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Peyton Ferrier, Monica Saavoss, and Samuel Williamson

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Welfare Effects of the 2022 U.S. HPAI Outbreak

Peyton Ferrier, Monica Saavoss, and Samuel Williamson[1]

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[1] Peyton Ferrier is an economist of the USDA's Agricultural Marketing Service, Monica Saavoss and Samuel Williamson are economists for the USDA's Animal Plant Health Inspection Service.

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Shocks to agricultural markets due to animal disease outbreaks are especially disruptive. We use an Equilibrium Displacement Model (EDM) to estimate the price and welfare effects of the U.S. outbreak of High Path Avian Influenza (HPAI) that reduced turkey production by 9 to 12 percent and egg production by 5 to 7 percent over the last three quarters of 2022. We find that HPAI reduced consumer welfare by $199.2 million for turkey and $3.56 billion for eggs and reduced coarse grain expenditures by $112.3 million.

Keywords: Animal Disease, Partial Equilibrium Model, Food Prices, Poultry, Eggs, Livestock, High Path Avian Influenza

Introduction

Shocks to agricultural markets due to animal disease outbreaks are especially disruptive. Depending on their severity, outbreaks lead to the depopulation of exposed animals, the establishment of quarantine zones restricting animal movement, the loss of trade access, and, when human health is at risk, sharp falls in demand. In recent history, all major animal product markets have suffered severe, disease shocks events including the 2003 discoveries of Bovine Spongiform Encephalopathy (BSE) in Canadian and then U.S. cattle, the 2019 outbreak of African Swine Fever in pigs in China, and the 2015 and 2022 outbreaks of High Path Avian Influenza[2] (HPAI) in the United States.

Animal disease shocks ripple through upstream markets for feed grains, machinery, and agricultural labor and downstream markets for packing, processing, and consumer food. When demand for animal products is inelastic at the wholesale level, producers, as a group, may counter-intuitively have sales revenue increase as price increases outpace the sales loss from reduced production. For these reasons, fully accounting for welfare losses from disease outbreaks requires a consideration of upstream and downstream markets, specifically the spillover effect across markets for other animal products using the same feed inputs and showing varying degrees of demand substitutability with each other[3].

Among other economic models, the Equilibrium Displacement Model (EDM) is well-developed and has been applied to animal disease shocks trace extensively (Hennessy and Marsh, 2021). In general, EDMs parameterize a set of interrelated markets by a set of tractable parameters defining supply and demand and then trace through the effects on price and output as an exogenous shock (disease loss, trade restrictions, taxes) causes the market to move from an

[2] Avian Influenza is an infectious, viral respiratory disease originating in birds and transmitted by contact with infected hosts. Epidemiologically, strains are classified into subtypes based on numbered classification of two proteins - hemagglutinin and neuraminidase - on the surface of the Influenza A virus, with the 2022-23 U.S. outbreak being a H5N1 sub-type. The 2022-23 outbreak is similar to the 2015 HPAI outbreak (subtype H2N2) in terms of its size (around 50 million birds), industries requiring bird depopulations (turkey and eggs), and negligible human health risk.

[3] See Kappes et al (2024) for a more general review of economic analysis of livestock health and disease economics.

initial observed equilibrium to another counterfactual one (Brester et al., 2023). We implement the model developed by Paarlberg et al (2008) that specifies the market for livestock (beef cattle, swine, broilers, egg-laying hens, sheep, dairy cattle, and turkeys), meat (beef, pork, chickens, eggs, lamb, milk, and turkey meat), and feed grains (soybeans, corn, wheat, forage), along with rice and soy oil. Importantly, this model also allows for shocks to persist over several periods due to the biological cycles of livestock.

Using this model, we compare prices, consumer welfare and producer welfare under the observed 2022 market equilibrium impacted by the large U.S. HPAI outbreak and a counter-factual scenarios removing the disease's effects on production and export access. In this simulation, the production counterfactual is calibrated from pre-outbreak forecasts of production and exports. In conducting our estimation, we note the similarity between the 2022 HPAI and the earlier 2015 HPAI outbreak which similarly affected turkey, egg, and broiler markets. While these outbreaks were both large and disruptive, the 2015 outbreak led notably to the comprehensive loss to all U.S. producers of export access to China and South Korea, both major markets for U.S. eggs, broilers, and turkeys at the time. In contrast, the 2022 outbreak led only to regionalized restrictions of exports from production areas with ongoing outbreaks and a much smaller impact on export access, especially with broilers.

The 2022 U.S. HPAI outbreak eventually led to the culling of 9.4 million meat turkeys, 43.3 million table egg laying hens, and 2.2 million broilers. After circulated in Europe and Asia since 2020, the specific virus responsible for the outbreak[4] was spread in the United States by wild birds along regular north-south migration flight ways – first, in the late winter and spring, followed by a notable summer lull, and then again in fall and winter. As shown in **Figure 1**, commercial depopulations – the destruction of live birds in facilities infected with HPAI – of turkeys and egg began in February of 2022.

<< **Figure 1** – Weekly Depopulations of Table Egg Layers and Turkeys due to HPAI >>

The similar 2015 HPAI outbreak had comparable losses across turkeys, egg-laying hens, and broilers. December 2014 marked the first detections of HPAI in wild bird populations at which time many countries including China and South Korea immediately banned U.S. poultry and egg imports entirely. Detections in and depopulations of commercial flocks did not begin until January of 2015 while large scale disruptions of production were concentrated between late March through June 2015, which marked the end of new detections. This abrupt end of the outbreak contrasts with the fall resurgence of the 2022 outbreak which continue sporadically through April of 2023 as shown in **Table 1**.

<< Table 1 – HPAI Related Depopulations of Poultry in 2015 and 2022 as a Share of Production and Inventory >>

In both the 2015 and 2022 outbreaks, the broiler industry saw only minor disease-related losses relative to total production. In contrast, 2022 production of turkeys fell 6.0 percent and shell-

[4]See Shi et al (2022) for a detailed discussion of the HPAI epidemiology.

eggs 2.4 percent compared to the previous year while average annual prices rose 26 percent for turkeys and 141 percent for eggs.
Figures 2 and 3 show that turkey and egg prices increased dramatically following the onset of the 2022 outbreak. For turkeys, prices for fresh boneless skinless tom breast prices rose 208 percent in May and whole hens rose 35 percent in their highest year-over-year peaks. For eggs, monthly prices for New York carton eggs[5] rose 217 percent and the Central States breaking eggs rose 379 percent in their highest year-over-year peak. For eggs, price volatility increased dramatically with the greatest upward spikes occurring in the weeks preceding holidays in which demand increases and retail outlets often run loss-leading egg promotions. Despite their severity, the 2022 price increases were comparable with those of 2015 when the monthly average price for eggs rose 243%, the fresh boneless skinless turkey breast rose 52%, and whole frozen turkey hens rose 17% over the previous year's level.

<< **Figure 2** – Prices for New York Carton and Central States Broken Eggs >>

<< **Figure 3** – Prices for Frozen Whole Hens and Fresh Turkey Parts >>

Unlike the 2015 outbreak, however, the United States largely preserved access to export markets during the 2022 outbreak. **Table 2** shows that the share of U.S. production exported of turkey, eggs, and broilers in the years preceding and following the 2015 HPAI outbreak. Compared to the three years preceding the outbreak year, the share of broiler and turkey production exported abroad fell 3.8 percentage points while the export share of shell eggs, which are not largely exported, fell 0.6 percentage points. This decline was due both to export restrictions and to the decreased production and higher prices also caused by the HPAI outbreak. Additionally, whereas the 2015 outbreak was associated with the loss of key export markets as over 50 countries placed restrictions on U.S. poultry products, in 2022 most restrictions on U.S. exports were limited only to production regions in which the outbreak was active.

<< Table 2 – Aggregate Shares of U.S. Production Exported Before and After the 2015 HPAI Outbreak >>

Since 2015, the United States secured several agreements to regionalize trade restrictions, along with other animal health measures to better geographically isolate outbreaks as they occur. Subsequently, with most trade partners, export restrictions were limited regionally during the 2022-23 outbreak[6].

Empirical Framework

[5]Egg prices differ regionally but are highly correlated. We use the benchmark New York egg price which refers to the wholesale price of dozen-carton eggs delivered to the New York City market as reported daily by AMS.
[6]In lieu of more restrictive country-wide restrictions following an animal or plant disease output threat, the World Trade Organization's Agreement on Sanitary and Phytosanitary Restrictions encourages regionalization strategies that limit trade restrictions to geographic regions in which a phytosanitary threat is relevant. Such encouragements are often not formalized or binding in the absence of separate and more comprehensive bi-lateral trade agreement formalizing reporting and notification requirements and the permissible scope of trade restrictions where necessary.

To estimate the market and welfare effects under the counter-factual, we employ the Equilibrium Displacement Model (EDM) specifically developed by Paarlberg et al., 2008 to consider the welfare effects of animal disease shocks. Our EDM has been applied broadly in policy application to study the comprehensive market effects of various animal disease outbreaks (Thompson et al., 2019). Full documentation of this model is included in Paarlberg et al. (2008). **Table 3** describes the input-output process used in its embedded supply and demand linkages for 19 products. Of these, seven are animal products, seven are livestock used as inputs to animal products, and four are feedstuffs used as inputs to animal production. Soybeans are crushed to make soy oil and soy meal in a fixed ratio. On the demand side, eleven products are sold in final goods markets, including rice which has no animal product use but competes with feedstuffs for land and wheat and coarse grains which are used both as inputs to animal production and as final goods. Trade relationship, either as export demand, import demand or both, are defined for 14 products. Inventory demand, where inventory is carried across quarterly periods, is also incorporated for seven commodities.

On the production side, all products use capital in production and the exogenous input, a variable that captures labor and other inputs assumed to have a perfectly elastic supply. animal products use livestock animals as inputs; Livestock products use feedstuffs, forage, and, in the case of ruminants, land; And, finally, crops use land in production. Within **Table 3, "**B" denotes that the input is the reference input and other input levels are adjusted in reference to it.

<< **Table 3**–Commodities, Uses, Trade, Inventory, and Production Relationships in the Animal Disease Outbreak Model >>

The model also tracks cattle, swine, and sheep through their inventory periods in which the animals are being raised for future production and consuming feedstuffs but are not ready for slaughter. The inventory variables on both on the demand and production sides, along with reproduction and growth constraints of animals, can create persistence in the market effects across periods for certain types of shocks. The model incorporates these lags to replace lost animals and, accounts for stocks of animals at different ages with differing feed requirements[7]. In our specific application of HPAI in 2015, shocks enter directly into production variables, rather than to breeding stock variables. All shocks inputs and simulated changes from the counterfactual withing our EDM are made as log changes from the baseline of 2022 market conditions.

Data

Data used to calculate the initial equilibrium is drawn from various USDA sources and documented in Paarlberg et al (2008). Data describing initial market equilibrium levels (production, prices, exports, imports, trade, and inventories) largely follows the construction of commodity data reported monthly in the USDA's process of reporting World Agricultural

[7]The model allows for biological reproduction constraints, particularly with cattle, to create market cycles in the manner described by Rosen, Murphy and Scheinkman (1994) and allows for continuously updating price expectations to affect stocking decisions. Since our shock only affects poultry which does not face biological constraint on restocking, those options are turned off.

Demand and Supply Estimates (WASDE)[8]. Cost share variables for inputs and behavioral variables, including elasticities of demand, substitution, trade, and stocking, are drawn from available sources and documented in Paarlberg et al (2008).

Simulation

The scenario counterfactual is developed from the observed differences between actual 2022 values of poultry production and exports versus those predicted for 2022 by the WASDE forecast in December 2021. For broilers, these differences were relatively small and sometimes positive since as broiler HPAI outbreaks were minor. For this reason, in our counterfactual scenario, we assume that broiler were unaffected by HPAI and focus solely on turkey and eggs.

Production Effects Counterfactual

The baseline in out model is the observed market equilibrium in the last three quarters of 2022. The counterfactual is 2022 WASDE projection. The estimated impact of HPAI impact is the calculated welfare difference based on prices and quantities in the observed production baseline and the counterfactual scenario where the market regains the lost production and exports.

In our case, simply restoring production via a counterfactual supply shift did not return exports to plausible levels as it does not account for unobserved trade restrictions. HPAI, like other disease outbreak, can reduce exports in two ways. First, the decreased production caused by depopulations may result in fewer exports shifts the supply curve and raises prices, making U.S. turkey and eggs less competitive and reducing exports, other things equal. Second, other countries may restrict the importation of U.S. poultry products because of the HPAI detection. To separate out these two factors, we run two separate counterfactual scenarios. Scenario 1 restores lost production in 2022 due to HPAI but does not otherwise address trade. As we discuss later, this supply shift alone moves trade to a level far below its level forecast in the WASDE. Scenario 2 restores the same lost production and returns trade (exports, in the case of turkey and eggs) to their forecast level. The difference between the equilibrium in the two scenarios isolates the trade effect of the outbreak as compared to the production effect of the outbreak.

Within the mechanics of the model simulation, simply inputting the difference in equilibria production levels as a supply shock will induce a contemporaneous supply response that will offset the inputted shock. Conceptually, EDM practitioners can impose a movement from the actual to a counterfactual equilibrium by either iteratively adjusting and calibrating shifts in the supply curve until the counterfactual change is reached or they can simply turn off the internal supply responses by setting key supply elasticities in the model to be approximately zero. Our simulation considers both the production shock and the export access shock of HPAI for turkey and eggs. For the export access shock, we turned off internal supply responses – shifting the export demand to the levels projected in the WASDE estimates pre-HPAI and then

[8] Underlying data for WASDE itself is drawn from various USDA sources: production and stocks data from NASS, price data from AMS, and trade data from the Foreign Agricultural Service. bas

simultaneously setting the elasticity of export demand arbitrarily close to zero[9]. For the production shock, we used the calibration process over successive modeling runs.

We note that, as a practical matter, the magnitude of a supply curve shift is unknown even if the exact number of livestock lost is exactly observed. Birds might be lost in an early stage of production, rather than represent the loss of a market-ready animal. Also, producers can, to some degree, substitute inputs like feed and processing to affect production with the same number of animals by feeding animals to higher weights or retaining older, less productive layers longer than would ordinarily be optimal. Conversely, producers might reduce per animal production in response to other disease related factors, such as moving forward slaughter of smaller turkeys (at lower weights) to meet orders, sustain employment at packing plants, or to avoid a complete loss from potential future outbreaks. Also, APHIS requires a downtime period of 9 to 13 weeks before a depopulated facility (hen house, turkey barn) can re-stock to ensure the house is sanitized and virus free, thus reducing production capacity for 2 to 3 months.

Table 4 includes the levels for actual and forecast production for turkey, broilers, and eggs for each quarter in 2022.

<< **Table 4** - Estimated counterfactual difference between actual production in 2022 and forecast production without HPAI >>

Notice that broiler production significantly exceeded forecasts in the 3rd and 4th quarters of 2022 and this increase was associated with a significant fall in prices. Broiler depopulations at the time were also a very small share of production. For this reason, we assume that HPAI caused no substantive change in production for the purposes of our counterfactual simulation. **Table 5** provides the changes applied changes in the counterfactual.

<< **Table 5** - Estimated counterfactual difference between actual production in 2022 and projected production without HPAI >>

Our production effects counterfactual is that that the turkey supply would have been at least 9 percent greater and eggs at least 5 percent greater across the 2nd, 3rd, and 4th quarters of 2022 if the HPAI outbreak had not occurred, but broiler production would not have increased in the absence of HPAI.

Our trade effects counter-factual is similarly developed from actual and forecast export shares as reported in **Table 6**. The shortfall of actual exports from forecasted values for turkey and eggs ranged from 29.6 to 90.3 percent over the 2nd, 3rd, and 4th quarter of 2022. This compares with production shortfalls over the same period (shown in **Table 4**) ranging from only 4.7% to 12.3% for turkey and eggs over the same period. As a *prima facie* comparison, actual trade flows seem to over-respond to the production shock of the outbreak if one assumes that HPAI causes no other impact on trade (*i.e.* export restrictions in the form of complete or partial bans) other than

[9] Setting either the elasticities or consumer demand or export demand to be exactly zero prevents the model from reaching equilibrium.

through supply and price. Even in the absence of total bans, disease outbreaks can affect trade through regionalized restrictions that re-route supply chains or even quarantine restrictions that ban product if it moves through certain regions. In terms of predictive consequences, excluding trade restrictions is non-trivial when accounting for welfare effects because trade restrictions push product back into domestic markets and offsetting some of supply shortfalls and related price increases brought on by the initial production shock.

<< **Table 6** - 2022 WASDE export forecast, actuals, and percentage difference >>

Simulation the Effects on Prices, Production and Trade

From a base level of actual observed production, out first scenario incorporates only the production shock effect. The second scenario incorporates both the production shock effect and forces trade to remain effect. The difference between the simulated changes in export percentage in the two models can be interpreted as the percentage change in exports that can be attributed solely to export restrictions as opposed to production. For example, the production-only Scenario 1 model predicts that turkey exports would have been 2 percent higher in the fourth quarter in a world with no HPAI based on production effects alone, yet the actual difference between WASDE projected exports for turkey in the fourth quarter was 62 percent higher than the actual exports. The suggests that of the 62 percent difference between the forecasted and actual turkey exports in the fourth quarter, only 2 percentage points were due to production differences and the rest were due to export restrictions.

To account for the trade effect in Scenario 2, we include the counterfactual production from Scenario 1 but add additional export demand shocks in the magnitude described exactly in **Table 6**. Since exports are affected by production shocks separately from export restrictions, we artificially fix the import elasticity of demand to be close to zero so that we can specify the exact shock in export levels. The production effects and export effects of HPAI pull the price of poultry products in opposite directions. Decreased production lowers the supply of poultry products and increases the cost of production, which pushes the market price downwards. On the other hand, export restrictions increasing the domestic availability of poultry products in the short run and lower prices. For each commodity, the estimated price change varied considerably by quarter. Taking the simple average of percentage price differences across quarters, the model estimates that restoring lost HPAI production (without consideration of trade effects) would lower egg prices by 98.7 cents in the 4th quarter. With potential trade effects include, the estimated change is 89 89.8 cents per dozen from the observed price of $3.75 per dozen.

Like price effects, consumption effects for production and export shocks work in opposite directions. HPAI reduces domestic supply via production due to depopulations but increases domestic supply via restricting exports. The model estimates that the net effect of moving to a counterfactual situation with no HPAI would have increased domestic consumption of both eggs and turkey by around 4 percent on an annual level. The third quarter, when Thanksgiving drives a sharp increase in turkey consumption, the model estimates that consumption of turkey would have been 7 percent higher without HPAI.

In applying the counterfactual, we simulate the impact of the HPAI shocks on commodity production, retail prices, wholesale prices, imports, exports, consumption, and other variables on a quarterly level. Egg production would have been 4.7 percent higher throughout the year without HPAI than it was. While the export market for eggs is small to begin with, the model estimated that exports would have been 21 percent higher based on production effects alone, as shown in Scenario 1 of **Table 8**. That table also shows that in the absence of HPAI retail prices would have been 36 to 98 cents cheaper than actual retail prices, which ranged from 2.70 to $3.75 per dozen. This price difference would have caused the estimated per capita consumer expenditure to be nearly $8 more in the base scenario ($54.3) than in the counterfactual scenario with no HPAI ($46.2).

Turkey production would also have been 8.6 percent larger (5,216 million pounds rather than 4,804 million pounds over the 2nd, 3rd, and 4th quarters) in the absence of an HPAI outbreak. **Table 7** shows that turkey exports would have been only slightly higher at 416 million pounds rather than 407 million pounds. Similarly, estimated price effects of HPAI were less dramatic for turkeys compared to eggs, with the estimated counterfactual retail price of turkey at $1.46/pound in a world with no HPAI versus the observed average retail price of $1.52/pound.

Simulation of Consumer Welfare Effects

The appendix discusses how consumer welfare effects can be calculated using two methods. The exact method (ΔCS_{Actual}) is an analytical solution based on the demand elasticity and well-suited to considering supply shifts arising from a supply shift in a single market. One small shortcoming, however, is that the welfare change cannot be calculate when the demand elasticities with respect to price is unitary (*i.e.*, equal to one). Alternatively, the approximation method ($\Delta CS_{Est.}$, as presented in Brester *et al,* 2023) does not include the price elasticity in its formula and maybe conceptually better suited to considering multiple supply shifts simultaneously. We calculated the quarterly welfare change using both methods. We found little difference between the values. Specifically, for our Scenario 2 simulations, the $\Delta CS_{Est.}$ differed from the ΔCS_{Actual} in the 1st, 2nd, 3rd, and 4th quarters by -0.01, -0.32, -0.05 and -0.37 percent for eggs and -0.1, -0.4, 0.4, and 0.01 percent for turkeys. All reported estimates to follow are those of the exact method.

Results

Estimates of the consumer, producer, and input market welfare effects are typically quite sensitive to the parameterization of key elasticities. With a price elasticity of -0.27, demand for eggs is extremely inelastic and, subsequently, the HPAI shock simulations show that total retail revenue for egg sellers is expected to increase as price rises more than the quantity of sales decrease as layers are lost. Conversely, at -1.989, the demand elasticity for turkey is the highest (in absolute terms) across animal products. In this case, the demand is elastic and the HPAI supply shock causes smaller percentage increase in prices than in quantity, making retail revenue fall.

Tables 7 and **Table 8** show the effects of the HPAI shocks for turkey and eggs, respectively, under two scenarios. Scenario 1 adds back the lost production from HPAI depopulations so that it now equals the pre-HPAI forecast level (see **Table 5** for specific values). Scenario 2 adds back the lost production and, also, in compensating for lost export access during the HPAI shock, adds back exports so that they meet their pre-HPAI forecast levels. Our analysis focuses on the effects in the 2nd, 3rd and 4th quarter of 2022 because the HPAI did not begin until Feb 8th for turkeys and Feb 22nd for eggs. **Figures 4 and 5** show the information from **Tables 7 and 8** graphically.

<< **Table 7** – Effects of 2022 HPAI losses and export restrictions on turkey markets >>

<< **Table 8** – Effects of 2022 HPAI losses and export restrictions on egg markets>>

<< **Figure 4** – Price and Welfare Effects of 2022 HPAI Losses and Export Restrictions >>

<< **Figure 5** – Poultry Exports Lost Due to 2022 HPAI Losses and Export Restrictions (2022) >>

Notably, under both Scenarios considered, the elimination of the HPAI shock increases producer revenues for the turkey market but decrease it for the egg market. Moreover, as shown in **Table 5,** despite regained production losses in our simulation being smaller as a percentage of supply for eggs (losses of 6, 5, and 6 percent in Q2, Q3, and Q4) than turkey (losses of 10, 12, and 9 percent), eggs saw a larger percentage change in price in absolute value terms -- 25.6, 11.9, 26.3 for eggs versus 6.2, 6.1, and 4.1 for turkey – a difference stemming from eggs having more inelastic demand.

For turkeys, the simulation in Scenario 2 suggests that if trade reductions associated with the HPAI continued, despite regaining the lost production, price decreases would have been a bit larger (8, 9, and 6 percent) because only the domestic market would be the only outlet for the higher production levels. The higher prices of $1.33 to $1.52 observed in 2022 compare with a $1.25-$1.26 price expected over the same period. Summing the value in **Table 7** in the 2nd, 3rd, and 4th quarters (in Scenario 2) shows that had production not fallen due to HPAI, total consumer welfare would have been $199.2 million higher and production value $140 million higher for turkey sellers. The regained production would have also led to a $33.1 million increase in coarse grain purchases but only trivial changes in the soybean meal purchases.

Table 8 shows that for eggs, total consumer welfare would have been $3.562 billion higher, but egg seller revenue would fall by about $823.9. At the same time, average prices would be $0.61, $0.28, and $0.90 lower per dozen in the 2nd, 3rd, and 4th quarters. Even after subtracting the simulated prices increases from the base, egg prices would have still been above $2 in 2nd quarter, $2.50 in the 3rd quarter, and $2.75 in the 4th quarter, levels well above the pre-HPAI forecast range of $1.25 to $1.35. Given actual prices, our simulated egg prices are likely an underestimate of the true increase in prices (and relatedly, loss of welfare) due to the HPAI. Moreover generally, the notably higher consumer surplus loss for eggs is attributable to its larger level of baseline expenditure ($66.12 average annually per capita on eggs, $20.01 on turkey), its more inelastic demand, and its larger percentage change in price from the disease shock (35 to 99 percent price increase for eggs versus 6 to 9 percent for turkeys). We also find that had egg markets regained the lost production and trade access due to HPAI, feed demand for laying flocks would have raised coarse grain and soymeal expenditures in total across the 2nd, 3rd, and 4th quarters by $79.2 million and $56.1 million, respectively. Combining turkeys and eggs, coarse grain expenditures would have been $112.3 million higher without HPAI effects. If production had been regained, but trade disruptions were still in place (as in Scenario 1) then consumer welfare would have been increased $4.066 billion but egg seller revenue would have fallen $1.027 billion. The average price of a dozen eggs would have fallen $0.69, $0.36, and $0.99 in the 2nd, 3rd, and 4th quarter. As with turkeys, these large effects stem from the increase in available supply from regained production not being offset by exports returning to their original shares of production.

Conclusion

Animal disease shocks are extremely costly and disruptive and can have devasting effects on food prices, consumer welfare, input markets, and trade. In the most severe quarterly periods, the U.S. HPAI Outbreak of 2022 reduced production from its expected level by 7 percent for eggs and 12 percent for turkeys. In that same year, benchmark prices reached record highs for monthly averages of $5.03 per dozen for eggs in December and $1.80 per pound for turkeys in November, even as exports fell precipitously. We find that the combined effect of the HPAI outbreak on the production and trade in turkey and eggs lowered consumer welfare by $199.2 and $3,562 million over the 2nd, 3rd, and 4th quarters of 2022, or about $11.4 per person across the United States.

Estimating the welfare effects of animal disease shocks has several challenges. Welfare losses for producers for the affected goods may be shift forward to consumers in higher prices or backward to input markets through derived demand relationships. We find that producers of inelastically demanded eggs were able to raise total revenue (despite losses) but producers of elastically demanded turkey were not. Additionally, we were able to parse out the specific impact of production versus trade effects in our welfare analysis. Regionalization agreements, which restrain the scope of disease-related trade restrictions, benefit agricultural industries with large export shares, but may lead to larger price swings during disease shocks. In the short run, the ordinarily exported share of production is likely to be re-directed to domestic consumption channels, offsetting the supply loss from the outbreak. Since regionalization initiatives are largely undertaken to limit trade partners from reneging on free trade agreements by imposing arbitrary SPS-related trade restrictions for protectionist reasons, the potential short-run consumer benefits restrictions to exports should be cautiously weighed against the long-run cost of lost export markets and the potential persistence of restrictions long past any reasonable period of disease transmission threat.

By leveraging WASDE forecasts, we develop a plausible counterfactual for trade without needing to track the specific timing and scope of SPS restrictions across numerous trade partners. The use of WASDE production estimates also allows us to develop production counterfactuals that account for observable market changes (lower turkey bird weights, changes in egg-lay rates) that related to the outbreak and affect production but are not directly the result of disease loss. Our EDM developed by Paarlberg et al (2022) can then simulate various shocks to trade, production, demand, and breeding stock over time. The benefits of this approach are both the transparency of the assumptions about what ordinary price and production dynamics are assumed by the model and the ability to trace through an upstream production supply shock to downstream retail prices and demand and vice versa. We found that the egg and turkey disease shock had significant effects on coarse grain and soy feed markets.

A reasonable concern surrounding EDM models applied in agricultural settings are their sensitivity to parameterization and the representativeness of the initial equilibrium and to the related concern of misattributing the effect of all shocks in the analysis period to HPAI. For instance, 2022 also saw tightness in supplies in European and Asian egg markets due to their own HPAI outbreak, as well as historically high prices and low supplies in the turkey market preceding disease losses. We acknowledge these limitations and advise caution in implementing this model for small production shocks that are not easily distinguished from other market events. But in our case, the 2022 outbreak was not small, but instead large, disruptive, and costly to consumers and the public.

References

APHIS (2016). "Final Report for the 2014–2015 Outbreak of Highly Pathogenic Avian Influenza (HPAI) In the United States. Revised August 11, 2016" *United States Department of Agriculture, Washington, DC"*

Brester, Gary W., Joseph A. Atwood, and Michael A. Boland. *Equilibrium Displacement Models: Theory, Applications, & Policy Analysis*. (2023).

Biden, S., Ker, A. P., Larue, B., & Duff, S. (2024). "Economic Impacts of a Disease Outbreak in Canada's Pork Industry: Case of a Price-Taking, Open Country." *Food Policy*, 125, 102624.

Çakır, M., Boland, M. A., & Wang, Y. (2018). "The Economic Impacts Of 2015 Avian Influenza Outbreak on The US Turkey Industry and The Loss Mitigating Role of Free Trade Agreements." *Applied Economic Perspectives and Policy*, *40*(2), 297-315.

Hennessy, David A., and Thomas L. Marsh. "Economics of Animal Health and Livestock Disease." *Handbook of Agricultural Economics*. Vol. 5. Elsevier, 2021. 4233-4330.

Hafi, A., et al. "Economic Benefits of Implementing Trading Zones for Australian Livestock Disease Outbreaks of Limited Duration." *Australian Veterinary Journal* 100.4 (2022): 150-161.

Longworth, N., Jongeneel, R. A., & Saatkamp, H. W. (2019). A vertically linked dynamic partial equilibrium model to analyze market shocks caused by HPAI control in the Dutch egg production chain. *NJAS-Wageningen Journal of Life Sciences*, *88*, 112-128.

MacLachlan, M. J., Boussios, D., & Hagerman, A. D. (2021). Market Responses to Export Restrictions from Highly Pathogenic Avian Influenza Outbreaks. *Journal of Agricultural and Resource Economics*, *47*(1), 209-224.

Paarlberg, P. L., Seitzinger, A., Lee, J. G., & Mathews Jr, K. H. (2008). *Economic Impacts of Foreign Animal Disease* USDA Economic Research Service, Economist Research Report No. 1477-2016-121206.

Paarlberg, Philip L., et al. "Supply Reductions, Export Restrictions, And Expectations for Hog Returns in A Potential Classical Swine Fever Outbreak in the United States." *Journal of Swine Health and Production* 17.3 (2009): 155-162.

Paarlberg, P., Seitzinger, A., & Lee, J. (2007). "Economic Impacts of Regionalization of a Highly Pathogenic Avian Influenza Outbreak in the United States." *Journal of Agricultural and Applied Economics*, 39(2), 325-333. doi:10.1017/S1074070800023026

Ramos, S., MacLachlan, M., & Melton, A. (2017). "Impacts Of The 2014-2015 Highly Pathogenic Avian Influenza Outbreak on The US Poultry Sector." *Washington, DC, USA: USDA*.

Rosen, Sherwin, Kevin M. Murphy, and José A. Scheinkman. "Cattle Cycles." *Journal of Political Economy* 102, no. 3 (1994): 468–92. http://www.jstor.org/stable/2138619.

Seitzinger, Ann Hillberg, and Philip L. Paarlberg. "Regionalization of the 2014 and 2015 highly pathogenic avian influenza outbreaks." Choices 31.2 (2016): 1-8.

Shi, J., Zeng, X., Cui, P., Yan, C., & Chen, H. (2023). "Alarming Situation of Emerging H5 And H7 Avian Influenza and Effective Control Strategies." *Emerging microbes & infections*, *12*(1), 2155072.

Thompson, Jada M., et al. "Economic Impacts of Business Continuity on an Outbreak of Highly Pathogenic Avian Influenza in Minnesota Egg Laying Operations." *Journal of Agricultural and Applied Economics* 51.2 (2019): 235-248.

Thompson, J. M. (2018). "Effects Of Regionalized Trade Restrictions on Quantity Exported During a Highly Pathogenic Avian Influenza Event." *Journal of Agricultural and Applied Economics*, 50(2), 270-289.

USDA ERS (2023) "Livestock and Meat International Trade Data" https://www.ers.usda.gov/data-products/livestock-and-meat-international-trade-data/

USDA ERS, (2023) "Livestock and Meat Domestic Data" https://www.ers.usda.gov/data-products/livestock-and-meat-domestic-data/

USDA AMS (2023), Turkey Market News Reports, https://www.ams.usda.gov/market-news/turkey-market-news-reports

USDA APHIS, "2022-2023 Confirmations of Highly Pathogenic Avian Influenza in Commercial and Backyard Flocks" https://www.aphis.usda.gov/aphis/ourfocus/animalhealth/animal-disease-information/avian/avian-influenza/hpai-2022/2022-hpai-commercial-backyard-flocks

Tables

Table 1 – HPAI Related Depopulations of Poultry in 2015 and 2022 as a Share of Slaughter or Flock Size

	2022			**2015**		
Birds (1000s head)	Depopulated Birds	Previous Year's Slaughter or January Flock	Losses as Percentage of Slaughter or Flock	Depopulated Birds	Previous Year's Slaughter or January Flock	Losses as Percentage of Slaughter or Flock
Turkey	9,442	213,937	4.4%	7,400	237,500	3.1%
Egg Hen	43,291	394,962	11.0%	43,000	372,903	11.6%
Broiler	2,266	9,210,889	0.02%	NA	8,525,393	<0.01%

Table 2 – Aggregate Shares of U.S. Production Exported Before and After the 2015 HPAI Outbreak

	2012-2014	**2015**	**2016**	**2017**	**2018**
Broiler Exports	7,199	6,321	6,988	6,754	6,584
Broiler Production	37,202	40,048	37,830	38,565	40,048
Broiler Export Share	19.6%	15.8%	16.3%	16.3%	16.6%
Turkey Exports	771	529	624	574	601
Turkey Production	5,843	5,627	5,981	5,981	5,878
Turkey Export Share	13.2%	9.4%	10.4%	9.6%	10.2%
Egg Exports	391.7	341.8	304.2	354.9	333.2
Egg Production	7,149.9	7,015.8	7,509.2	7,811.3	8,042.6
Egg Export Share	5.5%	4.9%	4.1%	4.5%	4.1%

Source: USDA ERS, (2023) "Livestock and Meat International Trade Data"; USDA ERS, (2023) "Livestock and Meat Domestic Data"

Table 3 – Commodities, Uses, Trade, Inventory, and Production Relationships in the Animal Disease Outbreak Model

		Sources of Demand						Production								Ani. Inv Feed Qtrs
	Commodity	Use			Trade		Inv. Dem	Inputs				Feed Grain Inputs				
		Final Use	Animal Input	Feed Input	Exp. Dem	Imp. Dem		Exog.	Cap.	AnimalSoybean	Land	WH	CG	SM	FO	
1	Beef (BF)	Y			Y	Y		Y	B	CT						
2	Pork (PK)	Y			Y	Y		Y	B	SW						
3	Lamb (LM)	Y				Y		Y	B	SH						
4	Chicken (PM)	Y			Y			Y	B				B	X		
5	Turkey (TK)	Y						Y	B	GB						
6	Eggs (EG)	Y			Y			Y	B	BD			B	X		
7	Milk (MK)	Y				Y	Y	Y	B	CT			B	X	X	
8	Wheat (WH)	Y		Y	Y		Y	Y	B							
9	Rice (RI)	Y			Y		Y	Y	B							
10	C. Grains (CG)	Y		Y	Y		Y	Y	B							
11	SoyOil (SO)	Y			Y		Y	Y	B	SB						
12	SoyMeal (SM)			Y	Y			Y	B	SB						
13	Forage (FO)			Y			Y	Y	B							
14	Cattle (CT)		BF		Y	Y		Y					B	X	X	5
15	Swine (SW)		PK		Y	Y		Y					B	X		3
16	Sheep (SH)		LM		Y	Y		Y					B	X	X	3
17	Birds (BR)		EG					Y					B	X		
18	Gobblers (GB)		TK					Y					B	X		
19	SoyBean (SB)				Y		Y	Y	B							

Table 4 - Estimated Difference Between Actual and Forecast Production in 2022

	Forecast Production			Actual Production			Percentage Difference		
	Turkey	Broiler	Eggs	Turkey	Broiler	Eggs	Turkey	Broiler	Eggs
Q1	1,390	11,250	2,345	1,374	11,170	2,316	1.2%	0.7%	1.3%
Q2	1,405	11,400	2,345	1,275	11,279	2,218	10.2%	1.1%	5.7%
Q3	1,420	11,690	2,365	1,264	11,896	2,259	12.3%	-1.7%	4.7%
Q4	1,425	11,260	2,425	1,310	11,861	2,277	8.8%	-5.1%	6.5%

Egg production values are in million dozen; turkey and broiler production values are in millions of pounds.

Table 5 - Estimated Counterfactual Increase in Production in 2022 in the Absence of HPAI

Quarter	Turkey	Broiler	Eggs
2	10.2%	0.0%	5.7%
3	12.3%	0.0%	4.7%
4	8.8%	0.0%	6.5%

Table 6 – Estimated Difference Between Actual and Forecast Exports in 2022

	Forecast Exports			Actual Export			Percentage Difference		
	Turkey	Broiler	Eggs	Turkey	Broiler	Eggs	Turkey	Broiler	Eggs
Q1	130.7	1,856.3	84.4	107.2	1,831.9	71.8	21.9%	1.3%	17.6%
Q2	140.5	1,801.2	89.1	108.4	1,804.6	51.0	29.6%	-0.2%	74.7%
Q3	140.6	1,858.7	94.6	96.1	1,724.9	49.7	46.3%	7.8%	90.3%
Q4	155.3	1,925.5	89.7	95.6	1,933.3	54.6	62.4%	-0.4%	64.2%

Table 7 – Effects of 2022 HPAI losses and export restrictions on turkey markets

		Change ($/CWT)		Percent Change	
Period	Base	Scenario 1	Scenario 2	Scenario 1	Scenario 2
Retail Prices (dollars/CWT)					
Q1	128.6	(1.0)	0.5	-0.8%	0.4%
Q2	132.8	(8.3)	(6.8)	-6.2%	-5.2%
Q3	141.0	(8.5)	(5.8)	-6.1%	-4.1%
Q4	151.9	(6.2)	(3.7)	-4.1%	-2.5%
Retail Production Value (dollars, millions)					
Q1	666.2	3.1	10.8	0.5%	1.6%
Q2	638.8	22.8	33.5	3.6%	5.2%
Q3	672.1	34.2	52.0	5.1%	7.7%
Q4	748.0	35.5	54.7	4.8%	7.3%
Consumer Surplus (dollars, millions)					
Q1	-	10.9	(5.4)	1.7%	-0.9%
Q2	-	90.9	74.7	15.5%	12.8%
Q3	-	105.6	70.7	17.7%	11.9%
Q4	-	90.0	53.8	15.0%	9.0%
Exports (lbs., millions)					
Q1	107.4	0.4	23.6	0.4%	22.0%
Q2	108.7	3.4	32.6	3.1%	30.0%
Q3	96.2	2.9	44.3	3.0%	46.0%
Q4	95.2	1.9	59.0	2.0%	62.0%
Feed Use - Coarse Grains Costs (dollars, millions)					
Q1	101.4	1.3	1.3	1.2%	1.3%
Q2	106.1	11.3	11.8	10.6%	11.1%
Q3	89.4	10.9	11.5	12.2%	12.8%
Q4	96.8	9.0	9.8	9.3%	10.1%
Feed Use - Soybean Meal Costs (dollars, millions)					
Q1	5.2	0.0	0.0	0.0%	0.0%
Q2	6.0	0.0	0.0	0.1%	0.1%
Q3	5.1	0.0	0.0	0.2%	0.3%
Q4	6.4	0.0	0.0	0.1%	0.1%

Source: Model outputs.

Notes: Scenario 1 incorporates only the production shock effect. Scenario 2 incorporates both the production shock effect and forces trade to remain in effect.

Table 8 – Effects of 2022 HPAI losses and export restrictions on egg markets

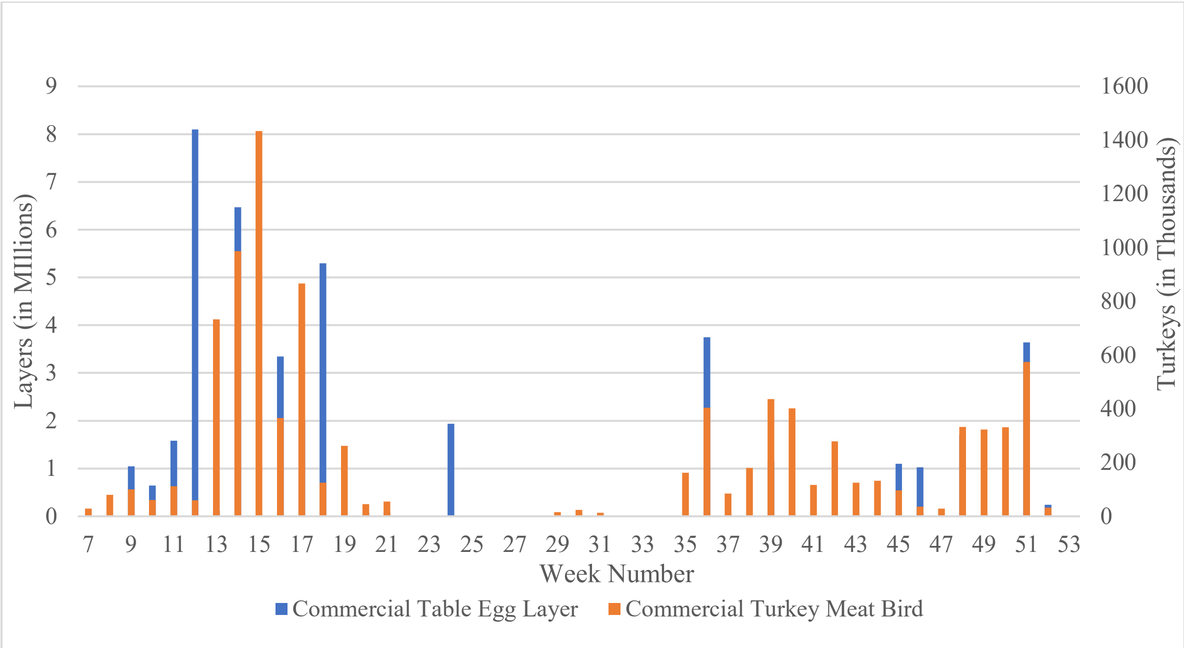
		Change (Level, Cents/Dozen)		Percent Change	
Period	Base	Scenario 1	Scenario 2	Scenario	Scenario 2
Retail Prices (cents/doz)					
Q1	199.3	(11.0)	(8.7)	-5.5%	-4.4%
Q2	269.7	(69.2)	(60.6)	-25.6%	-22.5%
Q3	298.5	(35.5)	(28.3)	-11.9%	-9.5%
Q4	375.3	(98.7)	(89.8)	-26.3%	-23.9%
Retail Production Value (dollars, millions)					
Q1	1,301.0	(58.6)	(39.1)	-4.5%	-3.0%
Q2	1,683.3	(361.9)	(294.0)	-21.5%	-17.5%
Q3	1,897.7	(148.3)	(87.9)	-7.8%	-4.6%
Q4	2,404.2	(516.8)	(442.0)	-21.5%	-18.4%
Consumer Surplus (dollars, millions)					
Q1	-	219.8	172.7	4.3%	3.3%
Q2	-	1,361.1	1,187.2	34.2%	29.8%
Q3	-	696.1	554.3	19.3%	15.4%
Q4	-	2,008.9	1,820.1	85.7%	77.7%
Exports (dozens, millions)					
Q1	71.1	4.9	12.8	6.9%	18.0%
Q2	51.6	16.5	38.7	32.0%	75.0%
Q3	49.1	7.3	44.2	14.8%	90.0%
Q4	54.6	17.9	34.9	32.9%	64.0%
Feed Use - Coarse Grains Costs (dollars, millions)					
Q1	294.6	3.3	4.2	1.1%	1.4%
Q2	311.5	17.8	20.7	5.7%	6.6%
Q3	261.7	12.9	15.2	4.9%	5.8%
Q4	273.6	18.1	20.2	6.6%	7.4%
Feed Use - Soybean Meal Costs (dollars, millions)					
Q1	394.9	4.4	5.7	1.1%	1.4%
Q2	391.2	22.4	26.0	5.7%	6.6%
Q3	417.1	20.5	24.2	4.9%	5.8%
Q4	392.8	26.0	29.0	6.6%	7.4%

Source: Model outputs.

Notes: Scenario 1 incorporates only the production shock effect. Scenario 2 incorporates both the production shock effect and forces trade to remain in effect.

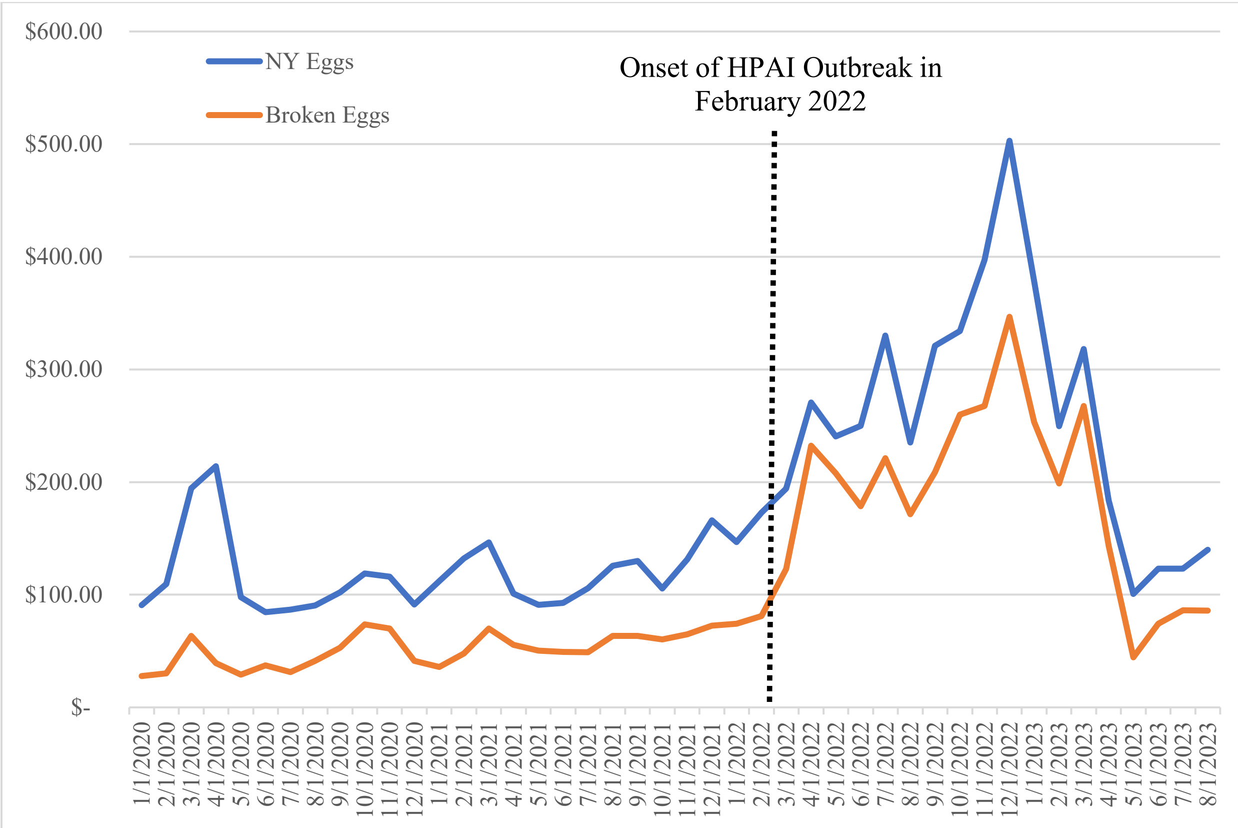
Figures

Figure 1 – Weekly Depopulations of Table Egg Layers and Turkeys due to HPAI in 2022



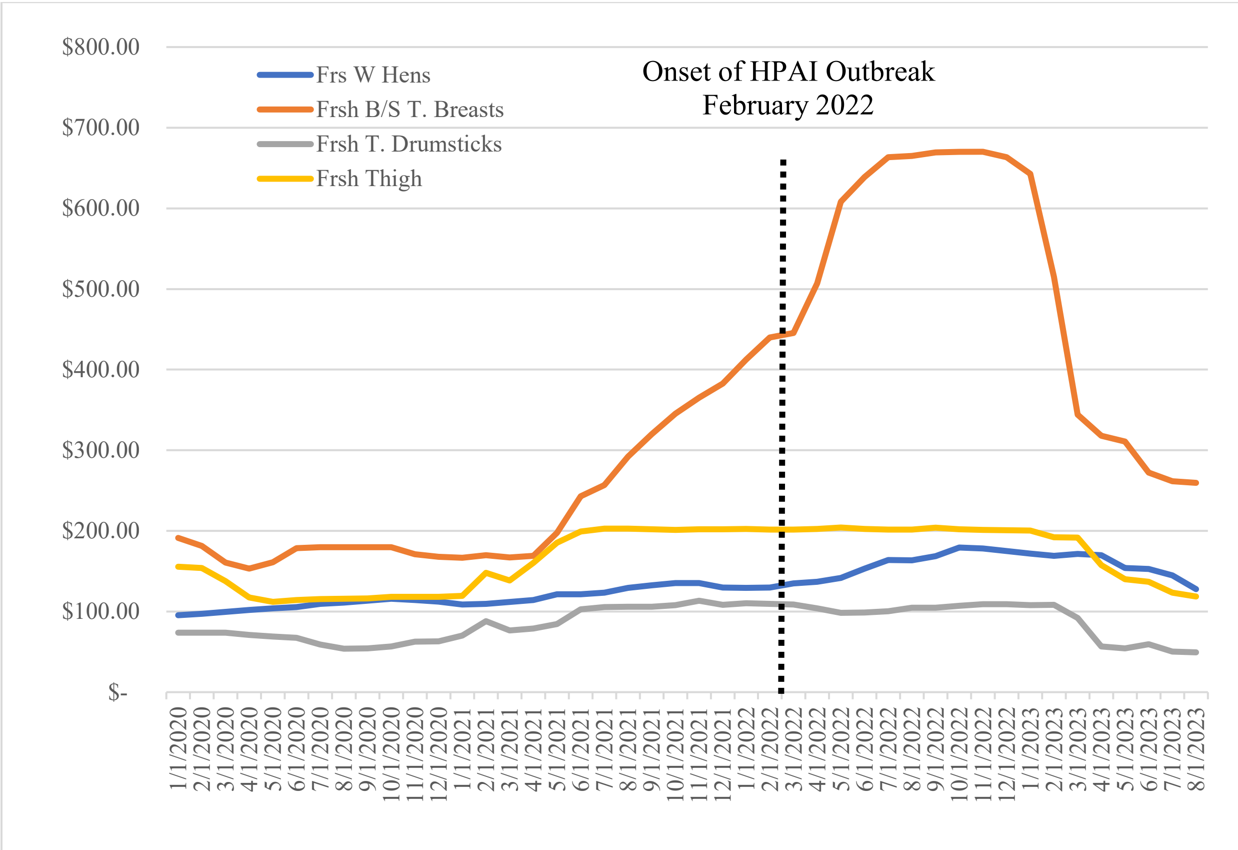
Source: USDA APHIS, "2022-2023 Confirmations of Highly Pathogenic Avian Influenza in Commercial and Backyard Flocks"

Figure 2 – Prices for Delivered New York Eggs and Central States Broken Eggs



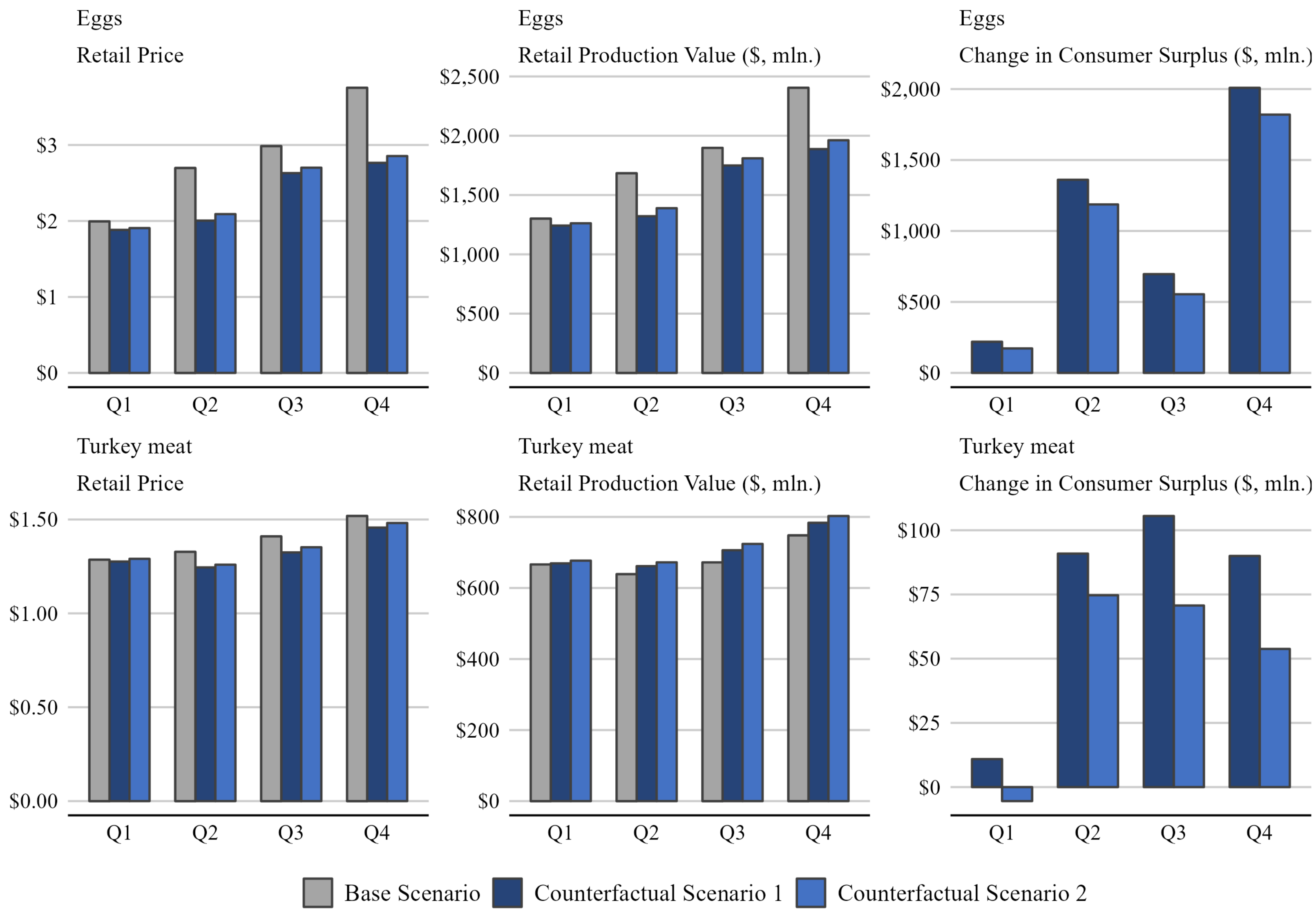
Source: USDA AMS (2023), Egg Market News Reports

Figure 3 – Prices for Frozen Whole Hens and Fresh Turkey Parts



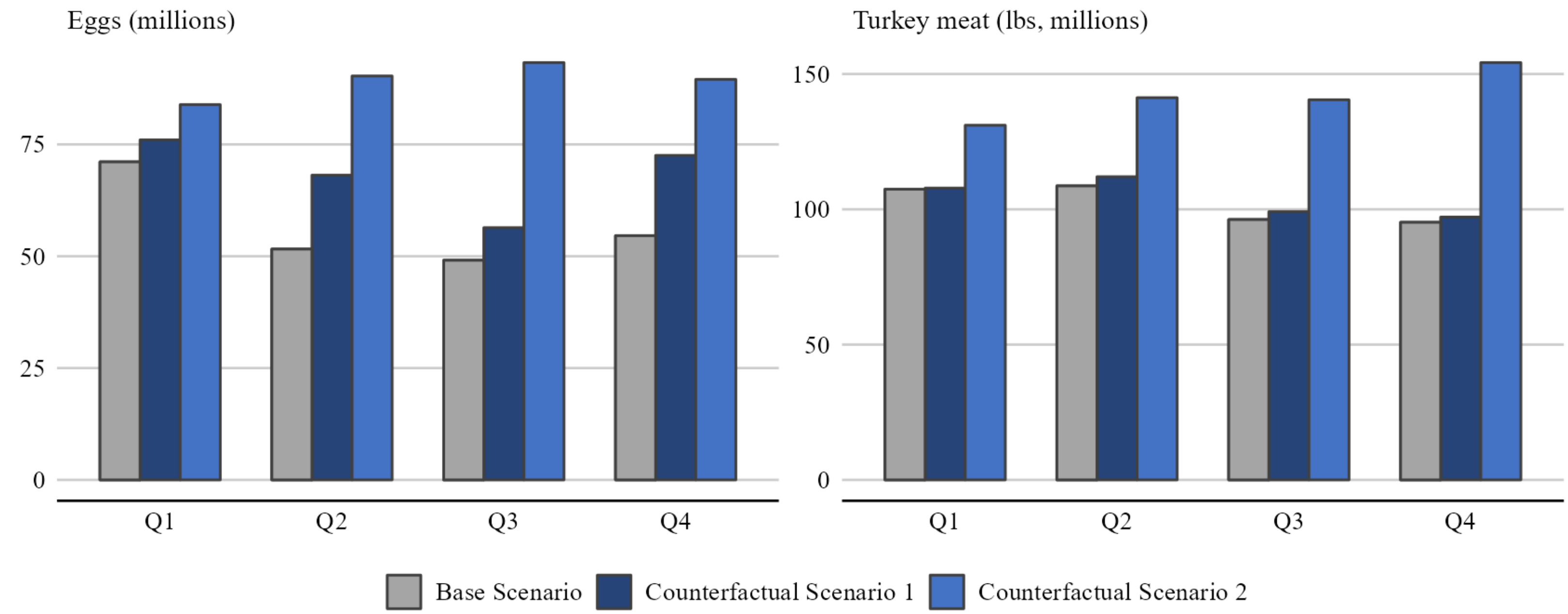
Source: USDA AMS (2023), Turkey Market News Reports

Figure 4 – Price and Welfare Effects of HPAI Depopulations and Export Restrictions (2022)



Source: Model outputs. Egg and turkey meat prices are per dozen and per pound, respectively.

Figure 5 – Poultry Exports Lost Due to HPAI Depopulations and Export Restrictions (2022)



Source: Model outputs.

Appendix

The consumer welfare effects of the disease shocks can be calculated in two ways. Using the simulated percentage changes in quantity and price, Brester et al. (2023, Ch. 8) and Ferrier et al. (2023) show the consumer welfare loss is approximately:

$$\Delta CS_{Est.} \approx -dlP \times (1 + 0.5dlQ) \times P_0 Q_0 \tag{1}$$

where dlP is the change in the log value of price (or, identically, the percentage change in price from the base), dlQ is the change in the log value of quantity, and $P_0 Q_0$ is the initial level of total expenditure, and ΔCS is the change in consumer surplus[10]. This equation only estimates the true change in ΔCS because the EDM's assumed demand elasticities are point estimates of the slope of a fully defined demand curve.

In contrast, Paarlberg et al (2008) use the point estimate of the demand elasticity and the initial prices and quantity to fully specify a constant elasticity of demand function of the form:

$$Q = AP^{\varepsilon} \tag{2}$$

where ε_d is the (constant) elasticity of demand, Q_0 and P_0 are the (initial) base quantity and price, A is set to $\frac{Q_0}{P_0^{\varepsilon}}$ to ensure the market is in equilibrium at the initial price. In this case, the change in consumer surplus as the price falls from P_1 to P_0 is:

$$\Delta CS_{Exact} = \int_{P_0}^{P_1} AP^{\varepsilon} dP = A \frac{1}{\varepsilon+1} (P_1^{\varepsilon+1} - P_0^{\varepsilon+1}) \tag{3}$$

Like Equation (1), Equation (3) can be recast as percentage change from the initial equilibrium. Substituting the Equation (2) demand formula back into Equation (3) yields:

$$\Delta CS_{Exact} = \frac{1}{\varepsilon+1} (P_1 Q_1 - P_0 Q_0) \tag{4}$$

Note that $P_1 Q_1$ can be re-written as $(1 + dlP)P_0(1 + dlQ)Q_0$. With some manipulation, ΔCS_{Exact} becomes:

[10]In Brester, the terminology *E(P)* is used to denote our *dlP.*

$$\Delta CS_{Exact} = \left(1 + \frac{1}{\varepsilon+1} dlQ\right) \times dlP \times P_0 Q_0 \tag{5}$$

Our paper uses the ΔCS_{Exact} to calculate the change in consumer welfare reported in this paper. However, we note two reasons practitioners may opt to use $\Delta CS_{Est.}$ instead. First, Equation (3-5) is incalculable when demand is exactly unit elastic ($\varepsilon = -1$) due to zero appearing in the denominator. This issue seems limited to the exact specification of unit elastic demand and results seem reasonable when ε is disturbed to be arbitrarily close to -1 but not equal to it[11]. Since unit elastic demand is often the "default" setting on demand systems, the need to perturb slightly the elasticity to ensure calculability might be frequent and feel arbitrary. Second, more substantively, if the animal disease shocks affect multiple goods simultaneously, the Equation (3) will recalculate changes in the quantities the production of multiple goods while ignoring potential cross-price effects that shift the demand curve itself. While Equation (1) does not distinguish the role of cross-price effects either, it does use observed changes in quantities to account for them.

[11]Equation (4) provides some intuition for this problem in the following cases by consider the separate movement of the first term $(1/(\varepsilon + 1))$ and second term $(P_1 Q_1 - P_0 Q_0)$ assuming that P_1 is greater than P_0. As ε moves from an inelastic to unit elastic value, the first term is positive and approaches positive infinity which the second term is positive and approaches zero. Conversely, in the case where ε moves from an elastic to unit elastic value, the first term is negative and approaches negative infinity and the second term is negative and approaches zero. The limiting effects largely cancel out and generate reasonable results except where demand is exactly unitary elastic, in which case, Equation (4) is incalculable.