Demand Response to Avian Influenza Outbreak and Information*

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Abstract

This study investigates the impact of avian influenza on consumer meat and poultry purchasing decisions. Specifically, I focus on two aspects: self-searched avian flu information and state-level outbreaks. First, employing the Exact Affine Stone Index (EASI) implicit Marshallian demand system, I estimate the impact of avian flu search intensity on the demand for meat and poultry products, with consideration of price substitution effects. In addition, I evaluate the effects of avian influenza outbreaks on poultry and meat demand using a quasi-experimental design, shedding light on the temporal and geographical disparities in consumer responses. The findings reveal that heightened public interest in avian influenza leads to an increased demand for poultry during non-outbreak periods; conversely, it decreases poultry demand when domestic outbreaks occur. Moreover, during outbreak periods, outbreak states exhibit a higher demand for poultry products compared to states without outbreaks.

*Researcher(s)' own analyses were calculated (or derived) based in part on data from Nielsen Consumer LLC and marketing databases provided through the NielsenIQ Datasets at the Kilts Center for Marketing Data Center at The University of Chicago Booth School of Business. The conclusions drawn from the NielsenIQ data are those of the researcher(s) and do not reflect the views of NielsenIQ. NielsenIQ is not responsible for, had no role in, and was not involved in analyzing and preparing the results reported herein.

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1 Introduction

The prevalence of global avian influenza outbreaks is increasing in frequency and scale. According to Szablewski et al. (2023), over 325 million bird losses were reported across 95 countries from 2013 to 2022. In light of growing health consciousness, policymakers and producers are interested in comprehending consumers' reactions to these incidents. Avian influenza differs from other food safety concerns and animal diseases like Salmonella, E. coli, and mad cow disease, as it does not pose a direct health risk through the consumption of properly cooked poultry products (Chmielewski and Swayne, 2011). Nevertheless, previous research and surveys have shown that misconceptions about the health risks associated with avian flu can lead to a reduction in poultry consumption (Turvey et al., 2010). For example, a 2006 Harvard School of Public Health (HSPH) survey revealed that 46% of respondents claimed they would stop consuming poultry products during bird flu outbreaks.

The media plays a pivotal role in determining the speed and extent of consumer responses to food safety crises, mainly by influencing the perceived health risks (Böcker and Hanf, 2000, Zhou and Liu, 2023). However, quantifying the impact of food safety information on consumer demand poses several challenges. First, the price change induced by food safety concerns may subsequently impact the demand responses (McKenzie and Thomsen, 2002). Second, relying merely on public food safety information overlooks the gap between information dissemination and public awareness. Moreover, the increased fragmentation of media consumption further complicates determining the relative importance and impact of information from different sources and channels (Ma, Seenivasan and Yan, 2020). Hence, consideration of these factors is crucial to understanding the influence of food safety on consumer behavior.

This paper investigates the impact of avian influenza on consumer purchasing decisions. In particular, I explore how avian influenza information impacts the demand for meat and poultry, utilizing the public's information-seeking behavior regarding avian influenza. Because the media sources that people consult for food safety issues are becoming increasingly fragmented and self-selective, an avian flu information search indicator better captures the public's interest in the topic (De Paola and Scoppa, 2013; Kornelis et al., 2007). The association between avian flu information and the demand for poultry products can be mixed. Increased knowledge about avian influenza may alleviate concerns about poultry consumption and lead to higher purchase rates, particularly when there are concerns about limited supply during ongoing outbreaks. On the other hand, information highlighting the increased prevalence of bird flu might create food scares, negatively affecting poultry consumption.

Furthermore, previous studies (e.g., Zhou, Li and Lei, 2019) show that consumers in high-occurrence outbreak areas have significantly different risk perceptions. To identify the heterogeneous demand responses across time and space, I employ a quasi-experimental design to compare consumption patterns in outbreak states with those in non-outbreak states during the 2014/15 outbreak in the US. The within-state avian influenza outbreaks can potentially generate different consumption decisions through greater media attention and awareness in the community, which jointly alter risk perceptions.

To answer those research questions, I estimate meat and poultry demand using the Exact Affine Stone Index (EASI) implicit Marshallian demand system proposed by Lewbel and Pendakur (2009) in consideration of the substitution effects. The avian flu search intensity is included in the estimation as a demand shifter that captures the public's interest in avian influenza. Furthermore, to account for biases in a staggered outbreak setting, I integrate the two-stage difference-in-differences framework introduced by Gardner (2022) into the demand system to compare consumption differences between outbreak state and non-outbreak state consumers during the domestic outbreak period.

I utilize nationally representative consumer purchase data from Nielsen Homescan Data spanning 2014 to 2015. This data set includes the trip-level expenses of 59,221 unique meat-purchasing US households and detailed information on household characteristics. I aggregate the household fresh meat purchase data into monthly expenditures, categorized into beef, pork, chicken, turkey, and other meat. Below, I refer to beef, pork, and other non-poultry meat as "meat" and to chicken and turkey as "poultry." To capture the public's interest in avian influenza over time, I collect monthly search intensity data using the keyword "bird flu" from Google Trends.

The results show that the level of public interest in avian influenza was positively associated with poultry demand before the 2014/2015 outbreak but negatively affected the demand for chicken during the outbreak. Although broiler chicken is less susceptible to avian influenza than turkey and wild birds, consumers substitute other meat products for chicken in the presence of greater public attention to avian flu during the outbreak. In addition, households with heads without high school degrees and with graduate degrees are less responsive to the increased public attention to avian influenza, which can be explained by too little or complete assimilation to the avian flu information. These results offer updated insights on consumer responses to avian flu after a large-scale outbreak and provide new evidence of consumer responses to avian flu by demographic groups.

Additionally, I investigate the impact of avian flu state outbreaks on meat and poultry demand. The results suggest that consumers in the outbreak states exhibited increased demand for poultry and reduced demand for meat during the outbreak. Furthermore, the event study results reveal a time difference in the responses, with chicken demand showing immediate responses and turkey demand showing later but greater responses. The results provide an understanding of the geographical heterogeneity in consumer responses to avian flu outbreaks.

This study contributes to the existing literature on consumer responses to food safety information. To model the food safety impact on demand, previous literature incorporates various demand shifters in the demand estimation. These demand shifters include the number of food recall incidents (Zhou and Liu, 2023,Tonsor and Olynk, 2011, Marsh, Schroeder and Mintert, 2004), the number of food safety-related news articles (Browning, Hansen and Smed, 2019, Wang and de Beville, 2017, Mu et al., 2015, Smed, 2012, Beach et al., 2008, Piggott and Marsh, 2004), the timing of the food recall, outbreak or government advisory (Yim and Katare, 2023, Toledo and Villas-Boas, 2019, Ishida, Ishikawa and Fukushige, 2010,Schlenker and Villas-Boas, 2009, Shimshack, Ward and Beatty, 2007), and stochastic parameters (Mazzocchi, 2006). Mu et al. (2015) previously suggested that the increasing prevalence of food safety incidents significantly impacted consumers' meat purchasing behaviors. This research updates our understanding of consumers' response to avian flu self-search information following one of the largest outbreaks in the US. In addition, it contributes to the literature by using a search intensity measure that captures the public's interest in, and assimilation of, food safety information, while addressing potential endogeneity concerns.

Furthermore, this research contributes to identifying the heterogeneous responses to food safety issues. Shimshack, Ward and Beatty (2007) and Carrieri and Principe (2022) have identified variations in consumer responses following government advisories, suggesting that individuals with higher levels of education tend to exhibit greater compliance with such information. Schlenker and Villas-Boas (2009) observed a more pronounced purchase response to mad cow disease in areas of higher incomes and a higher percentage of minority populations. Additionally, Adda (2007) has demonstrated the influence of factors such as the age of household heads, household size, and urbanization on responses to mad cow disease. Further, Toledo and Villas-Boas (2019) found a more significant reduction in egg purchases in states with a history of egg recall incidents. This study adds the following insights regarding the heterogeneous demand response to avian influenza. Firstly, unlike mad cow disease or food recall events, avian influenza does not have a negative impact on food quality – in other words, it poses limited health risks. Secondly, consumers' diverse perceptions of avian flu health risks and trust in food safety prevention strategies can lead to various responses. Therefore, this study offers valuable evidence showcasing the heterogeneous consumer responses by demographic characteristics. Furthermore, this research provides geographically heterogeneous responses, incorporating modern difference-in-differences methods into the demand system estimation to consider staggered state outbreaks.

This research further contributes to the avian influenza studies on consumer risk perception and response. A strand of literature explores how consumer risk perception influences consumption through willingness to pay for safe products (e.g., Zhou et al., 2016, Li et al., 2017, Dillaway et al., 2011). Turvey et al. (2010) examine risk perception of avian influenza through survey design, revealing that the discovery of infected chickens generates more fear than human infection cases in the US, leading to more significant reductions in chicken consumption. Zhou et al. (2016) survey consumer risk perception regarding avian influenza and find that consumers who believe eating infected chicken significantly endangers their lives exhibit reduced chicken consumption. In addition, they find the self-reported reduction in chicken demand is amplified in cities experiencing frequent outbreaks. While it is straightforward to analyze consumers' responses to food safety information and risk perception with a survey design, self-reported responses may result in biases, including recall bias (Del Boca and Darkes, 2003). This research provides demand estimation using actual purchase data that could be less subject to response biases and tracks a more extended period to reflect the change in responses.

Given the increasing availability of media data, a growing literature in economics studies the effects of information and media on behavior. Agüero and Beleche (2017) utilize Google search data for hand sanitizer to suggest a positive relationship between H1N1 outbreaks and the demand for hygiene products. Carpenter and Churchill (2023) employ beauty pageant-related Google search data to identify awareness of home-state pageant victories and explore the potential influence on health behaviors. Kearney and Levine (2015) use Google Trends and Twitter data to investigate teenage girls' attitudes toward pregnancy prevention actions. In the context of avian influenza, Yi et al. (2019) examine public opinion's impact on prices in the Chinese broiler market using Baidu and Google search data. Other studies focus on the media's influence on consumer responses. For example, using retail-level data, De Paola and Scoppa (2013) estimate the effect of brand fraud information from Google News and Search on cheese demand. They find a persistent reduction in sales for the products being negatively mentioned in the press and increases in sales for the unmentioned brands. This study contributes to the literature by providing evidence of the impact of food safety information search behavior on purchase decisions. In addition, this study adds to the literature on the media's role in public health and crisis communication. With detailed household information, this research controls for household characteristics and media market fixed effects that contribute to information acquisition and exposure heterogeneity. More importantly, this study addresses potential endogeneity issues that arise from investigating the association between information-seeking and purchasing decisions.

In conclusion, this research builds on previous work in several critical aspects. It contributes to using proactive search data to identify interest in food safety information, explore the heterogeneous responses to the avian influenza outbreak, and address the staggered treatment effect in a demand system setting. The findings from this research can provide valuable insights to the government and the meat industry regarding the communication of food safety information in order to maintain the resilience of the meat supply.

The remainder of this paper is organized as follows. Section 2 introduces the background of avian flu outbreaks in the US and the potential impact pathway of animal disease. Section 3 presents the theoretical framework and the empirical models for demand system estimation. Section 4 discusses the data used in this study. Section 5 showcases empirical results. Finally, Section 6 concludes the study.

2 Background

This section provides the foundational background for this research, encompassing the avian flu outbreak's causes, the involvement of government agencies, and recent domestic avian flu outbreaks.

Avian influenza, also known as bird flu, is an infectious disease primarily affecting poultry and potentially transmissible to mammals under specific conditions. The United States Department of Agriculture (USDA) highlights that migratory waterfowl are carriers and distributors of the avian flu virus. The virus can be passed to domestic poultry via the bird feces in water sources, feed, or shared environment (Chmielewski and Swayne, 2011). Notably, Humphreys et al. (2021) underscore a strong spatial-temporal correlation between domestic poultry farm outbreaks and the movements of wild birds. Their research suggests that chicken and turkey farms north of the 40-degree latitude face heightened risks during fall migration, while southern poultry farms are more vulnerable during spring migration. Instances of low pathogenic avian influenza (LPAI) are often observed in wild birds exhibiting minimal to no signs of illness.

Nevertheless, certain virus strains can prove lethal to poultry through indirect exposure to contaminated equipment or feed. Since the early 2000s, the US has experienced five significant highly pathogenic avian influenza (HPAI) outbreaks in 2004, 2014/15, 2016, 2017, and 2022/23. The 2014/15 episode was the most severe outbreak until the 2022/23 incident, resulting in the loss of over 50 million birds. While previous avian flu outbreaks were relatively contained in terms of scale, time, and location (see Table 1), the 2014/15 outbreak exhibited multiple occurrences across states and months (see Table 2). The 2014/15 avian influenza outbreak led to a 7.46% decrease in turkey inventory and a 10% reduction in egg-laying chickens inventory. According to the APHIS report, the states most severely affected were Iowa, Minnesota, and Nevada, which are also important turkey production areas in the

US (Figure A3). Notably, the H5N2 virus prevalent during the 2014–2015 outbreak demonstrated greater virulence and adaptability for infecting turkeys and egg-laying chickens than broiler chickens.

Close contact with infected birds or contaminated environments is a potential route for transmitting avian flu virus to humans (Chmielewski and Swayne, 2011). As of 2023, 878 human cases have been reported from 23 countries, with a case fatality rate of 52% (WHO, 2023). However, no direct evidence links the avian flu virus to human health impacts via consuming properly cooked poultry products.

The United States Department of Agriculture's Food Safety and Inspection Service (FSIS) ensures food safety and integrity within the meat and poultry supply chain. Amendments to the Federal Meat Inspection Act and the Federal Poultry Inspection Act in 1967 and 1968 mandated federal or state officials' inspections of all commercial establishments. These establishments undergo regular checks to ensure operational compliance and also monitor potential diseases like E. coli, Salmonella, and avian flu through their Hazard Analysis and Critical Control Point (HACCP) system (FSIS, 2021).

Furthermore, the USDA's Animal and Plant Health Inspection Service (APHIS) oversees the avian influenza surveillance program, taking measures to curb disease spread. Commercial farms and backyard producers are monitored for signs of avian influenza. Upon identification of a highly pathogenic avian influenza (HPAI) case, quarantine and depopulation procedures are initiated as necessary. Compensation is provided for the culled poultry, and post-sanitation tests and processes are undertaken before restocking is allowed. In this study, the onset of the avian flu virus's initial detection marks the start of the outbreak period, and the effect persists for five months because the average quarantine period lasted for 149 days during the 2014/2015 outbreak (APHIS, 2016).

3 Model

3.1 Theoretical model

Rational consumers make consumption bundle decisions for meat and poultry products to maximize utility. Following Piggott and Marsh (2004), I assume that meat and poultry expenditure is weakly separable from other expenditures and avian influenza information is captured in vector τ, which represents a measure of meat or poultry quality $q(\tau)$. The problem can be represented as the following,

$$\max_{x_{meat}, x_{poultry}} u(x_{meat}, x_{poultry}, q(\tau), z) \tag{1}$$

$$\text{s.t. } p'_{meat}x_{meat} + p'_{poultry}x_{poultry} \leq M,\ x_i \geq 0\ \forall i$$

Let the consumer's utility function be presented as $u(x_{meat}, x_{poultry}, q(\tau), z)$, which satisfies the concavity condition with respect to vectors x. x_{meat} and $x_{poultry}$ are the quantity vectors of meat and poultry products, p_{meat} and $p_{poultry}$ are the price vectors of meat and poultry products, M is the total expenditure on meat and poultry, and z is the vector of household characteristics.

For ease of data collection, a dual version of this problem is the expenditure minimization problem, which is shown as the following:

$$\min_{x_{meat}, x_{poultry}} e(p, u) = p'_{meat}x_{meat} + p'_{poultry}x_{poultry} \tag{2}$$

$$\text{s.t. } u(x_{meat}, x_{poultry}, q(\tau), z) \geq u,\ x_i \geq 0\ \forall i$$

The general solution to the above problem, also known as the Hicksian (or Compensated) demand, is denoted by

$$h^* = x(p, e(p, u)) = f(p, u, q, z)$$

Instead of constructing the Marshallian demand from the above specification, Lewbel and Pendakur (2009) introduce the cost function by substituting expenditure (y) for utility (u) to obtain implicit Marshallian demand.

$$m^* = f(p, y, q, z)$$

3.2 Empirical models

Information impact

Following the theoretical framework, I adopt the Exact Affine Stone Index (EASI) framework to estimate the effects of avian flu information on meat and poultry demand. Instead of adopting the characteristic space demand model, such as the BLP framework introduced in Berry, Levinsohn and Pakes (1995), the aggregate product space demand model is suitable for the goal of this study, given that the impact of the avian flu information is on choices of meat and poultry, but not necessarily on other product characteristics. In addition, the EASI model offers enhanced flexibility for household-level estimation compared to the Almost Ideal Demand System (AIDS) introduced by Deaton and Muellbauer (1980) and has proven effective in estimating elasticities within food demand systems (Hovhannisyan et al., 2020, McCullough et al., 2022, Zhen et al., 2014). The EASI model accommodates unobserved consumer heterogeneity and flexible forms of the Engel Curves. Moreover, the EASI framework allows for weak separability assumptions between meat and poultry purchases and other product categories. The approximate EASI demand system estimation is shown as follows:

$$w_{imdt} = \sum_{r=0}^{3} \alpha_{mr} \tilde{y}_{idt}^{r} + \sum_{n=1}^{4} \beta_{mn} p_{ndt} + \gamma_{1m} Search_t + \gamma_{2m} Search_t \times Post_t + \sigma_m z_{idt} + u_q + v_d + \varepsilon_{imdt} \quad (3)$$

$$m \in \{Beef, Pork, Chicken, Turkey\}; \forall i = 1, ...N; d = 1, ..., D; t = 1, ..., T$$

where w_{imdt} specifies household i's budget share for meat or poultry m in market area d and time t; N is the number of households; D is the number of the designated market areas (DMA); and T is the number of the sample periods. I estimate the demand system for four meat and poultry categories (beef, pork, chicken, and turkey), and I drop the fifth meat category, "other meat", from the system estimation. Still, the parameters are recoverable given the adding-up constraint. p_{ndt} is the average log price index of meat or poultry type n in DMA d and time t. I first create household-level meat and poultry price indexes by taking the weighted average of the barcode-level unit price by purchased quantity. Then, I take the average of the meat or poultry prices at the DMA level. I replace the household-level price index with the DMA average price index to mitigate measurement error for individual households (Stevens, 2017). Following Lewbel and Pendakur (2009), I replace real total meat and poultry expenditure y_{idt} with Stone price-deflated real expenditure $\tilde{y} = x - \sum_{j=1}^{5} p_j w_j$ to estimate the approximate EASI model in a linear form which x indicates the log nominal total meat and poultry expenditures. Also, I assume coefficient symmetry constraint $\beta_{mn} = \beta_{nm}$ and adopt the cubic Engel Curve specification in the model, given the likelihood ratio test result.

Furthermore, $Search_t$ indicates the search intensity index regarding bird flu at time t, and $Post_t$ specifies the time after the 2014/2015 outbreak. z_{idt} is a vector of household characteristics of household i in DMA d and time t, which includes household size, household income, age of the household head, the highest level of educational attainment of the household head, and race. u_q is the quarter fixed effect, and v_d is the DMA fixed effect.

Finally, ε_{imdt} is the error term — in other words, the unobserved preference heterogeneity (Lewbel and Pendakur, 2009). The month-year time fixed effect captures the seasonal food pattern and the amount of available avian influenza information. In addition, the DMA fixed effect captures unobserved market-level heterogeneity in food consumption patterns and media exposure.[1]

In this study, I address two endogeneity issues. First, expenditure endogeneity arises from being on both sides of the demand estimation. Second, omitted variables can jointly impact the information-seeking behavior for avian flu information and meat and poultry purchase decisions. For instance, consumers with greater health awareness or dietary restrictions may be more interested in food safety information while having limited options for protein consumption.

To account for the endogeneity and the interdependency among the error terms in those equations in the system of equations estimation, I implement the three-stage least square analysis (3SLS) introduced in Zellner and Theil (1962). In the first stage, I separately regress the two sets of endogenous variables: (1) linear, quadratic, and cubic form of expenditure and (2) *Search* itself and the interaction term of *Search* and *Post* on the sets of instrumental variables and other exogenous variables. Next, the predicted values from the first stage are included in the EASI estimation by substituting the endogenous variables in Equation (3). The variance and covariance matrix of the error terms is further computed. Lastly, to obtain efficient estimates of the parameters, I simultaneously re-estimate the parameters of the system of equations using the generalized least squares method with the estimated covariance matrix from the second stage.

The first-stage estimation is shown as the following,

[1]Designated Market Area (DMA) region, also known as the media market, is defined by the Nielsen Company, representing geographical zones sharing the same media offerings.

$$\tilde{\boldsymbol{y}}_{imdt} = \sum_{r=0}^{3} \mu_{mr} \bar{y}_{idt}^{r} + \sum_{n=1}^{4} \delta_{mn} p_{ndt} + \eta_m SARS_t + \xi_m z_{idt} + u_q + v_d + \nu_{imdt} \tag{4}$$

$$\boldsymbol{Search}_{mt} = \sum_{r=0}^{3} \theta_{mr} \bar{y}_{idt}^{r} + \sum_{n=1}^{4} \lambda_{mn} p_{ndt} + \pi_m SARS_t + \rho_m z_{idt} + u_q + v_d + \pi_{imdt} \tag{5}$$

where $\tilde{\boldsymbol{y}}$ indicates the linear, quadratic, or cubic form of $\tilde{y}$ and $\boldsymbol{Search}$ indicates variables $Search$ or $Search \times Post$. As suggested in Lewbel and Pendakur (2009), the instruments to address endogeneity for $\tilde{y}$ and its quadratic and cubic form are the linear, squared, and cubic forms of $\bar{y} = x - \sum_{j=1}^{5} p_j \bar{w}$, where $\bar{w}_j$ is the average budget share across consumers in the sample for meat or poultry j.[2] On the other hand, I include $SARS_t$ as the instrument for $Search_t$, in which $SARS_t$ is the search intensity for SARS-related information in time t. Avian flu and SARS have multiple similarities. For instance, both diseases can cause respiratory symptoms, and the potential outbreaks cause public health concerns (Leppin and Aro, 2009). The instrument satisfies the condition of being uncorrelated with demand for meat and poultry but highly correlated with search behavior for avian flu information.

Based on the parameters estimated, I further compute the Hicksian price elasticity (compensated price elasticity), which is specified as

$$h_{mn} = \frac{\beta_{mn}}{w_m} - 1_{mn} + w_n$$

where $1_{mn} = 1$ when $m = n$ and 0 otherwise. The own-price elasticity is specified as $h_{mm} = \frac{\beta_{mm}}{w_m} - 1 + w_m$ and the cross-price elasticity is specified as $h_{mn} = \frac{\beta_{mn}}{w_m} + w_n$.

To make inferences representative of the US, I include normalized weight for all demand analyses. Following Zhen et al. (2009), the normalized weight is calculated as the individual household survey weight divided by the average survey weight of the sample.

[2] I follow the procedures in Lewbel and Pendakur (2009) to generate the expenditure instruments through iterated 3SLS estimation.

Outbreak Effect

This study further investigates the outbreak effect on demand by incorporating the demand system into the difference-in-differences framework to distinguish the possible heterogeneity in demand responses. Using a self-reported survey, Zhou et al. (2016) found that consumers with different levels of exposure to avian influenza outbreaks may show different demand results. Therefore, focusing on the 2014/15 outbreak period, I assume that consumers residing in the outbreak states will respond differently than those in the non-outbreak states, given different levels of interest in avian influenza information, which may increase or reduce the perception of health risks.

During the 2014/15 US avian influenza outbreak, poultry commercial farm outbreaks were identified across nine states and four months (shown in Table 2). The avian influenza outbreaks provide a quasi-experimental setting for quantifying the difference in demand responses between the outbreak and non-outbreak states. However, recent literature on the two-way fixed effects (TWFE) model based on multiple treatment timing shows that the estimates are biased when the treatment effect varies across groups and times. To address this issue, subsequent work has proposed an alternative estimator to TWFE to uncover unbiased estimations in a staggered Difference-in-Differences setting (Sun and Abraham, 2021, Callaway, Goodman-Bacon and Sant'Anna, 2021,Goodman-Bacon, 2021).

I estimate the difference-in-differences model using the two-step estimation approach introduced in Gardner (2022) to obtain an unbiased estimator along with the demand system estimation. The first stage estimates the treatment group and time fixed effects using only the control group observations (non-outbreak states) and the not-yet-treated observations from the treatment group (outbreak states) to generate a counterfactual. The second step provides an unbiased treatment effect by regressing the residuals from the first-stage estimation on the outbreak indicator after controlling for group and time fixed effects.

The two-step design provides flexibility in estimating the outbreak effect in a more complex setting. I extend Equation (3) to two stages to consider meat and poultry demand substitution and the price symmetry constraint. Following Gardner (2022), the first-stage estimation includes the not-yet-treated and never-treated samples. It is shown as the following:

$$w_{imdgt} = \sum_{r=0}^{3} \alpha_{mr} \tilde{y}_{idgt}^{r} + \sum_{n=1}^{4} \beta_{mn} p_{ndgt} + \sigma_m z_{idgt} + v_d + s_g + u_t + \varepsilon_{imdgt} \tag{6}$$

where s_g captures the outbreak-state group g occurring in the same month, v_d captures the time-invariant factors at the DMA level (e.g., media exposure), and u_t captures the seasonality in demand.

The second-stage estimation is estimated by regressing the predicted residuals from the first stage on the outbreak indicator with the full sample. The results provide the outbreak effect for the full sample after excluding the time and outbreak group fixed effects. The second-stage model is specified as

$$\hat{\varepsilon}_{imdt} = \sum_{r=0}^{3} \alpha'_{mr} \tilde{y}_{idt}^{r} + \sum_{n=1}^{4} \beta'_{mn} p_{ndt} + \nu Outbreak_{st} + \sigma'_m z_{idt} + \epsilon_{imdt} \tag{7}$$

where $\hat{\varepsilon}_{imdt}$ is the residual generated by the parameters estimated in Equation (6).[3] $Outbreak_{st}$ is a dummy variable equal to one if an outbreak is experienced in time t and state s. Additionally, I estimate the dynamic effect of the outbreak using an event study framework, in which I replace the outbreak indicator for months after the outbreak. I investigate the dynamic outbreak effect for five months, given that the quarantine procedure and the duration to restock poultry lasts at least five months (APHIS, 2016).

[3] As stated in Lewbel and Pendakur (2009), the error terms of the demand system can be interpreted as the unobserved preference heterogeneity or random utility parameters.

4 Data

4.1 Household Scanner Data

I utilize meat and poultry purchase data for 59,221 unique meat-purchasing households from Nielsen Consumer Panel Data in 2014 and 2015. This comprehensive dataset contains longitudinal information about purchases made by US households annually. The data encompass self-reported details, including purchase dates, locations, quantities, and prices of household items. However, products intended for business purposes or on-site/restaurant consumption are excluded from the dataset. The utilization of household scanner data offers greater flexibility in model specifications compared to other sources such as annual expenditure surveys, disappearance data, or retail scanner data. It provides detailed insights into product type, brand, purchase timing, location, and household characteristics.

Unlike food recall incidents, the avian flu outbreak is not limited to a specific meat type, brand, or company. Consequently, I aggregate trip-level data to derive monthly household meat and poultry purchases across four types: beef, pork, chicken, and turkey. Additionally, I incorporate a fifth category labeled "other meat" to encompass miscellaneous meat purchases, including other meat categories such as lamb and fish. I focus only on fresh meat and poultry products since frozen meat purchases account for a small proportion of the data in the period of interest.

In addition, I calculate the household-level monthly price index for each meat or poultry type by taking the average unit price for each product weighted by the purchased quantity. Drawing from McCullough et al. (2022) and other demand literature, I replace the household-level price index with the median purchase price index within the same designated market area (DMA) to mitigate potential biases in household prices.[4] Furthermore,

[4]As discussed in Berry and Haile (2021), price endogeneity in the demand system estimation can arise in the simultaneity of the supply and demand, measurement error, and omitted variables. Although the

I employ DMA-monthly-averaged prices for substitutable products. If a particular meat or poultry product remains unpurchased by any household within a DMA during a specific month, I substitute the state median price for the price index. All prices in this study are adjusted using the Consumer Price Index (CPI). To comprehensively capture factors influencing meat and poultry consumption or the propensity to integrate media information into purchasing behavior, I include household characteristics such as household size, income, age of household head, educational attainment of the household head, and race in the demand estimation.

4.2 Google Trend

To capture people's interest in avian influenza, I obtained search data for "bird flu" from Google Trends from 2014 to 2015. The search index measures the search intensity for a specific term, calculated by the search volume of the keywords of interest divided by the total number of Google searches at the given time in the same area. The index is then scaled to range from 0 to 100, where 100 represents the maximum search intensity in the location within a time interval, 0 represents insufficient searches, and the rest of the months are assigned an index of 1-99 based on the relative search volume with the maximum searches in the exact location. For example, the search intensity 50 represents 50% of the searches compared to the month with maximum searches. To address the endogeneity issue in information-seeking behavior, I adopt the instrumental method using search intensity for "Severe acute respiratory syndrome (SARS)" in the same period.

Google search data is gaining popularity in social science studies as a measure for capturing media attention, for the following reasons. First, the search index provides a relatively

simultaneity concern is less of a problem for individual-level estimation (Lewbel and Pendakur, 2009), the use of market-product level prices may not fully address endogeneity from unobserved market-product shocks that may correlate with the market-product price (e.g., advertisements about other food safety issues). Since this research focuses on the impact of bird flu information on demand instead of on price elasticities, I focus on addressing endogeneity problems in expenditure and avian flu information.

comprehensive measure of exposure to information, interest in the topic, and information assimilation. Second, Google Trends data is nationally representative and not very susceptible to biases by subsample (Bacher-Hicks et al., 2022). Third, Google search data provide a summary measure of information from most media channels and have better coverage of the available information (Ma, Seenivasan and Yan, 2020). However, one of the limitations of Google Trends search data is that it is restricted to those who have internet access and use Google as their search engine (Bacher-Hicks et al., 2022). The issue is less of a concern since 96% of this study's household scanner sample have home internet access. In addition, Google accounted for 88% of the global desktop search market in 2015.[5]

To compare the Google search index with information from other media channels, I aggregate the news frequency of the keywords "bird flu" or "avian influenza" from Nexis Uni Database, U.S. Newsstream, and Factiva in generating the news index. I focus on news articles published in the nationwide English-language television, print, and web news articles between 2010 and 2020 and aggregate the amount of news at the monthly level.[6] To make the two indexes comparable, I scale the news frequency to 0-100. Figure 1 illustrates the alignment of the news and search index from 2010 to 2020. The figure shows similar trends of the two indexes with evident spikes during domestic or international outbreaks. To better examine the spatial relationship between the avian flu outbreak and search intensity, I collected state-level Google search intensity data during the 2014/15 outbreak. Figure 2 shows a greater search popularity for bird flu in the outbreak states in 2015.

The summary statistics of variables used in the 2014-2015 analysis are shown in Table 3. Comparing the budget share in the pre- and post-outbreak samples, the mean for beef and turkey increases while the mean share for chicken decreases. In addition, both the news and

[5]See https://www.statista.com/statistics/216573/worldwide-market-share-of-search-engines/.

[6]For the TV news, I select five nationwide TV broadcasts, which are CBS, ABC, FOX, NBC, and CNN. I choose the New York Times and Wall Street Journal to represent national newspapers. In line with the approach of Tonsor and Olynk (2011) and others, I apply equal weights to all news articles during the aggregation process. This strategy helps avoid subjective judgments.

search indexes show an increase in the 2015 sample.

5 Results

5.1 Meat and Poultry Demand Estimation

I adopt the EASI model to model the prices and avian influenza search intensity effect on meat and poultry demand. Following Bewley (1985), to identify the proper specification for the expenditure, I adopt the Bewley adjusted likelihood ratio (B_{LR}) test in comparing the model fit with linear, quadratic, cubic, and quartic Engel curves.[7] The result in Table 4 indicates that the EASI model with the cubic Engel curve better fits the data than the linear and quadratic Engel curves. Therefore, the rest of the analysis will be based on the cubic Engel curve specification.

To address the potential endogeneity in the search indicator and expenditure variables, I run the three-stage least square estimation. Table A1 shows the first stage of the estimation, which captures the relationship between the selected instruments and endogenous variables. None of the F-statistics for the joint significance of the instrumental variables in the first stage is weak, showing an F-statistic greater than 1000. Table 5 presents the results of the avian flu search intensity's impact on the demand for meat and poultry after instrumenting the avian flu search intensity variable with the SARS searches and expenditure instruments in the EASI estimation.

The results indicate a significant change in consumer response to avian influenza information before and after the domestic outbreak. The result in the pre-outbreak period

[7] The adjusted likelihood ratio test is computed by $B_{LR} = 2(LL^u - LL^r) \times \frac{eN-k^u}{eN}$, where $LL^u(LL^r)$ is the maximum log-likelihood value of the unrestricted (restricted) model, N is the sample size, e is the number of equations, and k^u is the number of parameters in the unrestricted equations.

shows that consumers increase poultry demand and reduce other meat demand in response to heightened interest in avian influenza. An increase of one standard deviation of avian influenza searches during the non-outbreak period is associated with a 6.4% point increase in chicken demand and a 7.5% point increase in turkey demand. The positive association between avian flu interest and demand for poultry products specifies that the worry about future avian flu outbreaks is driving an increase in purchases. The variable $Search \times Post$ specifies the change in effect after the occurrence of domestic outbreaks, which captures both the effect of the avian flu information and people's concern for the avian flu. The results show that, during the occurrence of a domestic avian flu outbreak, an increase of one standard deviation in avian influenza searches reduced chicken demand and turkey demand by 10.1% and 4% points. The result is consistent with Wang and de Beville (2017), showing that, since turkey demand is usually linked to special occasions and traditions, turkey is relatively less substitutable by other meat products than chicken.

Next, I conduct the exact estimation with other measures of avian flu information. Table 6 presents the results of the impact of avian flu information on the demand for meat and poultry using the news article frequency index and search intensity index without being instrumented. The result in the first section shows that an increase of one standard deviation of avian flu-related attention in the mass media reduces beef demand by 1.3% and increases chicken demand by 6.8%. During the outbreak, however, the increased news discussion on avian influenza reduced chicken demand. The results' signs and scale are consistent with the beef and chicken estimations in Table 5. On the other hand, the second section of Table 6 presents the avian flu search intensity relationship with meat and poultry demand without instrument adjustment. The results show opposite signs compared to previous discussions, implying the potential issues that may arise without the control for the confounder between purchase and information-seeking behavior.

Table A3 presents the price elasticity and expenditure elasticity evaluated at the sample mean value from the EASI estimation. All the elasticities presented are calculated based on the parameters from the estimation. The table shows negative own-price elasticities and positive cross-price elasticities for all estimations. In addition, pork is the most price-elastic in the estimation, while beef is the least price-elastic. The results are consistent with theory and most food demand studies (Andreyeva, Long and Brownell, 2010). As for the expenditure elasticity results, beef and chicken were expenditure-elastic in the estimation. Table A4 summarizes the price and expenditure elasticity results in previous literature; the results show a wide range for both price and expenditure elasticity. Other estimated parameters are shown in Table A5.

5.2 Heterogeneous Effects

To identify the heterogeneity of the effects of avian flu information on meat and poultry purchases, I interact the search index with demographic characteristics before and after the 2014/2015 outbreak.

Education: Educational attainment is often viewed as a proxy for one's ability to access and comprehend food safety information (Peña-Y-Lillo and Guzmán, 2022, Shimshack, Ward and Beatty, 2007). To explore the varying impacts of avian influenza information across different educational attainment groups, I focus on the household heads with greater educational attainment among the two heads, considering them as the primary shoppers and decision-makers. I categorize these educational attainment groups into four categories: those with education levels below a high school degree, those with a high school degree, those with a college degree, and those with degrees beyond college. The results in Table 7 show that different educational attainment groups have divergent responses on meat and poultry purchases. Specifically, I observe that the avian influenza search intensity does not influence purchasing decisions for households whose heads do not hold high school degrees.

These findings align with previous research, such as that of Shimshack, Ward and Beatty (2007), which suggests that consumers with the lowest educational levels are less responsive to food safety information and advisories. Furthermore, this study presents evidence indicating that highly-educated households, characterized by those with graduate degrees, may thoroughly process such information, resulting in no significant adjustments to their purchasing behavior. The results imply that highly-educated consumers are more informed about the relatively low health risks associated with avian flu, leading them to maintain their purchasing habits without modification.

Race: Table 8 presents findings on the varied responses of different racial groups to avian influenza information. The racial categories considered are White, Black, Asian, and other racial groups. The results reveal that households from these racial groups exhibit distinct patterns in adjusting their meat and poultry consumption in response to avian influenza information, reflecting disparities in their perceptions of health risks associated with different products. For instance, Asian households make significant adjustments in their turkey purchases in light of avian influenza information. Similarly, Black households demonstrate significant responses in their pork purchases, both before and during the outbreak. According to Choi and Lee (2023), Black households tend to consume pork less compared to other meat and poultry products, while Asian households consume turkey less frequently. Consequently, the results suggest that meat and poultry types with lower initial purchase frequencies display more pronounced adjustments in response to avian influenza information.

Income: The result in Table 9 reports the heterogeneous responses to avian influenza information by income groups. The income groups include below 30K, 30-50K, 50-70K, and above 70K. The results show that consumers with higher incomes exhibit a greater capacity to adjust their purchases. Prior to the outbreak, annual income above 70K households responded significantly to the avian flu attention with a one standard deviation increase in avian flu searches led to a 13% increase in turkey purchases, 7.5% and 20% reduction in beef and pork purchases.

5.3 Outbreak Impact

5.3.1 Demand

The following section identifies the impact of 2014/2015 HPAI events on meat and poultry demand between the outbreak and non-outbreak states. Given the variation in outbreak timing and location, I implement the difference-in-differences framework into the demand system estimation to identify the staggered state outbreak effect on meat and poultry demand. As proposed in Adda (2007), I view the state outbreak of avian influenza as a natural experiment in investigating the adjustment of purchasing behavior. Although consumers have prior beliefs from previous domestic bird flu outbreaks, the number of infected birds and the geographical scope of the 2014/15 outbreak were unprecedented. Therefore, new information and uncertainty were created, causing unequal shifts in consumer risk perception based on their awareness, internalization of the knowledge, and interest in the events. I assume that the difference in risk perception between the outbreak and non-outbreak regions may result in different purchasing behaviors. Therefore, I utilize the staggered outbreak setting to isolate those avian flu-driven demand effects from other unobserved preference heterogeneity in our EASI demand estimation.

Table 10 summarizes the staggered treatment effect of the avian influenza outbreak on the outbreak states in the post-outbreak period compared to the non-outbreak states. The results show that, under the same price level and national-level avian influenza information, the outbreak states purchased 15.68% additional turkey and 37.13% less pork than the non-outbreak states within five months after the outbreak.

Next, I investigate the outbreak effect across time with an event study estimation. The event studies results in Table 11 show greater chicken demand in the outbreak areas compared with the non-outbreak area during the first month of the outbreak. In addition, the outbreak-state residents purchased more turkey than residents of the non-outbreak states three months after the outbreak. The results in Table 11 suggest that consumers in outbreak states increased chicken demand because they were better informed that the avian flu impact mostly affected turkey products at the beginning of the outbreak. As for turkey demand, the difference between the outbreak and non-outbreak states arose three months after the outbreak, when the concerns about supply shortages in the outbreak states increased. The time lag between the effects on chicken and turkey also indicates the difference in consumer trust for the products heavily impacted by avian flu (turkey) and those less impacted (chicken). Furthermore, the demand for beef and pork in the outbreak states was significantly less than in the non-outbreak states three months after the outbreak as a result of substituting the increased poultry demand.

Chambers and Melkonyan (2013) indicate that perception of risk and uncertainty affects how fast consumers recover from demand reduction. Results in this study suggest that residents in the outbreak states recovered faster from the food scare. The results suggest two potential explanations. First, given the greater interest in local media, the people in the outbreak states were more likely to have been exposed to information explaining the low-level risk that avian influenza poses to human health; therefore, they had less concern about poultry purchases. Second, the outbreak states may have been more concerned about the local supply shortage, which led to a stockpiling effect for poultry products. The turkey responses show up later after the first identified outbreak case; this suggests that the increasing uncertainty about future turkey supply may have increased turkey demand. Given the less substitutable nature of turkey products (Wang and de Beville, 2017), those stockpiling effects are more significant in the outbreak states, as people prepared for future use.

In sum, these findings provide valuable insights into how avian influenza information influences consumer behavior, emphasizing the importance of considering spatial and temporal disparities when analyzing food safety information impacts on meat and poultry purchases.

5.3.2 Price and Google Search

The discussion above focuses on the demand differences between states that experienced avian flu outbreaks and states that did not. I further examine two other potential impacts of the avian flu outbreak: differences in retail prices of poultry products and search intensity during the outbreak periods. The following plots show the staggered outbreak effect on price and information using the method introduced by Callaway, Goodman-Bacon and Sant'Anna (2021). The control group includes the states that were never treated (didn't experience avian flu outbreak in 2015) and not-yet-treated (experienced avian flu outbreak later in 2015). The plot presents the event study of the staggered treatment effect, aggregated by the average treatment effect in a certain period for the states that first experienced outbreaks.

Regarding poultry prices, Figures 3 and 4 show that chicken and turkey market prices in the outbreak states were not significantly different from the non-outbreak states throughout the outbreak. The insignificant results imply that uniform retail pricing still holds during supply disruptions (DellaVigna and Gentzkow, 2019).

As for avian flu information, the result in Figures 5 shows that the commercial farm outbreaks in the state of residence contribute to a 5.4% and 3.8% increase in searches in the first two months compared with the control areas. The result suggests that residents in the outbreak states were more likely to be informed of the outbreak and had greater interest in the topic. This shows that the difference in avian influenza awareness and attention is a potential mechanism for different demand responses between the outbreak and non-outbreak states.

I further test whether the states that experienced backyard farm outbreaks show different responses in Google searches for bird flu than the non-outbreak states. The result in Figure ?? suggests that Google searches in the backyard farm outbreak states do not show significant differences compared with the non-outbreak state. Given the limited impact, the results indicate that backyard farm outbreaks lack public attention.

6 Conclusion

The increasing occurrence of avian influenza outbreaks is striking the poultry industry worldwide. Policymakers are constantly concerned about how consumers respond to those incidents. Although avian influenza viruses do not pose a direct health risk via poultry consumption, the previous literature has documented the impact of avian influenza on consumer purchasing decisions through media information (Wang and de Beville, 2017; Mu et al., 2015). Hence, a better understanding of the heterogeneous responses is required to predict consumer responses and communicate more effectively with the public about health risks.

The main objective of this study is to analyze the impact of avian influenza on meat and poultry purchases. Focusing on one of the largest animal health emergencies in US history, this paper investigates consumer responses to the 2014/15 avian influenza outbreak. Using an information-seeking index, this research estimates the effect of avian influenza on demand, capturing the awareness and information assimilation that is often overlooked in food safety studies. Additionally, this study provides empirical evidence illustrating demand disparities among different demographic groups and geographic regions.

The EASI estimation results reveal that avian influenza search intensity affected meat and poultry demand differently before and after the 2014/15 outbreak. This implies that consumers acquire and interpret information about avian flu differently when a domestic outbreak occurs. Furthermore, heterogeneous effects are shown for demand responses. Leasteducated households and the most-educated households are less responsive to avian influenza information. Additionally, households of different racial groups respond significantly to the least purchased meat and poultry types.

In addition, by implementing a staggered difference-in-differences design in the EASI demand system estimation, this study assesses the impact of state-level outbreaks on meat and poultry demand. The findings demonstrate that consumers in outbreak states exhibited increased demand for poultry and reduced demand for other meat products compared with non-outbreak consumers during the outbreak period. Additionally, the event study results indicate that the increase in turkey demand in outbreak states occurred later in the outbreak period. This suggests that the concern for supply shortage surpassed the concern for avian flu health risks.

This research contributes to the existing literature on how animal disease outbreaks impact consumer decision-making. In contrast to most studies that primarily examine the average effects of food recall incidents or animal disease outbreaks, this study takes a deeper dive into comprehending the diverse range of consumer responses. These findings have significant policy implications. Policymakers and public health agencies need to adapt their communication and risk management strategies to address the different consumer responses during different periods. During non-outbreak periods, efforts may focus on educating and providing information to consumers to dispel misconceptions. During outbreaks, the focus may shift to assuring consumers of food safety and adherence to strict control measures in rebuilding consumer trust in the safety of poultry products. Additionally, industry stakeholders should be prepared to manage supply chain disruptions during outbreaks and potentially expand marketing efforts to regain consumer confidence afterward.

With the increasing reliability of web searches as primary health information sources, providing comprehensive and easily accessible web-based information can serve as a valuable policy instrument. Moreover, tailoring this information to cater to diverse demographic groups and regions can enhance its effectiveness in conveying the message, particularly during periods of heightened public interest.

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Figures

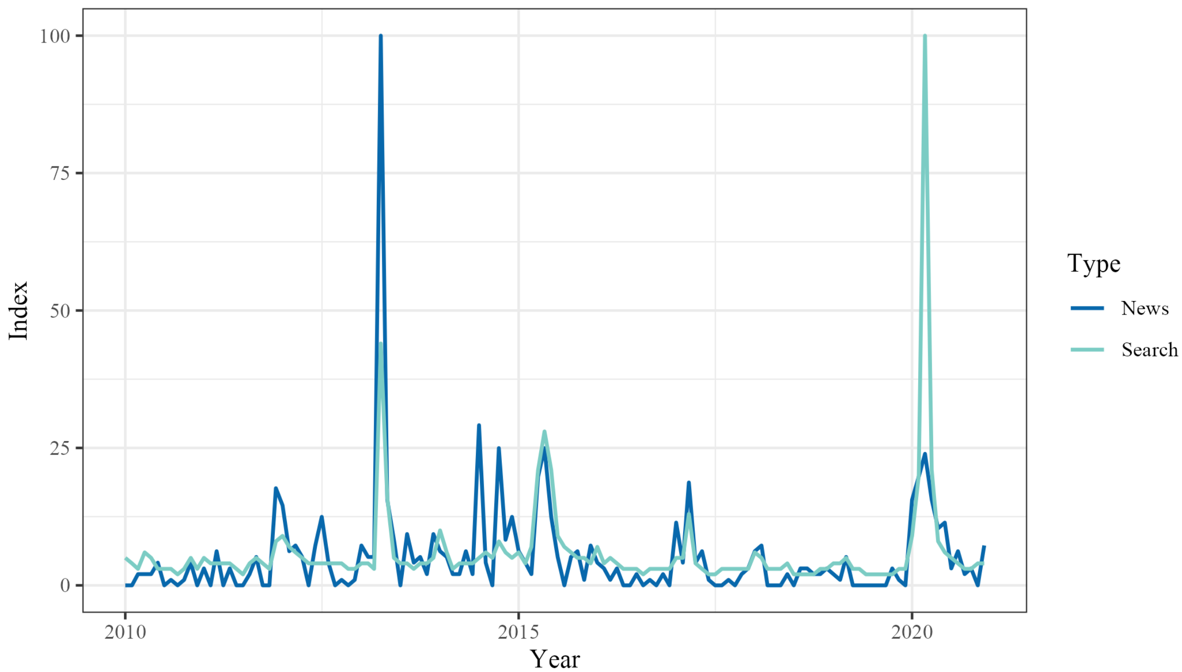

Figure 1: US avian flu news and search index from 2010-2020
Data Source: Nexis-Uni, Factiva, Newsstream, Google Trends
Note: The two monthly indexes are normalized between 0 and 100 from 2010 to 2020.

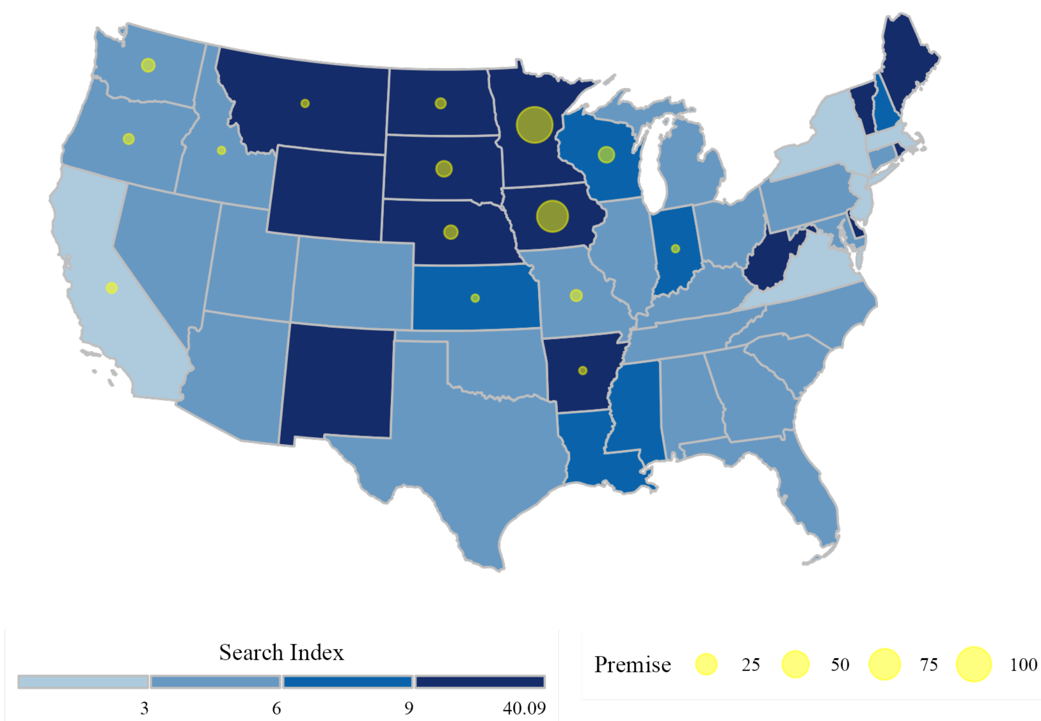

Figure 2: 2015 Search Index and Outbreak Premises
Note: This figure plots the 2015 Google search intensity for bird flu and the amount of outbreak premises.

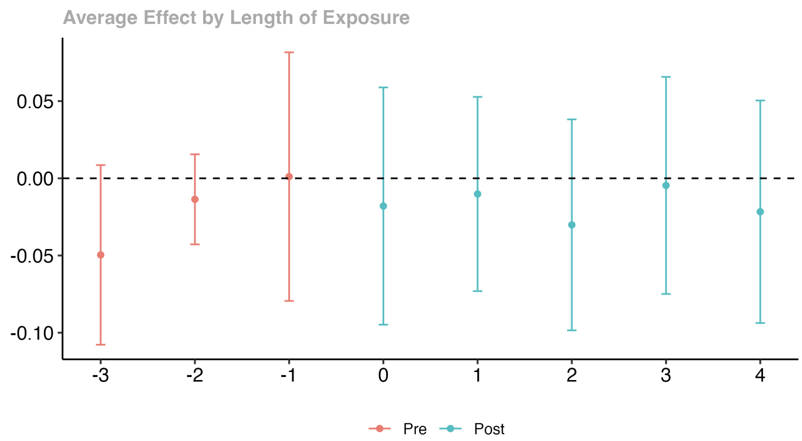

Figure 3: 2015 Avian influenza outbreak impact on log chicken price (cents/oz)
Note: This figure plots the staggered difference-differences result of log chicken prices comparing prices in the commercial poultry farms outbreak states versus those in the non-outbreak states. The x-axis specifies the number of months after the outbreak.

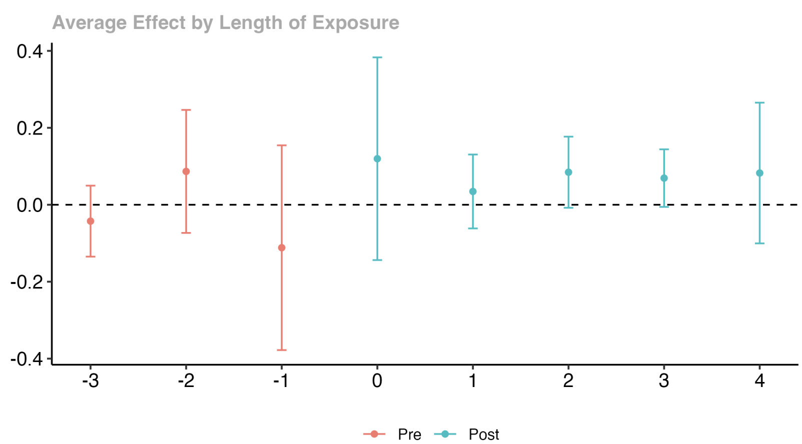

Figure 4: 2015 Avian influenza outbreak impact on log turkey price (cents/oz)
Note: This figure plots the staggered difference-differences result of log turkey prices comparing prices in the commercial poultry farms outbreak states versus those in the non-outbreak states. The x-axis specifies the number of months after the outbreak.

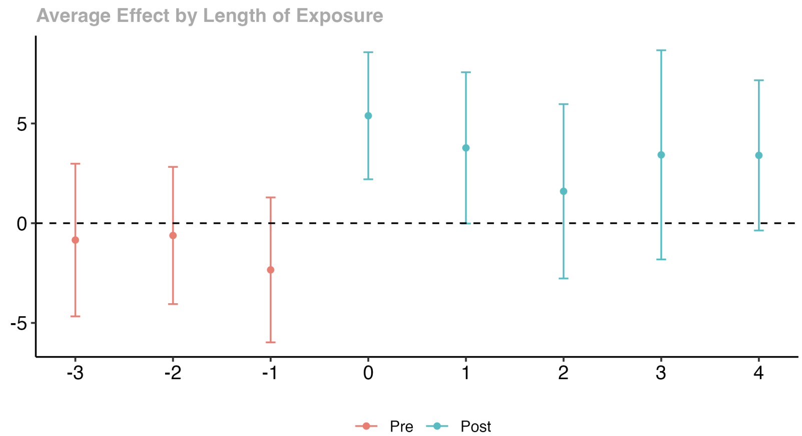

Figure 5: 2015 Avian influenza commercial farm outbreak impact on log search index
Note: This figure plots the staggered difference-differences result of Google search intensity of bird flu comparing prices in the commercial poultry farms outbreak states versus those in the non-outbreak states. The x-axis specifies the number of months after the outbreak.

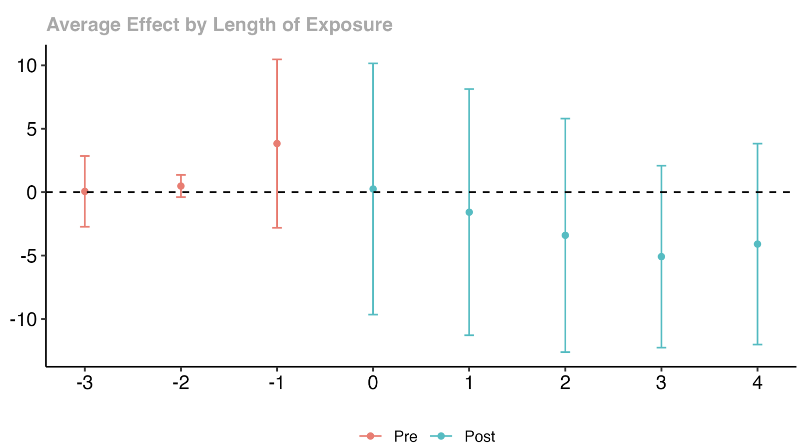

Figure 6: 2015 Avian influenza backyard farm outbreak impact on log search index
Note: This figure plots the staggered difference-differences result of Google search intensity of bird flu comparing prices in the backyard poultry farms outbreak states versus those in the non-outbreak states (exclude commercial farm outbreak states). The x-axis specifies the number of months after the outbreak.

Tables

Table 1: US Avian Influenza outbreaks from 2010 to 2020

Year	State	Production Type	Pathogenicity
2011	Missouri/Minnesota	Turkeys	LPAI
2013	Arkansas	Broiler breeders	LPAI
2014	California	Qual and Peking ducks	LPAI
2015	Arkansas/California/Idaho/Indiana/Iowa/Kansas Minnesota/Missouri/Montana/Nebraska/North Dakota/ Oregon/South Dakota/Washington/Wisconsin	Turkeys and layers	HPAI
2016	Indiana/Missouri	Turkeys and layers	HPAI&LPAI
2017	Tennessee/Alabama/Georgia/Kentucky/Wisconsin	Broiler breeders and other birds	HPAI&LPAI
2018	Texas/Missouri/Minnesota	Turkeys and Broiler chicken	LPAI
2020	North Carolina/South Carolina	Turkeys	LPAI

Source: GAO(2017) & USDA (2018,2019,2020)

Table 2: US Avian Influenza outbreaks in 2014/2015

Start Month	State	Production Type
Dec, 2014	Oregon/Washington	Backyard Farm
Jan, 2015	California	Commercial Farm
Jan, 2015	Idaho	Backyard Farm
Mar, 2015	Arkansas/Minnesota/Missouri	Commercial Farm
Mar, 2015	Kansas	Backyard Farm
Apr, 2015	Iowa/North Dakota/South Dakota/Wisconsin	Commercial Farm
Apr, 2015	Montana	Backyard Farm
May, 2015	Nebraska	Commercial Farm
May, 2015	Indiana	Backyard Farm

Source: USDA
Note: In total, 211 commercial flocks and 21 backyard flocks are impacted with 50 million bird losses, most of which are turkeys and layers. The start date of the outbreak is defined when the first confirmed premise is recorded in the state.

Table 3: Descriptive statistics

		All		2014		2015	
	Variable	Mean	SD	Mean	SD	Mean	SD
Budget shares	Beef	0.44	0.45	0.44	0.45	0.45	0.46
	Pork	0.07	0.24	0.07	0.23	0.07	0.24
	Chicken	0.23	0.38	0.24	0.39	0.23	0.38
	Turkey	0.18	0.36	0.18	0.35	0.19	0.36
	Other meat	0.07	0.18	0.07	0.18	0.07	0.18
Log-expenditure	x	2.45	0.77	2.45	0.77	2.45	0.78
	$x - p \cdot w$	-0.48	0.80	-0.46	0.79	-0.49	0.80
Log Prices	Beef	3.08	0.09	3.05	0.09	3.11	0.08
	Pork	3.13	0.20	3.13	0.20	3.13	0.20
	Chicken	2.60	0.11	2.59	0.11	2.60	0.12
	Turkey	2.84	0.10	2.83	0.10	2.85	0.10
	Other meat	3.12	0.10	3.11	0.10	3.12	0.11
Demographics	One member household	0.16	0.37	0.16	0.37	0.16	0.37
	Two member household	0.43	0.50	0.43	0.50	0.43	0.49
	Three member household	0.17	0.37	0.17	0.37	0.17	0.37
	Four member household	0.14	0.35	0.14	0.35	0.15	0.35
	Five member household	0.06	0.24	0.06	0.24	0.06	0.24
	Over five member household	0.03	0.18	0.03	0.17	0.03	0.18
	<30k income	0.20	0.40	0.20	0.40	0.20	0.40
	30-50K income	0.24	0.43	0.25	0.43	0.24	0.43
	50-70 income	0.19	0.39	0.19	0.39	0.19	0.39
	>70K income	0.37	0.48	0.36	0.48	0.37	0.48
	Male head age < 30	0.02	0.13	0.02	0.13	0.02	0.14
	Male head age 30-39	0.09	0.29	0.08	0.28	0.10	0.29
	Male head age 40-49	0.16	0.37	0.16	0.37	0.16	0.37
	Male head age 50-64	0.34	0.47	0.35	0.48	0.33	0.47
	Male head age > 65	0.19	0.39	0.19	0.39	0.19	0.39
	Female head age < 30	0.03	0.16	0.02	0.16	0.03	0.17
	Female head age 30-39	0.12	0.32	0.11	0.32	0.13	0.33
	Female head age 40-49	0.19	0.39	0.19	0.39	0.18	0.39
	Female head age 50-64	0.40	0.49	0.41	0.49	0.40	0.49
	Female head age > 65	0.19	0.39	0.18	0.39	0.19	0.39
	Less than high school	0.01	0.11	0.01	0.11	0.01	0.11
	High school	0.49	0.50	0.50	0.50	0.49	0.50
	College	0.33	0.47	0.33	0.47	0.33	0.47
	Post college	0.16	0.37	0.16	0.37	0.16	0.37
	White	0.82	0.39	0.82	0.38	0.81	0.39
	Black	0.12	0.32	0.11	0.32	0.12	0.32
	Asian	0.02	0.15	0.02	0.15	0.02	0.15
	Other race	0.05	0.21	0.04	0.20	0.05	0.21
Information	News index	11.30	21.94	5.57	9.84	17.17	28.39
	Search index	21.65	25.78	12.23	8.20	31.28	33.04
Observations		378,926		191,588		187,338	

Table 4: Model specification test

Model specification test	Likelihood ratio value	p-value
Linear vs. quadratic Engel curve	18785	0.00
Quadratic vs. cubic Engel curve	4596	0.00

Note: As suggested in Lewbel and Pendakur (2009), the degree of expenditure estimated cannot exceed the number of estimated meat groups (four); otherwise, the model may not converge. Both test results suggest that the higher-powered Engel curve provides a significantly better fit to the data than the lower-powered Engel curve.

Table 5: Avian flu information impact on meat and poultry demand

	Beef	Pork	Chicken	Turkey
Search	-0.0017^{***}	-0.0061^{***}	0.0025^{**}	0.0029^{***}
	(0.0006)	(0.0020)	(0.0012)	(0.0011)
Search x Post	0.0022^{***}	0.0037^{**}	-0.0039^{***}	-0.0016^{*}
	(0.0005)	(0.0016)	(0.0010)	(0.0009)

Note: *** p<0.01, ** p<0.05, * p<0.1. The table reports EASI coefficients divided by the mean of budget shares of each meat category. Standard errors in parentheses were obtained via the delta method. The coefficients specify changes in purchase in response to a 1 percentage point increase in the index.

Table 6: Avian flu information impact on meat and poultry demand without IV adjustment

	Beef	Pork	Chicken	Turkey
News	-0.0006^{*}	-0.0007	0.0031^{***}	0.0002
	(0.0003)	(0.0011)	(0.0006)	(0.0006)
News x Post	0.0003	0.0004	-0.0034^{***}	0.0008
	(0.0004)	(0.0011)	(0.0007)	(0.0007)
Search	0.0097	-0.1193^{***}	0.0077	-0.4098^{***}
	(0.0118)	(0.0356)	(0.0257)	(0.0356)
Search x Post	-0.0315^{***}	0.2733^{***}	-0.1090^{***}	0.1786^{***}
	(0.0079)	(0.0199)	(0.0114)	(0.0156)

Note: *** p<0.01, ** p<0.05, * p<0.1. The table reports EASI coefficients divided by the mean of budget shares of each meat category. Standard errors in parentheses were obtained via the delta method. The coefficients specify changes in purchase in response to a 1 percentage point increase in the index.

Table 7: Heterogeneity result of avian flu information impact on meat and poultry demand: By education group

		Beef	Pork	Chicken	Turkey
Less than high school	Search	-0.0021	0.0021	0.0037	0.0066
		(0.0038)	(0.0159)	(0.0077)	(0.0106)
	Search x Post	0.0023	-0.0019	-0.0032	-0.0058
		(0.0032)	(0.0130)	(0.0064)	(0.0094)
	Observation		4,603		
High school	Search	-0.0010	-0.0056^{*}	0.0030^{**}	0.0014
		(0.0007)	(0.0030)	(0.0014)	(0.0016)
	Search x Post	0.0014^{**}	0.0038	-0.0042^{***}	-0.0002
		(0.0006)	(0.0025)	(0.0012)	(0.0014)
	Observation		187,510		
College	Search	-0.0032^{***}	-0.0079^{***}	0.0034^{*}	0.0052^{**}
		(0.0012)	(0.0031)	(0.0019)	(0.0023)
	Search x Post	0.0036^{***}	0.0036	-0.0044^{***}	-0.0035^{*}
		(0.0010)	(0.0025)	(0.0017)	(0.0019)
	Observation		124,852		
Post college	Search	0.0003	-0.0074	-0.0029	0.0023
		(0.0020)	(0.0048)	(0.0031)	(0.0027)
	Search x Post	0.0010	0.0043	-0.0009	-0.0007
		(0.0016)	(0.0038)	(0.0025)	(0.0022)
	Observation		61,961		

Note: *** p<0.01, ** p<0.05, * p<0.1. The table reports EASI coefficients divided by the mean of budget shares of each meat category in the subsample analysis. Standard errors in parentheses were obtained via the delta method.

Table 8: Heterogeneity result of avian flu information impact on meat and poultry demand: By race group

		Beef	Pork	Chicken	Turkey
White	Search	-0.0020^{***}	-0.0049^{**}	0.0025^{**}	0.0037^{***}
		(0.0007)	(0.0023)	(0.0012)	(0.0012)
	Search x Post	0.0024^{***}	0.0030	-0.0035^{***}	-0.0024^{**}
		(0.0006)	(0.0019)	(0.0010)	(0.0011)
	Observation		309,548		
Black	Search	0.0025	-0.0218^{***}	0.0001	0.0013
		(0.0024)	(0.0065)	(0.0029)	(0.0026)
	Search x Post	-0.0013	0.0166^{***}	-0.0033	0.0004
		(0.0020)	(0.0047)	(0.0024)	(0.0022)
	Observation		43,803		
Asian	Search	-0.0029	0.0009	-0.0082	0.0147^{***}
		(0.0042)	(0.0096)	(0.0059)	(0.0054)
	Search x Post	0.0034	-0.0032	0.0054	-0.0112^{**}
		(0.0039)	(0.0083)	(0.0049)	(0.0048)
	Observation		8,486		
Other	Search	-0.0051^{*}	0.0032	0.0119^{***}	-0.0036
		(0.0027)	(0.0068)	(0.0046)	(0.0040)
	Search x Post	0.0051^{**}	-0.0097	-0.0113^{***}	0.0035
		(0.0023)	(0.0058)	(0.0041)	(0.0035)
	Observation		17,089		

Note: *** p<0.01, ** p<0.05, * p<0.1. The table reports EASI coefficients divided by the mean of budget shares of each meat category in the subsample analysis. Standard errors in parentheses were obtained via the delta method.

Table 9: Heterogeneity result of avian flu information impact on meat and poultry demand: By income group

		Beef	Pork	Chicken	Turkey
Annual income <30K	Search	-0.0012	-0.0031	0.0019	0.0004
		(0.0009)	(0.0042)	(0.0020)	(0.0023)
	Search x Post	0.0015^{*}	0.0027	-0.0032^{**}	0.0001
		(0.0008)	(0.0034)	(0.0016)	(0.0019)
	Observation		75,597		
Annual income 30-50K	Search	0.0001	-0.0144^{***}	0.0012	0.0049^{**}
		(0.0012)	(0.0034)	(0.0020)	(0.0025)
	Search x Post	0.0007	0.0107^{***}	-0.0033^{**}	-0.0032
		(0.0011)	(0.0027)	(0.0017)	(0.0022)
	Observation		92,391		
Annual income 50-70K	Search	-0.0002	0.0002	0.0041	-0.0033
		(0.0018)	(0.0046)	(0.0027)	(0.0031)
	Search x Post	0.0013	-0.0013	-0.0046^{**}	0.0025
		(0.0015)	(0.0037)	(0.0023)	(0.0028)
	Observation		71,780		
Annual income >70K	Search	-0.0029^{**}	-0.0078^{***}	0.0026	0.0051^{***}
		(0.0013)	(0.0029)	(0.0019)	(0.0018)
	Search x Post	0.0035^{***}	0.0043^{*}	-0.0043^{***}	-0.0033^{**}
		(0.0010)	(0.0024)	(0.0017)	(0.0015)
	Observation		139,158		

Note: *** p<0.01, ** p<0.05, * p<0.1. The table reports EASI coefficients divided by the mean of budget shares of each meat category in the subsample analysis. Standard errors in parentheses were obtained via the delta method.

Table 10: Outbreak effect on meat and poultry demand

Variable	Beef	Pork	Chicken	Turkey
Outbreak	0.0084	-0.3713^{***}	0.0382	0.1568^{***}
	(0.0475)	(0.1228)	(0.0693)	(0.0606)
Observations		378,926		

Note: *** p<0.01, ** p<0.05, * p<0.1. Standard errors, derived by the delta method, are in parentheses. The presented results are from the second stage estimation of the difference-in-differences EASI demand system. The dependent variable of the second stage utilizes the residual from the first stage, but the interpretation of the result remains the same as the first stage dependent variable.

Table 11: Outbreak effect on meat and poultry demand across outbreak period

Variable	Beef	Pork	Chicken	Turkey
Month0	-0.0256	-0.2951	0.0636^{*}	0.0481
	(0.0252)	(0.0740)	(0.0381)	(0.0372)
Month1	0.0189	-0.1594	0.0026	0.0183
	(0.0234)	(0.0995)	(0.0367)	(0.0481)
Month2	-0.0300	-0.0378	-0.0071	0.0712
	(0.0367)	(0.0817)	(0.0549)	(0.0518)
Month3	-0.0543^{*}	-0.1257	0.0219	0.1210^{***}
	(0.0317)	(0.0901)	(0.0542)	(0.0482)
Month4	-0.0240	-0.2143^{***}	0.0255	0.0665
	(0.0348)	(0.0885)	(0.0651)	(0.0474)
Observations		378,926		

Note: *** p<0.01, ** p<0.05, * p<0.1. Standard errors, derived by the delta method, are in parentheses. The presented results are from the second stage estimation of the Diff-in-Diff EASI demand system. The dependent variable of the second stage utilizes the residual from the first stage, but the interpretation of the result remains the same as the first stage dependent variable.

Appendix

A Poultry Market Equilibrium during Avian Flu Outbreaks

There are two ways that the avian influenza outbreak can impact the poultry market. First, the bird loss from the virus generates a left shift in the supply curve, increasing the equilibrium price. On the other hand, the increase in food scare may cause a left change in the demand curve given the trepidation of consuming ill poultry products and risk perception, showing a reduction in prices. Depending on whether the food scare effects overpower the supply shortage effect, the poultry product prices may reflect different results.

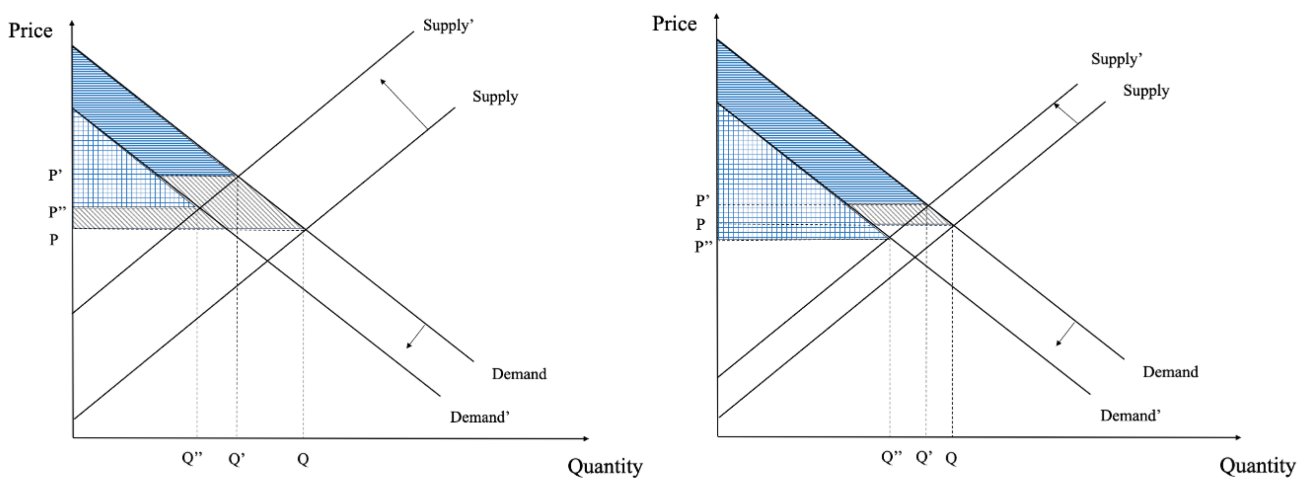

Figure A1: Demand-supply of poultry products during avian flu outbreak
Note: The left plot presents the scenario when the poultry market experiences a large supply shock which shifts the equilibrium price from P to P" (P">P). The right plot presents the scenario when the poultry market experiences a small supply shock which shifts the equilibrium price from P to P" (P"<P).

B Additional Tables and Figures

Table A1: First stage estimation

	Search	Search x Post	$\tilde{y}$	$\tilde{y}^2$	$\tilde{y}^3$
SARS	0.0978***	−0.1019***	0.0000	0.0001*	-0.0001
	(0.0015)	(0.0013)	(0.0000)	(0.0000)	(0.0001)
SARS x Post	2.1974***	2.5673***	−0.0005***	-0.0001	−0.0005**
	(0.0048)	(0.0041)	(0.0001)	(0.0001)	(0.0003)
$\tilde{y}\_inst$	0.0141	0.0942*	0.9826***	−0.0385***	0.1957***
	(0.0590)	(0.0500)	(0.0007)	(0.0013)	(0.0031)
$\tilde{y}^2\_inst$	0.0491	0.0518	−0.0052***	1.0009***	−0.0985***
	(0.0492)	(0.0417)	(0.0006)	(0.0011)	(0.0026)
$\tilde{y}^3\_inst$	0.0326	0.0089	0.0006*	0.0132***	0.9130***
	(0.0283)	(0.0240)	(0.0003)	(0.0006)	(0.0015)
F-stat	44561.67	102595.98	1043222.92	560862.43	463467.58
R^2	0.5615	0.7325	0.9366	0.8846	0.8651
Observations	378,926	378,926	378,926	378,926	378,926

Note: *** p<0.01, ** p<0.05, * p<0.1. Standard errors are in parentheses. The presented results are from the first stage estimation of the EASI demand system, where the outcomes are the search intensity for avian flu and stone index deflated expenditure.

Table A2: Avian flu information impact on meat and poultry demand with month fixed effect

	Beef	Pork	Chicken	Turkey
Search	-0.0015^{**}	-0.0014	0.0020^{*}	0.0021^{*}
	(0.0007)	(0.0018)	(0.0012)	(0.0012)
Search x Post	0.0018^{***}	0.0015	-0.0032^{***}	-0.0012
	(0.0006)	(0.0015)	(0.0010)	(0.0010)

Note: *** p<0.01, ** p<0.05, * p<0.1. The table reports EASI coefficients divided by the mean of budget shares of each meat category. Standard errors in parentheses were obtained via the delta method. The coefficients specify changes in purchase in response to a 1 percentage point increase in the index.

Table A3: Meat and poultry price and expenditure elasticity

	Beef	Pork	Chicken	Turkey
Beef	-0.7685	0.4249	0.6211	0.6592
	(0.0321)	(0.0807)	(0.0381)	(0.0470)
Pork	0.0666	-1.0001	0.0979	0.0482
	(0.0127)	(0.0541)	(0.0161)	(0.0197)
Chicken	0.3266	0.3283	-0.9182	0.1429
	(0.0200)	(0.0539)	(0.0436)	(0.0327)
Turkey	0.2691	0.1255	0.1110	-0.8842
	(0.0192)	(0.0512)	(0.0254)	(0.0496)
Expenditure	1.0863	0.3318	1.1404	0.2738

Note: All price elasticities are statistically significant at 0.01 level. Standard errors in parentheses were obtained via the delta method. The elasticities specify percent changes in purchase in response to a 1% increase in the price or expenditure.

Table A4: Meat and poultry elasticity result in previous literature

Research	Time	Meat	Own-Price Elas.	Exp Elas.
Zhao et al. (2023)	2017-2020 Monthly	Beef	-0.94	0.98
		Pork	-0.93	1.12
		Chicken	-0.92	1.00
		Turkey	-1.44	1.03
		Fish	-0.98	0.95
		Other meat	-0.90	0.94
Lee et al. (2020)	1984-2012 Biweekly	Beef	-1.35	0.78
		Pork	-1.07	0.68
		Poultry	-0.78	0.69
		Other meat	-0.67	0.71
Mutondo and Henneberry (2007)	1995-2005 Quarterly	Beef	-0.71	1.26
		Pork	-0.46	0.81
		Poultry	-0.30	1.04
Marsh, Schroeder and Mintert (2004)	1982-1998 Quaterly	Beef	-0.78	0.59
		Pork	-0.49	0.28
		Poultry	-0.08	-0.35
Tonsor, Mintert and Schroeder (2010)	1982-2007 Quaterly	Beef	-0.42	0.91
		Pork	-0.74	0.01
		Poultry	-0.09	-0.58
Taylor and Tonsor (2013)	2007-2011 Monthly	Beef	-0.72	1.06
		Pork	-2.38	1.09
		Chicken	-0.90	0.90
		Turkey	-3.51	0.54

Table A5: EASI result parameters with an instrument on avian flu search

	Beef		Pork		Chicken		Turkey	
Beef price	-0.0949***	(0.0143)	-0.0014	(0.0056)	0.0412***	(0.0089)	0.0389***	(0.0085)
Pork price	-0.0014	(0.0056)	-0.0049	(0.0038)	0.0066	(0.0038)	-0.0039	(0.0036)
Chicken Price	0.0412***	(0.0089)	0.0066	(0.0038)	-0.0356***	(0.0102)	-0.0165**	(0.0059)
Turkey Price	0.0389***	(0.0085)	-0.0039	(0.0036)	-0.0165**	(0.0059)	-0.0120	(0.0090)
Search	-0.0008**	(0.0003)	-0.0004**	(0.0001)	0.0006*	(0.0003)	0.0005**	(0.0002)
Search x Post	0.0010***	(0.0002)	0.0003*	(0.0001)	-0.0009***	(0.0002)	-0.0003	(0.0002)
$Adj - Logexpenditure$	0.0049	(0.0052)	-0.009***	(0.0025)	0.0017	(0.0060)	-0.0745***	(0.0065)
$Adj - Logexpenditure^2$	-0.0145***	(0.0036)	0.0193***	(0.0014)	-0.0252***	(0.0027)	0.0326***	(0.0028)
$Adj - Logexpenditure^3$	0.0145***	(0.0020)	-0.0107***	(0.0014)	-0.0017	(0.0021)	0.0085***	(0.0025)
Two member households	0.0227***	(0.0068)	-0.0073**	(0.0028)	-0.0114*	(0.0049)	-0.0061	(0.0054)
Three member households	0.0443***	(0.0093)	-0.0092**	(0.0031)	-0.0175**	(0.0059)	-0.0168**	(0.0064)
Four member households	0.0360***	(0.0086)	-0.0081*	(0.0033)	-0.0072	(0.0069)	-0.0191**	(0.0070)
Five member households	0.0451***	(0.0114)	-0.0082**	(0.0032)	-0.0011	(0.0089)	-0.0259***	(0.0078)
Six member households	0.0812***	(0.0134)	-0.0139***	(0.0038)	-0.0133	(0.0097)	-0.0414***	(0.0088)
20-30K income	-0.0082	(0.0096)	0.0022	(0.0026)	0.0003	(0.0064)	0.0079	(0.0078)
30-40K income	-0.0203*	(0.0092)	0.0025	(0.0031)	-0.0063	(0.0075)	0.0266**	(0.0082)
40-50K income	-0.033***	(0.0089)	0.0086*	(0.0040)	-0.0058	(0.0076)	0.0306***	(0.0077)
50-60K income	-0.0499***	(0.0106)	0.0116***	(0.0031)	-0.0052	(0.0078)	0.0436***	(0.0081)
60-70K income	-0.0334***	(0.0098)	0.0057	(0.0035)	-0.0000	(0.0089)	0.0347***	(0.0090)
70-100K income	-0.0517***	(0.0078)	0.0102**	(0.0034)	0.0051	(0.0070)	0.0464***	(0.0071)
100K income	-0.0747***	(0.0083)	0.0147***	(0.0035)	0.0148	(0.0078)	0.0602***	(0.0069)
Male head 30 years	-0.0163*	(0.0081)	-0.0248***	(0.0032)	0.0087	(0.0066)	0.0406***	(0.0061)
Male head 30-39 years	-0.0395*	(0.0168)	-0.0318***	(0.0051)	0.0135	(0.0115)	0.0700***	(0.0133)
Male head 40-49 years	-0.0293**	(0.0110)	-0.0202***	(0.0042)	0.0137	(0.0087)	0.0488***	(0.0087)
Male head 50-64 years	-0.0095	(0.0092)	-0.0217***	(0.0036)	0.0099	(0.0068)	0.0291***	(0.0061)
Male head 65 years	0.0044	(0.0081)	-0.0137***	(0.0032)	0.0068	(0.0065)	0.0063	(0.0052)
Female head 30 years	0.0332***	(0.0089)	-0.0194***	(0.0038)	-0.0189**	(0.0070)	0.0140	(0.0078)
Female head 30-39 years	-0.0042	(0.0129)	-0.0305***	(0.0048)	0.0024	(0.0099)	0.0461***	(0.0101)
Female head 40-49 years	-0.0041	(0.0099)	-0.0279***	(0.0033)	-0.0028	(0.0075)	0.0466***	(0.0076)
Female head 50-64 years	0.0121	(0.0089)	-0.0209***	(0.0034)	0.0019	(0.0070)	0.0192**	(0.0072)
Female head 65 years	0.0158	(0.0081)	-0.0162***	(0.0034)	-0.0027	(0.0062)	0.0129	(0.0068)
High school	-0.0100	(0.0160)	0.0014	(0.0061)	-0.0024	(0.0124)	0.0117	(0.0124)
College	-0.0537***	(0.0151)	-0.0032	(0.0063)	0.0035	(0.0123)	0.0484***	(0.0122)
Post college	-0.0726***	(0.0168)	-0.0035	(0.0068)	-0.0016	(0.0127)	0.0675***	(0.0134)
White	0.0278**	(0.0099)	0.0141***	(0.0028)	-0.0293***	(0.0067)	-0.0124	(0.0079)
Black	-0.084***	(0.0123)	0.0012	(0.0043)	0.0057	(0.0082)	0.0452***	(0.0100)
Asian	-0.0142	(0.0172)	0.0336***	(0.0067)	0.0096	(0.0155)	-0.0492***	(0.0137)
Second quarter	0.0310***	(0.0058)	0.0021	(0.0018)	0.0051	(0.0034)	-0.0184***	(0.0035)
Third quarter	0.0433***	(0.0036)	0.0022	(0.0019)	-0.0092**	(0.0032)	-0.014***	(0.0021)
Fourth quarter	0.0292***	(0.0030)	0.0098***	(0.0016)	-0.0196***	(0.0025)	-0.0042	(0.0025)
Constant	0.3949***	(0.0206)	0.0759***	(0.0081)	0.3696***	(0.0163)	0.0422*	(0.0171)

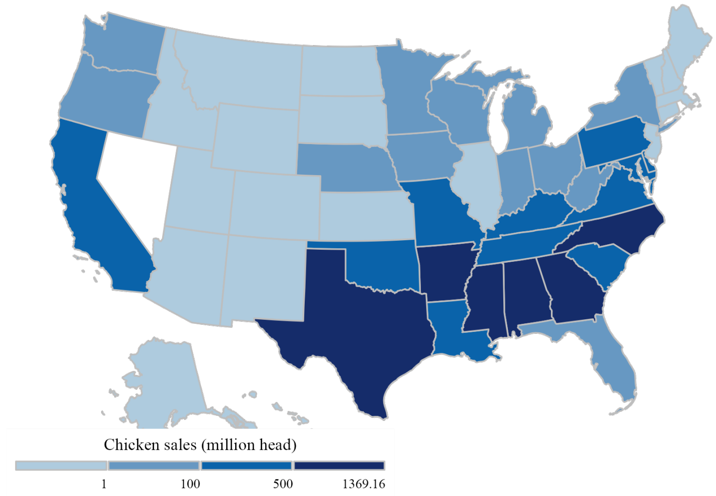

Figure A2: US broiler sales in 2012

Data Source: USDA, NASS

Note: The US broiler production is concentrated in the Southern States.

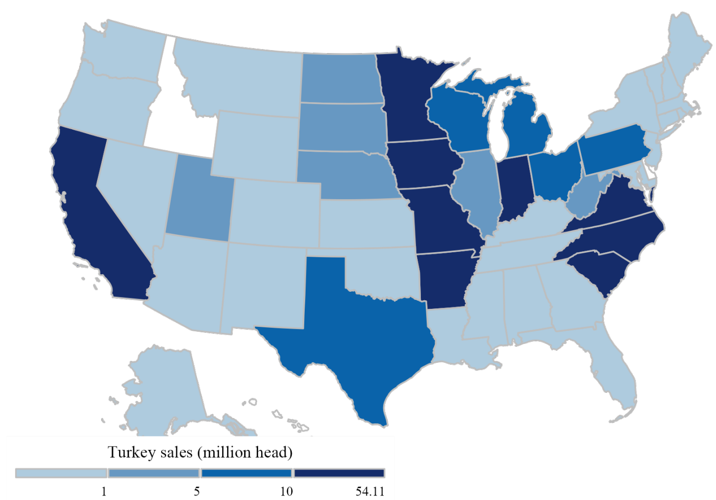

Figure A3: US turkey sales in 2012

Data Source: USDA, NASS

Note: The US turkey production is concentrated in the right of the Great Plains States.

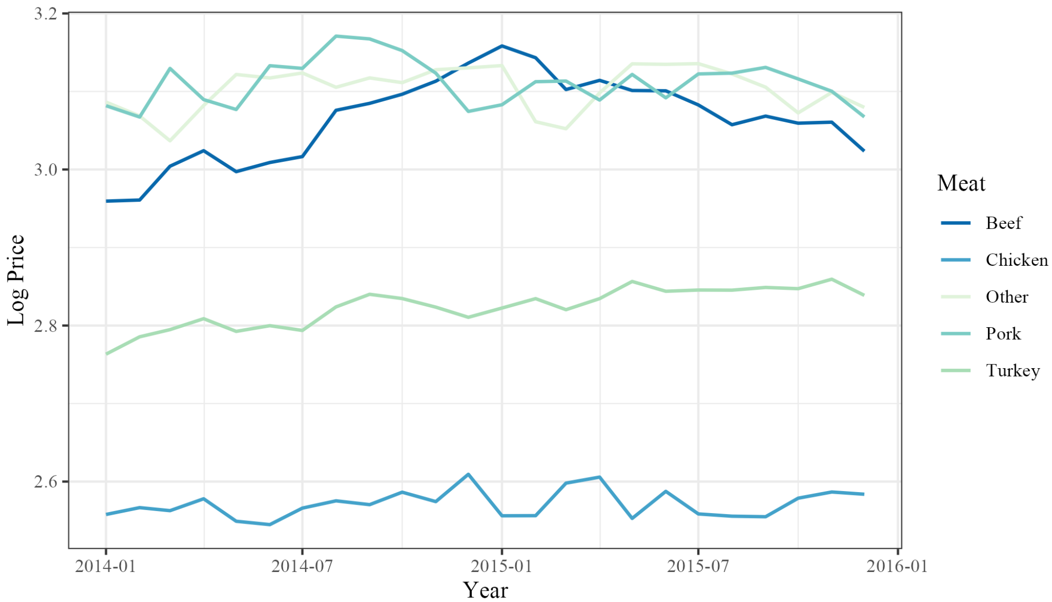

Figure A4: Average purchase price by meat types from 2014-2015

Data Source: Nielsen Homescan

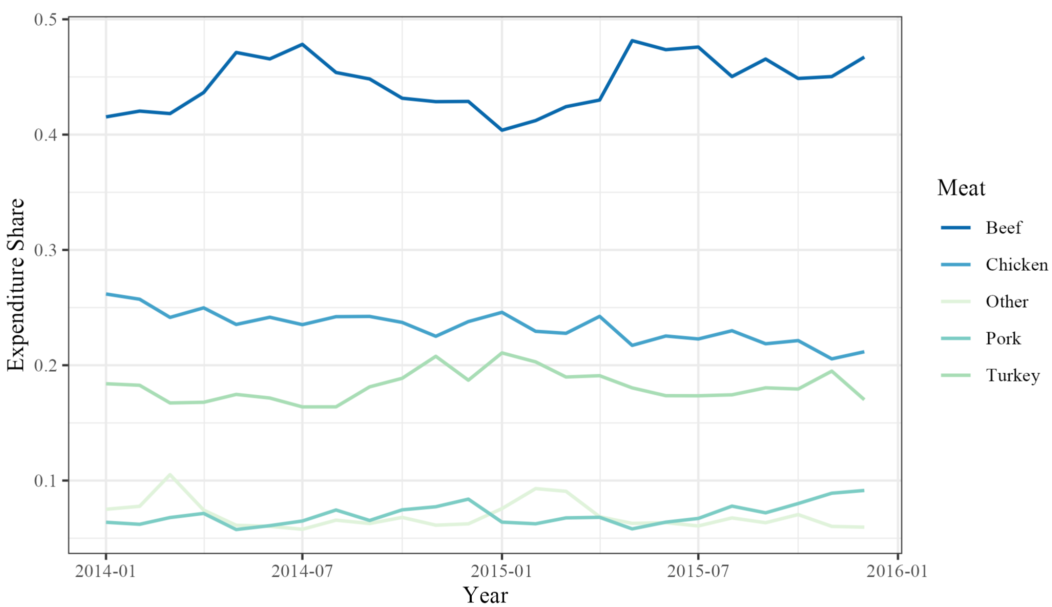

Figure A5: Average budget share by meat types from 2014-2015

Data Source: Nielsen Homescan

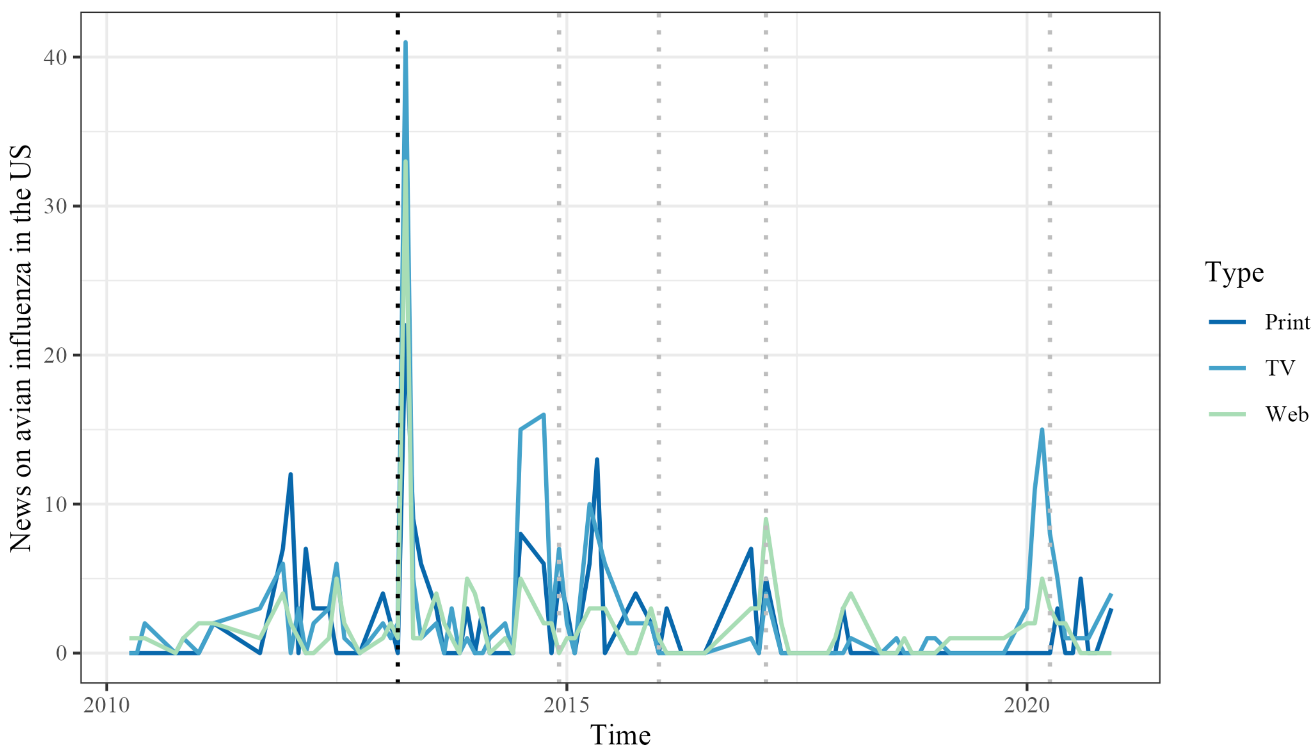

Figure A6: US avian flu news frequency from 2010-2020
Data Source: Nexis-Uni, Factiva, Newsstream
Note: The black and gray dotted line in the graph specify the international and domestic HPAI outbreak.

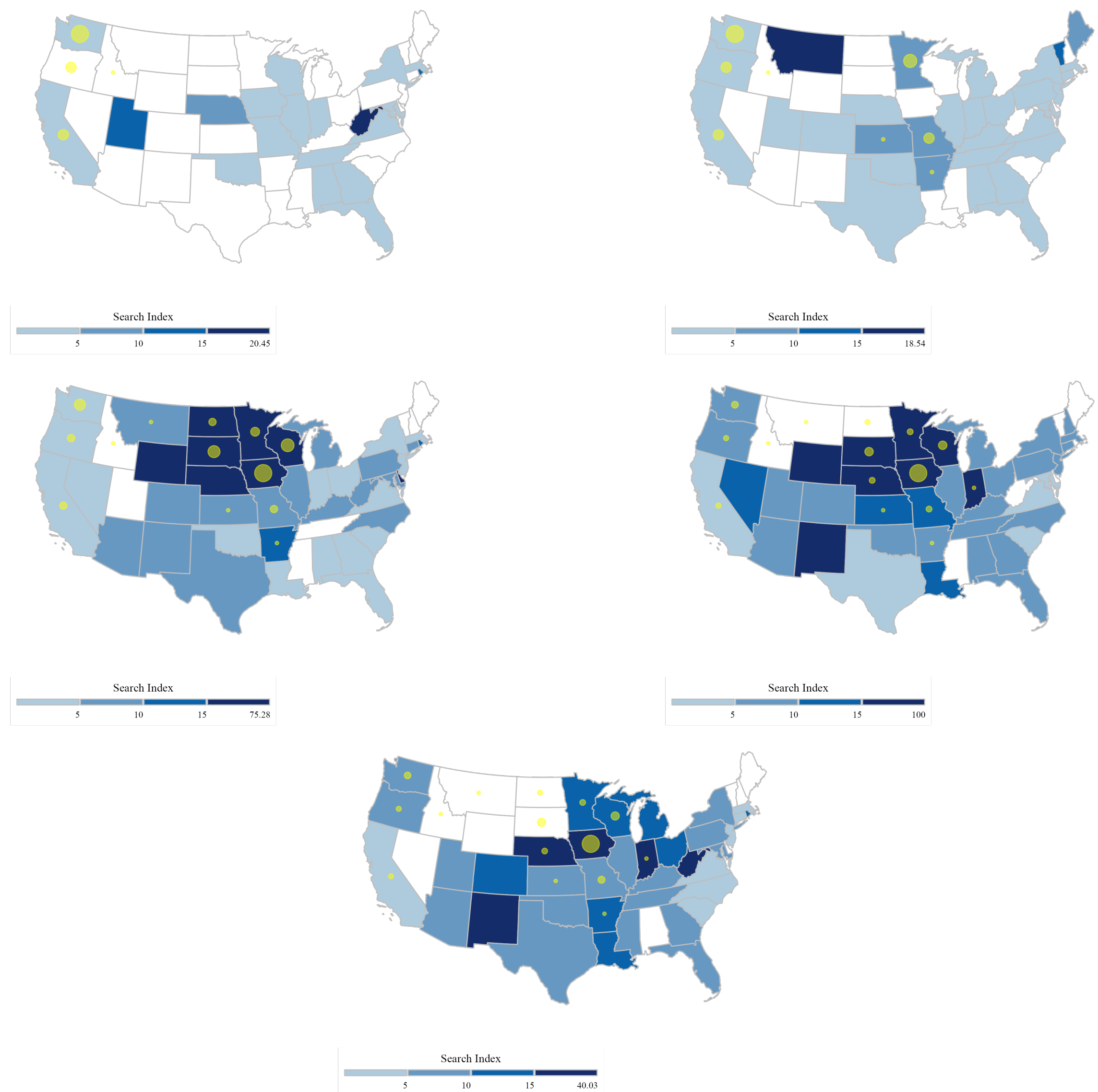

Figure A7: US Google search intensity for avian influenza from February 2015 to June 2015
Data Source: Google Trends
Note: Note: The plots demonstrate the state average Google search intensity from February to June 2015, starting from the top-left plot to the bottom.

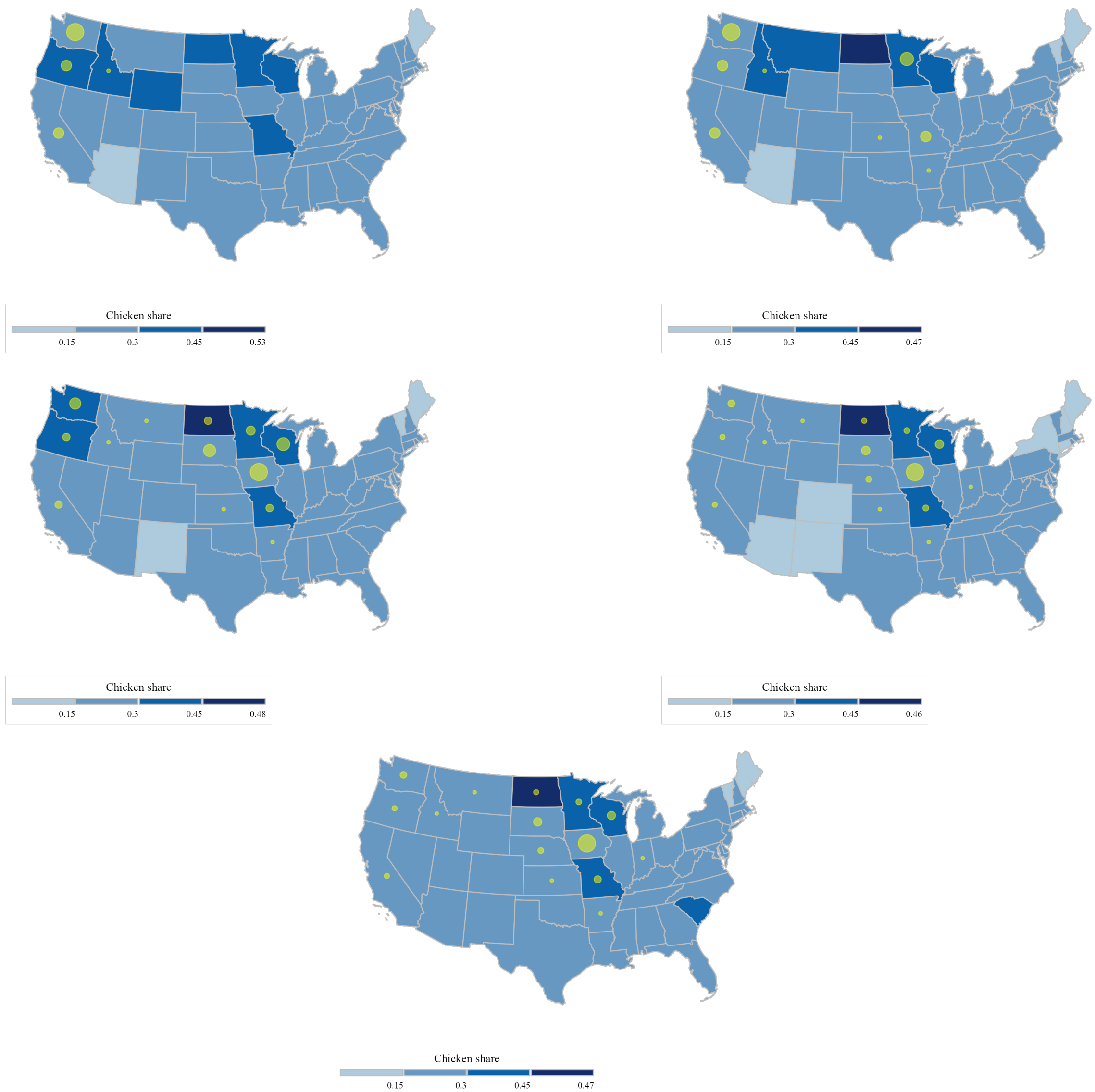

Figure A8: US chicken demand share from February 2015 to June 2015

Data Source: Nielsen Company

Note: The plots demonstrate the state average chicken demand from February to June 2015, starting from the top-left plot to the bottom.