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Economic Impacts from an On-Farm Highly Pathogenic Avian Influenza Event in Tennessee*

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Abstract: In March of 2017, two outbreaks of avian influenza, one highly- and one low-pathogenic, were reported in Tennessee poultry breeding flocks. This study estimates the potential economic impacts of a larger hypothetical event, in particular, indicating the magnitude of effects for poultry producers, industry organizations, policymakers, and other industry stakeholders. The economic impacts are estimated both with and without reductions in forward-linked processing of broiler breeders and broiler operations with depopulation rates of 10 to 25 percent in a nine-county area in the south-central part of Tennessee. Estimated reductions in gross regional product ranged from \$6.7 million to \$16.8 million.

Keywords: vian influenza, poultry, IMPLAN, economic impacts, multipliers

JEL Codes: C67, R11, Q180

1. INTRODUCTION

In March 2017, avian influenza was detected in two breeder flocks in Tennessee, specifically in Lincoln and Giles counties (Figure 1). Both low and highly pathogenic H7N9 avian influenza strains were detected.¹ Once detected, the affected farms were depopulated and a 6.2-mile (10.0 kilometers) control area was implemented to reduce the spread of the virus. The implementation of a control area is consistent with domestic and international animal health protocols (Tennessee Department of Agriculture, 2017).

Based on the 2017 Census of Agriculture, the majority of Tennessee poultry farms are concentrated in a nine-county region in Middle Tennessee. In terms of production (Figure

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¹North American H7N9 is genetically distinct from those H7N9 China outbreaks that impacted poultry and infected humans in Asia.

Figure 1: Location of Poultry Farms in Tennessee

Source: USDA/NASS, 2019

1), Tennessee had 9,662 poultry farms with the majority (8,830) classified² as layer operations, 1,457 as pullets, and 1,182 as broilers. For this same timeframe, poultry and egg sales were estimated at \$639.8 million (U.S. Department of Agriculture, National Agricultural Statistical Service, 2019a). In 2018, Tennessee was ranked 17th in the nation in cash receipts for broilers, 29th for table eggs, and 20th for poultry and eggs (U.S. Department of Agriculture, Economic Research Service, 2019). The most recent count of Tennessee poultry showed 30.5 million broilers, 2.0 million layers, and 1.3 million pullets (U.S. Department of Agriculture, National Agricultural Statistical Service, 2019a). In 2016, approximately 303.3 million birds were processed in Tennessee (U.S. Department of Agriculture, National Agricultural Statistical Service, 2019b).

The poultry industry is an important economic contributor to Tennessee's agriculture. A future outbreak of an on-farm Highly Pathogenic Avian Influence (HPAI) event and the resulting economic consequences is an important issue to poultry producers, industry organizations, policymakers, and other industry stakeholders. To quantify the magnitude of a HPAI event and the poultry industry, IMPLAN was used to estimate the economic impacts so interested stakeholders can better understand, assess, and cope with the risks faced. This analysis estimates the potential economic impacts from an outbreak of HPAI under

²A poultry operation may have more than one classification.

hypothetical depopulation scenarios of 10, 15, and 25 percent for broiler and broiler breeder operations in a nine-county poultry producing area in Tennessee. Further, the depopulation scenarios are compared with and without movement restrictions on processing facilities using information on production and expenditures for representative poultry operations.

2. BACKGROUND

Avian influenza, first recorded in 1878 as fowl plague, is a potentially zoonotic and trans-boundary reportable disease to the World Organization for Animal Health (OIE) for both low and high pathogenicities with H5 and H7 subtypes (Lupiani and Reddy, 2009; World Organisation for Animal Health, 2015). Highly pathogenic avian influenza (HPAI) can lead to high morbidity and mortality for poultry, which impacts supply chains, consumption, and trade. Many studies have discussed the impact of avian influenza (AI) outbreaks on an economy through descriptive analysis for several countries, such as the United States (Poss et al., 2003; Ramos et al., 2017) or Southeast Asia countries (Rushton et al., 2005; Dinh et al., 2006). These studies evaluate the effects of HPAI on the industry as a whole or discuss potential adverse effects on trade and/or tourism for underdeveloped countries. Other studies provide empirical evidence to investigate the impact on trade and welfare (Djunaidi and Djunaidi, 2007; Diao et al., 2009; Wieck et al., 2012; Thompson, 2018).

Avian influenza is a global problem and the literature discussing the topic is extensive. You and Diao (2007) developed a spatial equilibrium model and conducted simulations using the model to assess the impact of HPAI on the poultry sector in West Africa (Nigeria). They used poultry demand and the existence of an outbreak in a particular location as the shock parameter to simulate the model. They assembled West African spatially explicit datasets including the distribution of poultry and humans, the location of the outbreaks, and the migratory path of birds in the region. From the simulation, they found that the extent of economic loss depends on the size of the affected areas and on the mechanics of AI outbreak transmission, which occurs through either local transmission or through birds' migratory patterns. They also found the indirect economic loss from reduction in demand is larger than the direct effect of the outbreak in a particular region. Similarly, Diao et al. (2009) used a dynamic Computational General Equilibrium (CGE) model and a social accounting matrix (SAM) to investigate the economy-wide impact of HPAI outbreak in Nigeria. They found that the indirect cost of the outbreak to gross domestic product (GDP) is larger than the direct value-added loss from the outbreak. However, they found that the outbreak does not have significant impact on the poverty rate.

Using a trade framework, Wieck et al. (2012) analyzed the impact of AI outbreaks-induced policies on trade in Brazil, China, France, Germany, the Netherlands, the U.S., Russia, and Japan using a gravity model. From their empirical analysis, they found that regionalization is better at enhancing trade and reducing welfare losses than a trade-ban policy given an outbreak's circumstance. This is supported by Paarlberg et al. (2007), who modeled the effects of hypothetical regionalization during an HPAI event, and Thompson (2018), who estimated the economic impact of regionalization on trade during the 2014-2015 HPAI event.

In terms of U.S. livestock, the largest foreign animal disease event in U.S. history was

the 2014-2015 HPAI outbreak in U.S. poultry, which affected more than 49 million birds and cost tax payers \$950 million dollars to control and eradicate the disease (Paarlberg et al., 2007; Seitzinger and Paarlberg, 2016; Thompson and Pendel, 2016; U.S. Department of Agriculture, Animal and Plant Health Inspection Services, 2016a). The H5N2 virus strain was believed to be spread by migratory bird movements in the Pacific and Mississippi flyways. The economic impact of the event was estimated at \$1.2 billion (2015\$) where \$800 million was lost in egg, chicken, and turkey production and \$400 million in lost wages and taxes.

The typical control response to a highly pathogenic disease, and that used in the 2014-2015 HPAI event, is to implement control areas around the infected premise and implement movement restrictions in order to limit the spread of the disease (U.S. Department of Agriculture, Animal and Plant Health Inspection Service, 2015; World Organisation for Animal Health, 2016). These movement restrictions limit movement into and outside of the control area, which could lead to a situation where a processor is unable to find sufficient supply to operate at full capacity. These strains on continuity of business could lead to additional costs and shortages on an affected industry. Additionally, for affected poultry operations there is a recovery period - a period of time before production returns to pre-outbreak levels. For the 2014-2015 event, recovery was expected to take 18-24 months before reaching pre-outbreak production levels due to substantial demand for replacement birds. For those producers able to move eggs off of the farm, they were expected to experience elevated price levels for 6-9 months after the event ended (Eller, 2015; Iowa Department of Agriculture, 2015; Wappes, 2015; U.S. Department of Agriculture, Animal and Plant Health Inspection Services, 2016b). Movement permits can alleviate some of the business continuity strains (Thompson et al., 2019), but due to the size of the 2014-2015 event, even with movement permits, supplies were substantially reduced.

During the 2014-2015 outbreak, Iowa's poultry industry was heavily affected. Iowa has a concentrated poultry production, which, according to the most recent Census of Agriculture, has an estimated 78.5 million birds, 89.5 percent of which are layers and pullets (U.S. Department of Agriculture, National Agricultural Statistical Service, 2019a). Prior to the HPAI event, Iowa's inventory of chickens, pullets, and turkeys exceeded 69 million birds but approximately 31.5 million birds were affected, or nearly 50 percent, comprising of 77 premises in an 18-county area. Layers were predominantly affected with 24.7 million birds depopulated (Iowa Department of Agriculture, 2015). Mass depopulation and movement restrictions were implemented, but the size of outbreak required substantial logistical efforts from responders over the outbreak period.

Contrarily, the smaller 2017 Tennessee HPAI outbreak was isolated to two premises. The premises were grandparent stocks, which use a more stringent biosecurity protocol, and were immediately depopulated to reduce any risk of further spread. However, questions surfaced from poultry producers and industry leaders regarding the potential economic impacts of a larger outbreak, such as the event faced by Iowa, so that they could better understand the risks associated with a large-scale outbreak. Of Tennessee's 33.8 million-bird poultry industry, broilers represent 90.4 percent of production (U.S. Department of Agriculture, National Agricultural Statistical Service, 2019a). A larger poultry health event could have broader implications for the economy beyond the poultry sector, as there are production inputs for poultry purchased locally and farms hire local workers. Poultry also supplies local

processing, plus producers of local inputs and workers, in turn, make local purchases. Hence, the poultry industry has a multiplier effect in the local economy. Input-output models such as the Impact Analysis for Planning, commonly shortened to IMPLAN, captures industry-to-industry transactions and transactions made by households (consumers). Using Iowa as an example of catastrophic depopulation, more moderate disease scenarios were estimated using IMPLAN.

3. DATA AND METHODS

In this study, a multi-county region input-output model was created from the IMPLAN database. The IMPLAN-based model was created to construct the transactions for poultry input supplier industries and households and uses a doubly-constrained gravity model³ based on national trade flows to estimate regional purchase coefficients and other trade data for local purchases based on a region's characteristics (Lindall et al., 2006).

Multiplier analysis generally focuses on the impacts of exogenous changes on output of sector(s) in the economy and the resulting changes in household income, value added, and employment. In this study, direct impacts measure increases in spending and reductions in net income for poultry producers due to the presence and eradication of the virus. Total impacts are the sum of the direct and indirect impacts of the local purchases of electricity, feed, building/equipment repairs, insurance and other inputs, and deductions in household spending due to losses in net farm income.⁴

For the IMPLAN metrics calculated (i.e., economic activity (TIO), jobs, labor income, and value-added), projections of changes for the multi-county model used an analysis-by-parts (ABP) methodology, which, instead of building a specific industry, splits the impacts into respective parts (Lucas, 2019). The goods and services demanded from multiple industries were used to produce the impact. The level of expenditures was determined from the annual budgets of individual components or stages of the poultry supply chain. To determine the proportion of the estimated economic impacts attributed by broiler breeders and broilers, the number of representative broiler breeder operations was multiplied by the economic impacts.

Economic activity in Tennessee for 2017 for poultry/egg production was estimated at \$586.5 million and \$1.8 billion for poultry processing (Table 1). Jobs were estimated at 2,971 for poultry/egg production and 6,093 for poultry processing, respectively. Based on total output of \$684.6 billion and 4.0 million jobs for the Tennessee economy, poultry/egg production and poultry processing represented 0.1 and 0.3 percent, respectively, of total

³Gravity models assume that interactions (between product supply and demand in this case) decline at an increasing rate as distance increases. Based on Plane (1984), a double constrained gravity model imposes supply and demand constraints on the product flow in question. For example, Tennessee might purchase feed grain from Iowa, but are more likely to purchase the input from closer sources, such as Missouri, based on the amount of available supply in these and other states.

⁴For example, IMPLAN's total industry output (an economic measure) for a broiler breeder operation estimates the direct economic impacts at -\$55,078 (see Table 3), indirect economic impacts (input suppliers) estimated at -\$12,468, and induced (household spending) estimated at -\$13,254. Thus, the total economic impact was -\$80,800 (direct+indirect+induced).

Table 1: Proportion of Economic Activity and Jobs from Poultry/Egg Production and Poultry Processing for Tennessee and Study Region (2014\$)

Sector	State				Study Area ^a			
	Economic Activity ^b (Million \$)	%	Jobs ^c (Number)	%	Economic Activity ^b (Million \$)	%	Jobs ^c (Number)	%
Poultry/Egg Production	\$586.5	0.1	2,970.8	0.1	\$186.2	0.6	964.2	0.6
Poultry Processing	\$1,774.6	0.3	6,092.6	0.2	\$427.6	1.3	1,446.0	0.9
Total Economy	\$684,560.9		3,987,960.9		\$32,161.1		164,757.3	
Commodity Agriculture	\$3,644.2	16.1^d	66,582.5	4.5^d	\$532.9	34.9^d	10,141.4	9.5^d
Animal Slaughtering/Processing	\$5,295.7	33.5^e	11,799.8	51.6^e	\$442.7	96.6^e	1,469.4	98.4^e

^aBedford, Franklin, Giles, Lawrence, Lincoln, Marshall, Maury, Moore, and Wayne.

^bAnnual dollar value of goods and services that an industry produces or a measure of economic activity.

^cEstimated number of total wage and salary employees (both full- and part-time), as well as self-employed activity.

^dCompared to poultry/egg production.

^eCompared to poultry processing.

Source: IMPLAN 2017 data

economic activity, and 0.1 and 0.2 percent, respectively, of total jobs. However, compared to the state's commodity agriculture, poultry/egg production represented 16.1 percent of economic activity and 4.5 percent of jobs and for Tennessee's animal slaughtering and processing industry, poultry processing represented 33.5 percent of economic activity and 51.6 percent of jobs (IMPLAN Group LLC, 2017).

The modeling region included nine counties – Lincoln and Giles counties where the outbreak occurred – plus seven adjacent counties – Bedford, Franklin, Lawrence, Marshall, Maury, Moore, and Wayne (Figure 1) – that also had high levels of poultry (primarily broilers, layers, and pullets) production. Per IMPLAN, this multi-county region's total economic activity was estimated at \$32.2 billion and 164,757 jobs (IMPLAN Group LLC, 2017). Table 1 provides an overview of the economic impact of poultry production and processing for the study region. Compared to the multi-county region's total commodity agriculture (\$532.9 million), poultry/egg production represented 34.9 percent of economic activity and 9.5 percent of jobs. Likewise, poultry processing represented 96.6 percent of economic activity and 98.4 percent of jobs compared to the multi-region's total animal slaughtering and processing (\$442.7 million). For the multi-county region, the number of broilers were estimated at 9.0 million, with layers and pullets populations of 835,882 and 504,441, respectively (U.S. Department of Agriculture, National Agricultural Statistical Service, 2019a). Assuming this same ratio of birds processed as for the entire state, 89.2 million birds were estimated to be processed annually within the study region.

The broiler industry's supply chain was divided into four stages – broiler breeder, hatchery, broiler, and processing. Production loss from broiler breeders reduces hatchery production, which, in turn, reduces broiler production, and if supply of birds cannot be found

elsewhere, processing. These impacts result in a decrease in transactions within the region. In addition, the transactions that occur as a result of the government HPAI programs via virus eradication and bird reimbursement programs also impact the region. Extension budgets for two stages of poultry production – broiler breeder and broiler – were used. The inputs required by these budgets were assigned to industries reflected in the regional input-output model using the ABP methodology. The impacts for the other two stages (hatchery and processing) were evaluated using IMPLAN's input-output industries (IMPLAN sector 13 (poultry and egg production) for the hatchery) and poultry processing (IMPLAN sector 92). In addition, local inputs purchased for virus control and eradication result in countervailing positive economic activity. The hatchery impacts are based on the estimated sale price of baby broiler chicks and numbers of birds not produced.

Economic impacts from an interruption in the supply of regionally produced birds for regional poultry processing are estimated using a forward linkage process. Based on Giaratani's (1976) supply-side input-output analysis model (Miller and Blair, 2009), a primary input can interrupt the production of further processing. Based on the regional model, the poultry processing industry within the study region uses \$175.3 million in poultry and sells its products for \$422.8 million. Increasing the value of the bird by 241 percent. However, not all birds purchased are raised within the region. IMPLAN's 2017 data indicates that the average Regional Sales Coefficient (RSC) for poultry and eggs is 42.2 percent, implying that 42.2 percent of the broilers grown in the region are processed in the region. To determine the regional direct impact of this forward linkage, the regional impact resulting from lost production was first multiplied by the regional output of the processing sector divided by the value of purchases from the poultry and egg sector (i.e., the 241 percent) and then multiplied by the poultry and eggs sector regional sales coefficient (0.422). Therefore, if broilers cannot be found to replace what was lost, a \$1 million loss in the poultry sector equates to a \$1.02 million loss in the poultry processing sector.

3.1. Scenarios and Stages of Poultry Production

The broiler breeder and broiler operations were represented by annual Extension budgets detailing expenditures required for a pre-specified size of operation considered the representative operation. There were two overarching scenarios that were analyzed 1) broiler supply chain analysis *excluding* processing from the control area, thus assuming the processors would be able to source additional supplies from outside the study region and state (*Processing Excluded Scenario (PES)*); and 2) broiler supply chain analysis *including* processing in the control area where the reduction in supply of broilers would limit availability to the processing sector during the HPAI event (*Processing Included Scenario (PIS)*). For each scenario, the supply chains evaluated were modeled as broiler breeder → hatchery → broiler → processor stages, both with and without the processor stage respectively. For each scenario, these two supply chain assumptions were modeled at 10, 15, and 25 percent depopulation rates to account for uncertainty around potential disease event size. These depopulations effectively translate into reduction in hatching eggs produced and broilers grown out.

Table 2: Budget Assumptions for Contract Grower Representative Broiler Breeder^a and Broiler House^b Operations

Item	Value
Broiler Breeder	
Square feet of houses	33,600 (42' x 400')
Number of houses	2
Length of production cycle (weeks)	40
Duration of growing (finishing) season (weeks)	4
Females/males per placement	16,730 females/2,007 males
Eggs/cycle (dozen)	231,758
Number of hatching eggs (dozen)	226,146
Number of market eggs (dozen)	5,612
Hatchability percent to 65 weeks of age	83.9
Feed conversion to 65 weeks of age (lbs/dozen eggs)	6.66
Economic impact (months)	6
Broiler House	
Square feet of houses	33,000 (60' x 550')
Number of houses	2
Birds/year	484,000
Birds/flock	88,000
Flocks/year	5.5
Bird density	0.75
Economic impact (months)	6

^aBased on T. Vukina at NC State agricultural & resource economics 2003 enterprise budget for contract growers with cool cells, hatching eggs.

^bBased on University of Maryland Extension broiler production management for potential and existing growers (Rhodes et al., 2011).

3.1.1. Representative Broiler Breeder and Broiler Operations

The stylized broiler breeder operation and stylized broiler operation were defined by Vukina (2003) and Rhodes et al. (2011) (Table 2). Each representative broiler breeder operation assumed two 33,600 square feet houses, a 40-week production cycle, and 226,146 hatching eggs available per production cycle. Based on the broiler breeder annual budget, total revenue was estimated at \$127,562, with variable and fixed costs estimated at \$36,985 and \$71,610, respectively. Net income was estimated at \$18,968. Likewise, the representative broiler farm assumes two houses with each house 33,000 square feet and the number of birds in any one flock at 88,000 with the potential of 5.5 flocks per year. The broiler annual budget indicates estimated total revenue of \$144,494, with estimated variable and fixed costs at \$33,718 and \$68,747, respectively. Net income was estimated at \$42,029.

3.1.2. *Hatching Operations*

Since hatching operations are normally part of a vertically integrated system having proprietary cost information, external budgets for commercial hatching operations are not readily available. To estimate the impacts of lost transactions at the hatchery, the reduction in broiler birds produced was used to estimate the number of unavailable baby chicks, which was then multiplied by the dollar value of the baby chick when one to three days old.

3.1.3. *Broiler Processing*

The assumptions used to estimate the economic effects of HPAI on the broiler supply chain including processing impacts (*PIS*) were: 1) the economic impacts from the *PES* plus 2) the processor impacts over eight months of the number of birds available in each of the three simulated depopulation events. These events were estimated based on the broiler operation losses.

3.1.4. *Virus Eradication Payments*

According to USDA's Animal and Plant Health Inspection Service (APHIS), a flat rate payment for eliminating HPAI was \$6.45 (2015\$) per broiler breeder and \$1.15 (2015\$) per broiler (U.S. Department of Agriculture, Animal and Plant Health Inspection Services, 2017). Activities APHIS used to calculate the flat rate were barn preparation, cleaning, and heating of the barns for a minimum of three consecutive days to help eradicate the virus. The analysis assumes that the virus eradication activities occur on both the broiler breeder and broiler operations.

3.1.5. *PES and PIS Scenario Analysis*

Economic impacts for each of these stages were combined to provide information on the economic impacts within the study region. The assumptions used to estimate the economic effects of HPAI on the broiler supply chain excluding processing (*PES*) were: 1) the economic impact was for six months as responsible periods for both quarantine and restocking; 2) a reduction in hatchery baby chick sales of 10, 15, and 25 percent over the six-month period; and 3) incorporation of the economic impacts that occur as a result of the virus eradication payment and purchases of supplies required to disinfect the houses and equipment. The same assumptions are used in the *PIS* except that the birds not produced impact the poultry processing sector.

4. RESULTS

As a result of an HPAI event, both broiler breeder and broiler operations would have a negative impact on the multi-county region from inputs not purchased for production and loss of producer's income. Cleaning activities were an interjection of dollars that to some extent negate the impact of the production losses.

Table 3: Estimated Six Month Economic Impacts from a Highly Pathogenic Avian Influenza Event for Representative Broiler Breeder and Broiler Operations for Production, Producer's Income, and Virus Eradication for Study Region (2019\$)

Impact Type	Total Industry Output ^a		Jobs ^b		Labor Income ^c		Total Value Added ^d	
	Direct	Total	Direct	Total	Direct	Total	Direct	Total
<i>Broiler Breeder</i>								
Production								
Loss	-\$55,078	-\$80,800	-0.4	-0.6	-\$21,013	-\$28,626	-\$25,989	-\$39,508
Producer's								
Income Loss	-\$82,994	-\$128,091	-1.0	-1.4	-\$82,994	-\$96,072	-\$82,994	-\$107,916
Virus								
Eradication	\$94,939	\$143,263	3.0	3.4	\$83,096	\$96,777	\$84,383	\$110,855
<i>Broiler</i>								
Production								
Loss	-\$31,138	-\$44,813	-0.2	-0.3	-\$10,859	-\$14,838	-\$15,188	-\$22,200
Producer's								
Income Loss	-\$75,111	-\$114,369	-1.0	-1.3	-\$75,111	-\$86,496	-\$75,111	-\$96,805
Virus								
Eradication	\$77,614	\$116,457	2.5	2.8	\$66,684	\$77,676	\$67,717	\$88,992

^aAnnual dollar value of goods and services that an industry produces or a measure of economic activity.

^bEstimated number of total wage and salary employees (both full- and part-time), as well as self-employed.

^cEstimated employee compensation and proprietary income.

^dEstimated employee compensation and proprietary income, other property type income (payments from interest, rents, royalties, dividends, and profits), and indirect business taxes.

Source: IMPLAN 2017 data.

4.1. Impacts from Reduction in Broiler Breeder and Broiler Operations

Although many poultry operations have multiple houses, the representative operational structure used in this analysis consists of two houses. If a poultry operation had six houses, for example, the estimated economic impacts would be multiplied by three or the number of birds would require adjustment. The broiler breeder operation for this analysis had an inventory of 18,737 birds and the broiler operation had 88,000 birds.

The estimated total impacts for the representative broiler breeder operation not operational for six months were estimated as -\$80,800 as a result of production loss to the region's economy and -\$44,813 for the representative broiler operation (Table 3). Negative total employment impacts exceed one-half (-0.6) of one job per broiler breeder operation and -0.3 for the broiler. Total labor income and value-added impacts were estimated as -\$28,626 and -\$39,508, respectively, for the broiler breeder operation and -\$14,838 and -\$22,200, respectively, for the broiler. The lost producer income for the broiler breeder operation (broiler operation) impact to the regional economy was estimated at -\$128,091 (-\$114,369) in total regional output, -1.4 (-1.3) jobs, along with a decrease in value-added of -\$107,916 (-\$96,805).

Multipliers measure the additional total industry output or employment for an additional

Table 4: Scenario Parameters Used to Estimate Economic Impacts

Item	10 Percent	15 Percent	25 Percent
Birds Slaughtered Reduction ^a	4,459,513	6,689,269	11,148,782
Representative Broiler Operations Impacted	17	25	42
Representative Broiler Breeder Operations Impacted	5	8	13
Value of Broiler Production Lost ((\$/month) ^b	\$2,159,193	\$3,238,790	\$5,397,983
Direct Impact to the Regional Hatching Industry ^c	\$1,297,718	\$1,946,577	\$3,244,296
Direct Impact to the Regional Processing Industry ^d	\$17,581,139	\$26,371,708	\$43,952,846

^aSix months processed birds = 44.59 (89.19 birds processed annually).

^bAssumes a 2017\$ price of \$0.545 per pound and average bird weight of 5.3 pounds.

^cAssumes a 2017\$ average price of \$0.291 per baby chick.

^dBased on IMPLAN's RSC (42.2 percent) and forward linkage adjustment procedure plus eight months of lost production.

million dollars in economic activity. The total industry output multipliers for production loss and virus eradication were estimated at 1.47 and 1.51, respectively, for the broiler breeder operation and 1.44 and 1.50 for the broiler operation. The employment multipliers for the broiler breeder operation were 1.50 and 1.13 for production loss and virus eradication, respectively, and 1.50 and 1.12, respectively, for the broiler operation.

For both operations, the top industries negatively impacted for total industry output were maintenance and repair construction of nonresidential structures, electric power transmission and distribution, non-depository credit intermediation and related activities. For broiler breeder, other industries negatively impacted include other local government enterprises and support activities for agriculture and forestry. For the broiler operation, commercial and industrial machinery and equipment repair maintenance and insurance carriers were also negatively impacted. For virus eradication for both poultry operations, the top five industries positively impacted for total industry output were estimated to be support activities for agriculture and forestry, owner-occupied dwellings, limited service restaurants, offices of physicians, and wholesale trade.

For the estimated 89.2 million birds produced annually in the region (44.59 million for six months processed birds), a hypothetical reduction of 10, 15, and 25 percent equates to a reduction of 4.5 million, 6.7 million, and 11.1 million birds (Table 4), birds unavailable for processing as a result of reductions in both broiler breeder and broiler production operations. For the 10, 15, and 25 percent depopulation rate scenarios, an estimated 5, 8, and 13 representative broiler breeder operations were projected to shut down for six months, respectively, and 17, 25, and 42 representative broiler operations closed because of either a shortage of eggs and/or because of the disease itself (Table 4). Although the capacity of the broiler houses was 88,000 birds, it was assumed they were depopulated and, over the next six months, two other potential flocks were not grown. Consequently, production decreases were estimated to be 264,000 birds for each representative production facility.

For a loss of 13 representative broiler breeder operations under the 25 percent reduction scenario, the estimated economic impacts were -\$1.0 million for production loss and -\$1.6 million for the loss in producers' income (Table 5). However, income flows into the study

Table 5: Estimated Six Month Economic Impacts as a Result of Egg Production Losses and Virus Eradication by Scenario Due to a Highly Pathogenic Avian Influenza Event in Broiler Breeders in the Study Region (2019\$)

Scenarios & Production Stage	Total Industry Output ^a		Jobs ^b	
	Direct	Total	Direct	Total
<i>Total Net Impact 10%</i>	-\$215,665	-\$328,140	8.0	7.0
Production Loss	-\$275,390	-\$404,000	-2.0	-3.0
Producer's Income Loss	-\$414,970	-\$640,455	-5.0	-7.0
Virus Eradication	\$474,695	\$716,315	15.0	17.0
<i>Total Net Impact 15%</i>	-\$323,498	-\$492,210	12.0	10.5
Production Loss	-\$413,085	-\$606,000	-3.0	-4.5
Producer's Income Loss	-\$622,455	-\$960,683	-7.5	-10.5
Virus Eradication	\$712,043	\$1,074,473	22.5	25.5
<i>Total Net Impact 25%</i>	-\$539,163	-\$820,350	20.0	17.5
Production Loss	-\$688,475	-\$1,010,000	-5.0	-7.5
Producer's Income Loss	-\$1,037,425	-\$1,601,138	-12.5	-17.5
Virus Eradication	\$1,186,738	\$1,790,788	37.5	42.5

^aAnnual dollar value of goods and services that an industry produces or a measure of economic activity.

^bEstimated number of total wage and salary employees (both full- and part-time), as well as self-employed

region (\$6.45 per bird per APHIS) for cleaning and disinfecting the houses resulting in \$1.8 million generated in the local economy. Under this assumption, net employment in the poultry sector was not projected to be markedly impacted. Broiler houses were projected to be more significant (Table 6). Under the 25 percent reduction scenario, an estimated 42 representative broiler operations are impacted. The estimated economic impacts were -\$1.9 million for production loss and -\$4.8 million for the loss in producers' income offset by the \$4.9 million income flowing into the study region (\$1.15 per bird per APHIS) for cleaning and disinfecting the houses resulting in a net impact of -\$1.8 million impacting the local economy.

4.2. Impact from Virus Eradication Operations

Direct expenditures for virus eradication in a single stylized broiler breeder operation was estimated at \$143,263 assuming inputs for this eradication were purchased within the study region (see Table 3). These purchases result in an additional \$110,855 in value-added and adding 3.4 jobs. The impact is smaller if the broiler operation is affected. The broiler producer would receive \$77,614 in subsidies for implementing eradication of HPAI. Assuming that the \$77,614 is all spent within the region, the total impact on TIO is \$116,457 (i.e., the output multiplier is 1.50). Additional employment is estimated at 2.8 jobs. Based on the number of enterprises impacted, the estimated total economic impact of the eradication operations is estimated at \$0.7, \$1.1, and \$1.8 million (see Table 5) to the region's economy for broiler breeder operations and \$2.0, \$3.0, and \$4.9 million (See Table 6) for broiler

Table 6: Estimated Six Month Economic Impacts as a Result of Broiler Production Losses and Virus Eradication by Scenario Due to a Highly Pathogenic Avian Influenza Occurrence Event in Broilers in the Study Region (2019\$)

Scenarios & Production Stage	Total Industry Output ^a		Jobs ^b	
	Direct	Total	Direct	Total
<i>Total Net Impact 10%</i>	-\$483,705	-\$721,748	22.0	20.3
Production Loss	-\$525,986	-\$757,002	-3.4	-5.1
Producer's Income Loss	-\$1,268,782	-\$1,931,932	-16.9	-22.0
Virus Eradication	\$1,311,063	\$1,967,186	42.2	47.3
<i>Total Net Impact 15%</i>	-\$725,558	-\$1,082,623	32.9	30.4
Production Loss	-\$788,979	-\$1,135,503	-5.1	-7.6
Producer's Income Loss	-\$1,903,173	-\$2,897,898	-25.3	-32.9
Virus Eradication	\$1,966,594	\$2,950,778	63.3	70.9
<i>Total Net Impact 25%</i>	-\$1,209,263	-\$1,804,371	54.9	50.7
Production Loss	-\$1,314,965	-\$1,892,506	-8.4	-12.7
Producer's Income Loss	-\$3,171,955	-\$4,829,830	-42.2	-54.9
Virus Eradication	\$3,277,657	\$4,917,964	105.6	118.2

^aAnnual dollar value of goods and services that an industry produces or a measure of economic activity.

^bEstimated number of total wage and salary employees (both full- and part-time), as well as self-employed

production for the 10, 15, and 25 percent scenarios, respectively.

4.3. Impacts from Reduction in Hatcheries

In order to estimate the decrease in hatchery eggs supplied to the breeders as a result of the HPAI event, the direct impact to the economy was calculated based on the decrease in baby chicks produced. This value was estimated at \$0.291 (2017 Agricultural Statistics) per chick resulting in a direct impact on the region's economy of \$1.3 million, \$2.0 million, and \$3.3 million for the 10, 15, and 25 percent scenarios, respectively. Total economic impacts from the hatcheries loss were estimated at \$1.5, \$2.3, and \$3.8 million (Table 7).

4.4. Total Economic Impacts from HPAI Simulated Scenarios

Table 8 presents the total economic losses across all depopulation rates and scenarios. Not surprisingly, the impact of the HPAI is much larger if the poultry processing sector is *impacted as a result of the disease*. The total economic loss for PIS to the regional economy was estimated as \$5.65 per bird with value-added losses to the region estimated at \$1.50 per bird. For the 10, 15, and 25 percent scenarios, regional losses in output were \$25.2 million, \$37.8 million, and \$63.0 million, respectively. Two percent of the regional economic activity is lost under the 25 percent PIS. Value-added losses within the region were \$6.7 million, \$10.0 million, and \$16.8 million, respectively.

If the broiler processing sector is not impacted, under the PES 10 percent reduction the

Table 7: Estimated Economic Impacts as a Result of Estimated Hatchery and Broiler Processing Production Losses by Scenario Due to a Highly Pathogenic Avian Influenza Occurrence Event in Broilers in the Study Region (2019\$)

Scenarios & Production	Total Industry Output ^a		Jobs ^b	
Stage	Direct	Total	Direct	Total
Total Net Impact 10%:				
Hatchery Loss	-\$1,329,321	-\$1,538,149	-6.7	-8.3
Broiler Processing Loss	-\$17,971,689	-\$22,610,233	-59.5	-91.6
Total Net Impact 15%				
Production Loss	-\$1,993,981	-\$2,307,223	-10.1	-12.5
Broiler Processing Loss	-\$26,957,533	-\$33,915,334	-89.2	-137.4
Total Net Impact 25%				
Production Loss	-\$3,323,303	-\$3,845,373	-16.8	-20.8
Broiler Processing Loss	-\$44,929,220	-\$56,525,555	-148.6	-228.9

^aAnnual dollar value of goods and services that an industry produces or a measure of economic activity.

^bEstimated number of total wage and salary employees (both full- and part-time), as well as self-employed

estimated direct and total impacts (economic activity) were estimated at -\$2.0 million and -\$2.6 million, respectively. Employment impacts were estimated at 23.3 direct and 19.0 total. Total labor income and value-added impacts to the region's economy were estimated at \$0.5 million and -\$1.0 million, respectively.

The total industry output multipliers for the *PES* was 1.28 and 1.26 for the *PIS*. The employment multiplier was 0.82 for the *PES* and 2.00 for the *PIS*. The top five industries

Table 8: Estimated Six Month Economic Impacts from a Highly Pathogenic Avian Influenza Event for Broiler Supply Chain Sectors Excluding and Including Processing for 10, 15, and 25 Percent Depopulation Rate for the Study Region (2019\$)

Scenarios & Production	Total Industry Output ^a		Jobs ^b	
Stage	Direct	Total	Direct	Total
Processing Excluding Scenario (PES)				
10%	-\$2,028,691	-\$2,588,037	23.3	19.0
15%	-\$3,043,036	-\$3,882,056	34.8	28.4
25%	-\$5,071,728	-\$6,470,094	58.1	47.4
Processing Including Scenario (PIS)				
10%	-\$20,000,380	-\$25,198,260	-36.2	-72.6
15%	-\$30,000,569	-\$37,797,390	-54.4	-109.0
25%	-\$50,000,948	-\$62,995,649	-90.5	-181.5

^aAnnual dollar value of goods and services that an industry produces or a measure of economic activity.

^bEstimated number of total wage and salary employees (both full- and part-time), as well as self-employed

estimated to be negatively impacted for the *PIS* for total industry output were poultry processing, truck transportation, owner-occupied dwellings, wholesale trade, and monetary authorities and depository credit intermediation.

5. DISCUSSION

Broadly speaking, these results indicate the effects of a disease event are not limited to the directly affected industry but can have larger implications when estimating the effects on input suppliers and the region's economy. These types of estimates communicate the value of disease prevention and savings for producers, processors, consumers, and other linked industries. While a large-scale event could have greater impacts through trade restrictions, understanding the implications of disease and depopulation on the local, regional economy is important.

In their investigation of the economic impacts of foot-and-mouth disease (FMD) in south-west Kansas, Pendell et al. (2007) notes the magnitude of the economic impact relies heavily on where the incidence occurs. The authors introduced FMD scenarios for a cow-calf operation, a medium-sized feedlot, and for five large feedlots to determine the economic and epidemiological implications of the disease origin. The estimated economic impacts ranged from \$35 million for a single cow-herd, if rapid detection and control of the disease occurred quickly, to close to \$1.0 billion if FMD was introduced in five large feedlots. Similarly, there are differences in poultry production types, but Pendell et al. (2007) brings awareness, not just to the impact of disease, but also that there is heterogeneity in response to how and where that disease is introduced.

In this analysis, a set of hypothetical HPAs were developed based on secondary source information, which compared the economic implications of various magnitudinal disease outbreak scenarios. The analysis demonstrates that if the virus was not controlled it can have significant impacts on a region's economy. From an economic standpoint, societal intervention through eradication protocols to halt the disease are warranted. The burden of disease directly through morbidity and mortality and indirectly through industry linkages or trade implications can be costly. The virus eradication payments and disinfection activities result in a regional gain and reduces the economic impact of losses resulting from decreased production. This program offsets the impacts of producer income losses, but does not affect the losses resulting from reduced levels of input purchases resulting from empty poultry houses. For every dollar distributed through the virus eradication program, the region total economic activity increases by \$1.5. Based on this analysis, if the virus eradication payments increased \$0.39 per bird, then the economic losses to the region would zero out.

In this study region, economic activity is estimated to be reduced by over \$63 million. However, the majority of the loss originates with decreased operations in the broiler processing industry. The results indicate that while producers' impacts to the economy occur, the largest impact is a reduction in processing. A policy that promotes acquiring birds from outside the region to keep the processing facilities operating would reduce the potential economic impacts of an HPAI outbreak.

6. STUDY LIMITATIONS

It is important to note that this type of study has limitations. First, the results represent a single snapshot in time. This limitation could be addressed by a multi-period input-output model where impacts could be traced over time (Shishido et al., 2000). Second, many of the cost estimates used were from a variety of sources and are subject to change as the poultry industry expands or contracts and as more accurate information becomes available. Third, data applicable for the analysis was limited and the analysis assumes a homogeneity of breeder/broiler houses for all farms. Fourth, the total net effects of the economic impacts were difficult to capture and may be over- or under-stated. Fifth, the scenario results were specific to the assumptions stated. Deviation from the underlying assumptions would result in changes to the economic impacts estimated. For instance, if the economic impacts lasted only three months instead of six, the economic impacts estimated would be cut in half. Additionally, the scenarios were based upon specified hypothetical depopulation rates of affected flocks and do not specifically represent the epidemiology of any specific event. Sixth, the estimated economic impacts do not consider spillover effects that could occur outside the study region (i.e., other counties within Tennessee and neighboring states) or through trade restriction decisions globally. A multiregional model could be constructed (Hamilton and Jensen, 1983) that would account for feedback effects between Tennessee's economy and neighboring states or the use of a trade specific model could account for either of these two limitations. Seventh, how the inputs are purchased (monies from operating loans or funds by previous year's revenues/profits) may have policy or owner decision-making implications since it will impact the timing of the indirect and induced impacts. Eighth, a limited HPAI event resulted in negative economic impacts and loss of jobs in a production area. Responses to such outbreaks need to address both the direct farm impacts, as well as the local community impacts to include issues such as education and job loss assistance. A policy analysis matrix (Monke and Pearson, 1989), where externalities and other impacts (such as the cost of job loss assistance), would provide an analytical device for examining these types of impacts. Finally, this analysis did not model every decision point poultry producers' may face as a result of a HPAI outbreak. Additional research in the risk and uncertainty area for producers' faced with HPAI outbreak decisions may shed additional insight.

7. CONCLUSION

Due to a recent (2017) avian influenza event in the poultry industry in Tennessee, this analysis estimated the economic impacts for 10, 15, and 25 percent depopulation rates on two scenarios for the broiler supply chain in a nine-county area in south central Tennessee. Economic impacts were estimated for representative broiler breeder and broiler operations including broiler breeder, hatchery, broiler, and processing industries. Production and expenditures information from poultry Extension annual budgets were used to aid in estimating the potential economic impacts for the poultry operations. Based on two hypothetical depopulation rate scenarios, the estimated total economic impacts to the regional economy for the complete broiler chain industries were -\$25.2 million, -\$37.8 million, and -\$63.0 million for the 10, 15, and 25 percent scenarios, respectively, or a loss to the economy of an estimated

\$5.65 per bird. Gross regional product, as measured by value-added within the region, was decreased by \$6.7 million, \$10.0 million, and \$16.8 million, respectively, or an estimated \$1.50 per bird. These estimates provide an indicator for Tennessee producers of the effect HPAI could have economically. More broadly, these results show the regional implications of foreign animal diseases consistent with the literature. While animal diseases are often thought of as affecting only production and prices, this analysis provides a greater understanding of the cost to the economic linkages between agriculture and the broader economy. Producers manage disease risk for animal health purposes and their own economic situations, but the greater economic costs show additional burden as a result of disease, one that, as of yet, does not play an active role in biosecurity or on-farm decision making.

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