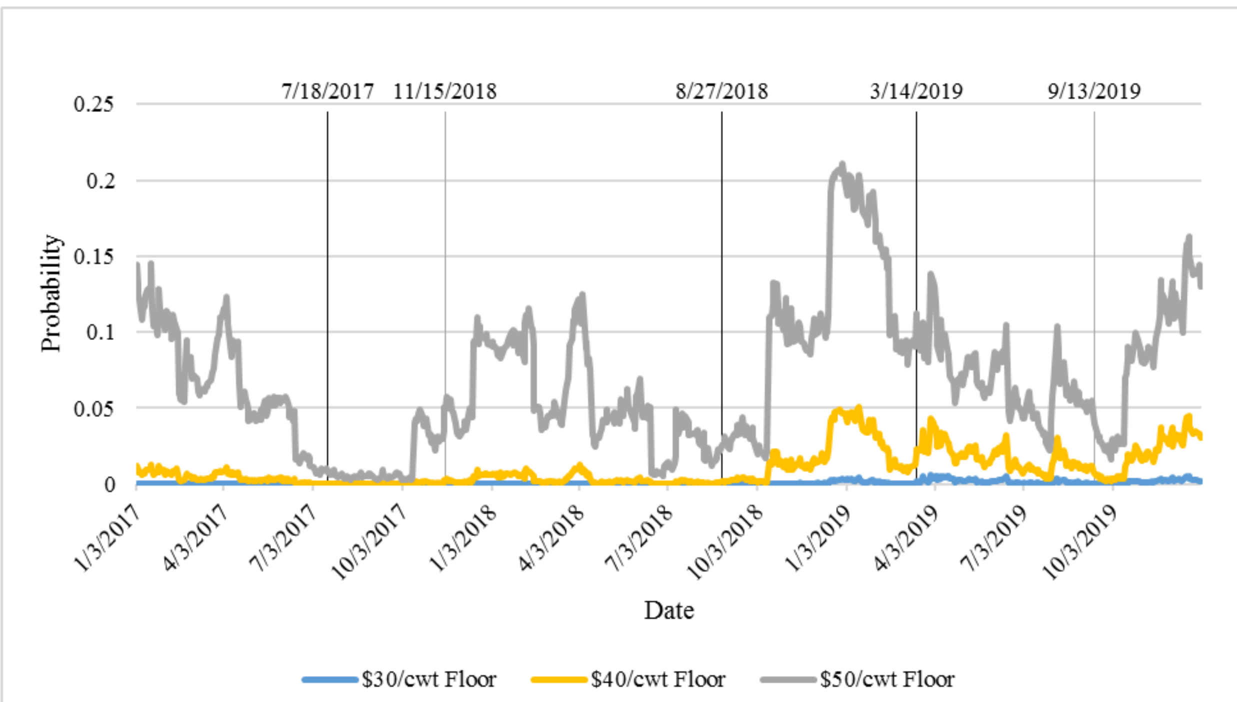

Figure 6: Probability of a catastrophic disease event, price floor method