U.S. DEPARTMENT OF AGRICULTURE

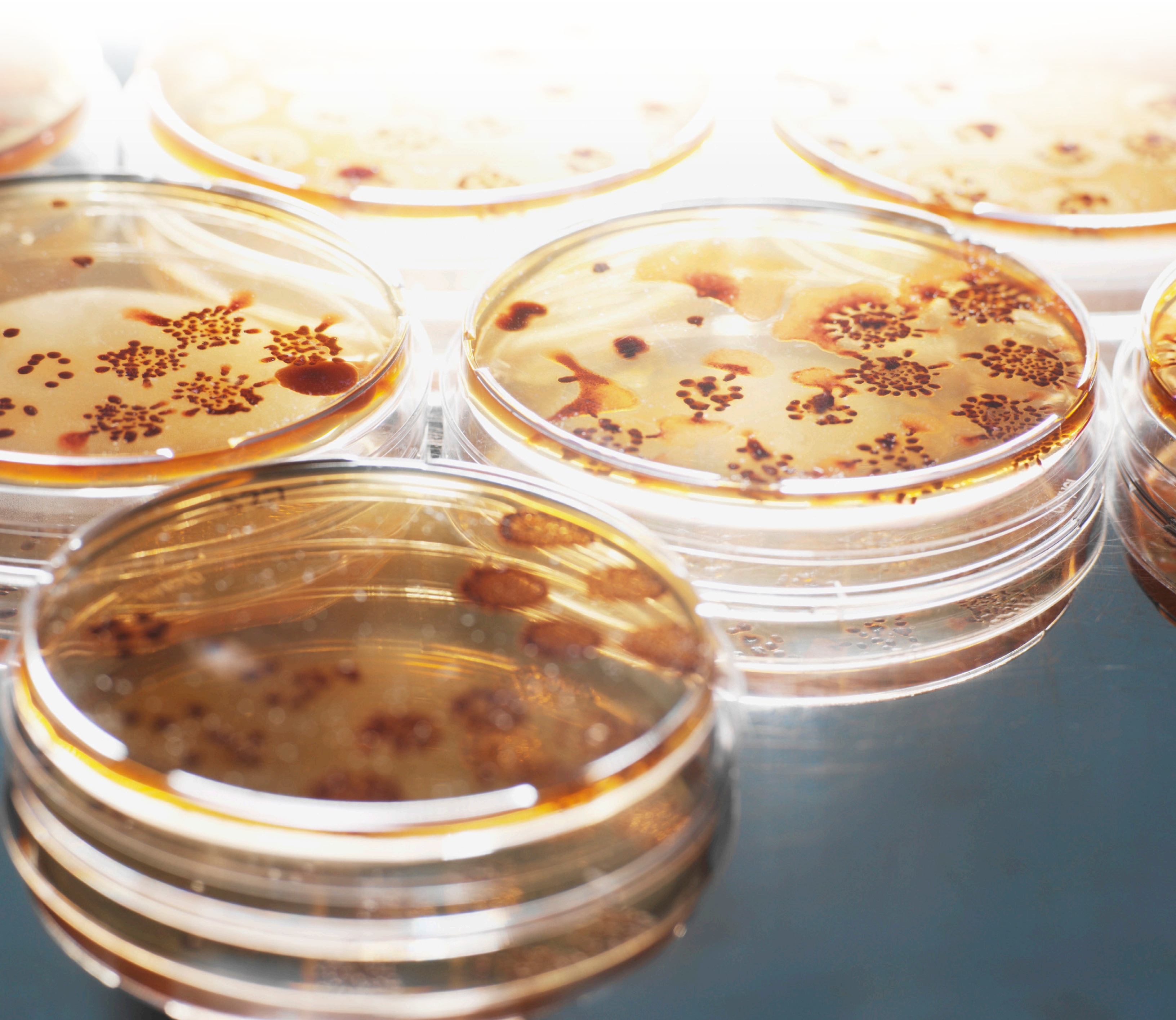
Economic
Research
Service

Economic
Research
Report
Number 284

February 2021

Attributing U.S. Campylobacteriosis Cases to Food Sources, Season, and Temperature

Sandra Hoffmann, Lydia Ashton, Jessica E. Todd,
Jae-wan Ahn, and Peter Berck



U.S. DEPARTMENT OF AGRICULTURE

Economic Research Service
www.ers.usda.gov

Recommended citation format for this publication:

Hoffmann, Sandra, Lydia Ashton, Jessica E. Todd, Jae-wan Ahn, and Peter Berck. February 2021. *Attributing U.S. Campylobacteriosis Cases to Food Sources, Season, and Temperature*, ERR-284, U.S. Department of Agriculture, Economic Research Service.

Cover photo image from Getty Images.

Use of commercial and trade names does not imply approval or constitute endorsement by USDA.

To ensure the quality of its research reports and satisfy governmentwide standards, ERS requires that all research reports with substantively new material be reviewed by qualified technical research peers. This technical peer review process, coordinated by ERS' Peer Review Coordinating Council, allows experts who possess the technical background, perspective, and expertise to provide an objective and meaningful assessment of the output's substantive content and clarity of communication during the publication's review.

In accordance with Federal civil rights law and U.S. Department of Agriculture (USDA) civil rights regulations and policies, the USDA, its Agencies, offices, and employees, and institutions participating in or administering USDA programs are prohibited from discriminating based on race, color, national origin, religion, sex, gender identity (including gender expression), sexual orientation, disability, age, marital status, family/parental status, income derived from a public assistance program, political beliefs, or reprisal or retaliation for prior civil rights activity, in any program or activity conducted or funded by USDA (not all bases apply to all programs). Remedies and complaint filing deadlines vary by program or incident.

Persons with disabilities who require alternative means of communication for program information (e.g., Braille, large print, audiotape, American Sign Language, etc.) should contact the responsible Agency or USDA's TARGET Center at (202) 720-2600 (voice and TTY) or contact USDA through the Federal Relay Service at (800) 877-8339. Additionally, program information may be made available in languages other than English.

To file a program discrimination complaint, complete the USDA Program Discrimination Complaint Form, AD-3027, found online at How to File a Program Discrimination Complaint and at any USDA office or write a letter addressed to USDA and provide in the letter all of the information requested in the form. To request a copy of the complaint form, call (866) 632-9992. Submit your completed form or letter to USDA by: (1) mail: U.S. Department of Agriculture, Office of the Assistant Secretary for Civil Rights, 1400 Independence Avenue, SW, Washington, D.C. 20250-9410; (2) fax: (202) 690-7442; or (3) email: program.intake@usda.gov.

USDA is an equal opportunity provider, employer, and lender.

U.S. DEPARTMENT OF AGRICULTURE

Economic Research Service

Economic
Research
Report
Number 284

February 2021

Attributing U.S. Campylobacteriosis Cases to Food Sources, Season, and Temperature

Sandra Hoffmann, Lydia Ashton, Jessica E. Todd,
Jae-wan Ahn, and Peter Berck

Abstract

This paper presents a new approach to estimating the relationship between consumption of specific foods and foodborne illness in the United States. We apply this approach to the case of foodborne sporadic campylobacteriosis illness. Most foodborne illness is sporadic and not part of a widespread outbreak. Foodborne *Campylobacter* infections are widely thought to be linked to chicken and are highly seasonal, primarily driven by temperature. We find that chicken purchased for consumption at home is not associated with sporadic *Campylobacter* infection in the United States, while ground beef and berries purchased for consumption at home are. The association between seasonality and the rate of *Campylobacter* infections is stronger than the association with temperature.

Keywords: *Campylobacter,* food source attribution, foodborne illness, big data, FoodNet surveillance, Homescan© purchase data, food exposures, foodborne disease epidemiology, food safety, poultry exposure, berries, leafy greens

Acknowledgments

The authors would like to thank the U.S. Centers for Disease Control and Prevention (CDC) for the use of FoodNet data. This research was supported by a cooperative agreement between the USDA's Economic Research Service (ERS) and the University of California, Berkeley, and by the intramural research program of ERS. We would also like to thank Dana Cole, USDA Animal and Plant Health Inspection Service, for the substantial contributions she made to this paper. We also appreciate the comments of five anonymous peer reviewers.

Contents

USDA
U.S. DEPARTMENT OF AGRICULTURE

A report summary from the Economic Research Service February 2021

USDA U.S. DEPARTMENT OF AGRICULTURE

Economic
Research
Service

Economic
Research
Report
Number 284

February 2021

Attributing U.S. Campylobacteriosis Cases to Food Sources, Season, and Temperature

Sandra Hoffmann, Lydia Ashton, Jessica E. Todd, Jae-wan Ahn, and Peter Berck

Attributing U.S. Campylobacteriosis Cases to Food Sources, Season, and Temperature

Sandra Hoffmann, Lydia Ashton, Jessica E. Todd, Jae-wan Ahn, and Peter Berck

What Is the Issue?

Each year, foodborne pathogens sicken roughly 48 million, or 1 in 6, Americans, causing more than $15.5 billion (in 2013 dollars) in economic damages. To efficiently manage efforts to prevent this, Government and industry need information about which foods are causing foodborne illnesses, an area of research called "food source attribution." Food safety and public health authorities have called for development of new methods to create a larger portfolio of approaches to studying food source attribution, which will provide a more reliable picture of the roles different food exposure routes play in foodborne disease. In particular, Federal agencies have emphasized the need for new methods that maximize the use of existing datasets and focus on sporadic illness. Sporadic illnesses are those not associated with wider outbreaks and account for more than 90 percent of foodborne illness in the United States. This study develops a new approach to food source attribution of sporadic campylobacteriosis in the United States using Homescan© daily consumer food purchase data. This type of data has not previously been used to study food source attribution. We chose to test this approach on campylobacteriosis because research indicates that sporadic foodborne campylobacteriosis may have different food exposure routes than outbreak cases.

What Did the Study Find?

We show using scanner data on daily consumer purchases can help determine which foods cause specific foodborne illnesses.

- We find that it is possible to estimate associations between campylobacteriosis and foods using data on daily food purchases.
- Different methods of studying the link between consumption of specific foods and foodborne illness can be expected to provide complementary information on outcomes, some confirmatory and others identifying new hypotheses.

This new food source attribution method confirmed the results of some previous studies and challenged others:

- Chicken prepared at home was not a campylobacteriosis risk factor, according to the results. This finding is consistent with a national case-control study that found consumption of chicken prepared in restaurants increased the risk of sporadic foodborne campylobacteriosis, but chicken prepared at home did not.
- Unlike prior U.S. studies, our results suggest that ground beef and berries purchased for consumption at home may be associated with increased risk of campylobacteriosis.
- Both ambient temperature and seasonality are independently associated with increased risk of sporadic campylobacteriosis in the United States.
- Geographic variation in sporadic campylobacteriosis persists even after controlling for variation in food purchases, ambient temperature, and the influence of seasonality.

How Was the Study Conducted?

We conducted cross-sectional time-series regression analysis of Foodborne Diseases Active Surveillance Network (FoodNet) illness data using household purchases of specific foods from the Nielsen Homescan© panel as explanatory variables, together with geographic region, temperature, and annual and seasonal fixed effects. FoodNet is an active surveillance program of the Centers for Disease Control and Prevention (CDC) and 10 State governments representing geographically diverse regions. It is the best available source of data about potentially foodborne sporadic illness in the United States and is widely used in case-control studies of foodborne illness. Homescan© collects data on purchases of food for home use from a panel of households located in both urban and rural areas across the United States. We studied foods purchased by consumers in counties that are in both FoodNet and Homescan© datasets. All food purchases were categorized based on prior research on foods associated with campylobacteriosis. Results are reported in terms of incidence rate ratios for daily campylobacteriosis incidence.

This study had to be conducted using data from 2000 to 2006 because in 2006, Homescan© stopped collecting quantity information on foods, like meat and fresh produce, that are sold by variable weight. The successor of Homescan©, IRI, now collects data on expenditures on these foods rather than quantities. ERS is working on developing methods to impute the quantity purchased from this expenditure data. Our study is primarily intended to explore how new data sources could be used to help us better understand food safety risks. But the timing of the data means the substantive results of our study are most useful to provide a picture of the recent risk factors for foodborne campylobacteriosis. They do add insights into persistent questions about the relative roles of specific food exposure routes, region, seasonality, and temperature in campylobacteriosis in the United States.

Attributing U.S. Campylobacteriosis Cases to Food Sources, Season, and Temperature

Introduction

Foodborne illness continues to be a major concern to consumers and the U.S. food industry. The U.S. Centers for Disease Control and Prevention (CDC) estimates that each year roughly 48 million, or 1 in 6, Americans contract a foodborne illness. Of these, approximately 128,000 are hospitalized and 3,000 die (Scallan et al., 2011). These illnesses and efforts to prevent them are costly to society. The USDA, Economic Research Service (ERS) estimates that the cost of illness from the 15 leading sources of foodborne pathogens is more than $15.5 billion (in 2013 dollars) (Hoffman et al., 2015). Consumers' response to outbreaks and other food safety events, such as food recalls, also affect the industry financially. For example, in a study of an *E. coli* O157:H7 outbreak in 2006 associated with spinach, Arnade et al. (2009) estimated that consumer expenditures on bagged spinach declined by $202 million in the 17 months following the outbreak. Even accounting for the increased sales of other leafy greens that consumers substituted for spinach, the leafy greens industry lost an estimated $60 million.

Since the mid-1980s, Federal food safety agencies have been working to develop ways to use information about risks to develop stronger and more effective food safety systems and management (National Academy of Sciences (NAS) 1985, 1987, 2003, 2009; Government Accountability Office (GAO) 1992; USDA, Food Safety and Inspection Service (FSIS) 1996, 2006; Food and Drug Administration (FDA) 2001). Recent efforts to improve the effectiveness of food safety policy have explicitly relied on information about the relative risks of foods (Batz et al., 2005). This information can be used to improve the speed of outbreak investigations and food recalls, to help food safety managers set priorities and to better target inspections. FSIS uses food-source attribution research to inform program priorities, develop strategic plans, and evaluate program performance (FSIS 2008, 2017a, 2017b). The Food Safety Modernization Act of 2011 requires the FDA and industry to use information on the riskiness of foods to inform all aspects of managing food safety—including setting standards, developing preventive control systems, and regulatory enforcement for both domestically produced and imported foods (FDA 2011).

These management improvements are supported by a relatively new area of research called food source attribution, which focuses on estimating the role different foods play in causing foodborne illnesses (Batz et al., 2005; Pires et al., 2014). Reviews of source attribution research conclude that multiple analytical methods are needed to get a reliable and complete picture of which foods cause specific foodborne illnesses campylobacteriosis (Pires et al., 2009, World Health Organization (WHO) 2012). The U.S. Interagency Food Safety Analytics Collaboration (IFSAC) was formed by FSIS, FDA, and CDC in 2011 to facilitate collaboration on the development of new analytical methods—including food source attribution methods—needed to support Federal food safety work (IFSAC 2011, 2012, 2016, 2017a, 2017b; CDC, 2019). IFSAC has identified a need to "develop new analytic approaches and models to maximize use of already available data" (IFSAC, 2017b).

Our study develops a new approach to food source attribution that productively exploits ERS' investments in household food purchase scanner data, a relatively new "big data" source (Einav et al., 2008). This type of data had not previously been used in food attribution research but is increasingly being used to study food demand and nutrition (Muth et al., 2020).[1] We use campylobacteriosis as a test case for this approach. *Campylobacter* is one of four priority pathogens in IFSAC's current strategic plan (IFSAC 2017b).

We meet a specific need for new source attribution methods to study sporadic foodborne illness not associated with outbreaks. CDC defines a foodborne outbreak as "an incident in which two or more persons experience a similar illness after ingestion of a common food" (CDC, 2011). For most pathogens, outbreaks account for a relatively small percentage of total cases. Fewer than 1 percent of campylobacteriosis cases, 5 percent of listeriosis and salmonellosis, and 19 percent of Shiga toxin producing *E. coli* (STEC: O157:H7) cases are associated with outbreaks (Ebel et al., 2016). The relative importance of sporadic cases has important implications for food source attribution. Research indicates that for some pathogens, such as sporadic and outbreak campylobacter illnesses may be caused by different food-exposure routes (Taylor et al., 2013; Friedman et al., 2004; Batz, 2005). Yet the primary food source attribution method used in the United States analyzes outbreak investigation data (Painter et al., 2013).

Attribution studies that focus on sporadic illness are mainly case-control studies relying on interviews with people who have been sick—and other people with similar demographic characteristics who did not get sick—to identify foods that may have caused the illness (Rothman et al., 2012). Respondent recall about past food consumption is known to have reliability problems (Decker et al., 1986; Mann, 1981). Using data on consumer food purchasing behavior, rather than relying on their dietary recall, allows us to simultaneously control for geographic region, temperature, annual variation, and season. This can provide insights into the relative influence of food exposure and other factors on the pronounced seasonality and regional variation seen in sporadic campylobacteriosis, which has not been possible using existing source attribution methods (Lal et al., 2012; Williams et al., 2010; Ailes et al., 2012).

---

[1] Muth et al. (2020) provide an excellent introduction to these data and their use in food policy research.

Related Research

Given that our main contribution is an expansion of approaches to identifying the sources of foodborne illnesses, we first summarize existing methods. We then summarize what the literature has found regarding food risks for sporadic campylobacteriosis and seasonal and regional differences in sporadic campylobacteriosis incidence in the United States and in other wealthy countries.

Review of Methodological Approaches

In a major review of source attribution methods, Pires et al. (2009) identified four main methods: (1) microbiological, (2) epidemiological, (3) intervention studies, and (4) expert elicitation. Other reviews of source attribution methods agree with the conclusions of Pires et al. (2009) that each has strengths, limitations, and specific data requirements (CDC, 2019; Pires et al., 2009; EFSA, 2008). In this section, we describe each of these major methods, their primary strengths and limitations, and their use in the United States.

Microbiological Methods

Microbial source attribution relies on the collection and genetic subtyping of microbial samples from patients and from foods or animals at multiple points in the food supply chain. Mathematical modeling is used to associate cases of illness with foods and, when possible, with animal reservoirs. The most advanced application of the method was developed for salmonellosis in Denmark (Hald et al., 2004). Microbial source attribution relies on reliable human disease surveillance and extensive isolate collection with sufficiently large and representative samples across potential food sources. Since 1999, Denmark has maintained an integrated system of *Salmonella* surveillance in humans, on foods, and on farms. This method also depends on there being heterogeneity in the pathogen genetic subtype. It has been used successfully for a limited number of pathogens, primarily *Salmonella* and *Campylobacter* (Pires et al., 2009; Dingle et al., 2001; French, 2007; Guo et al., 2011). The lack of integrated surveillance limits the application of this method in the United States. However, Guo et al. (2011) and Tyson (2016) applied microbial source attribution in the United States to estimate the proportion of human salmonellosis and campylobacteriosis attributable to chicken, beef, pork, eggs, and turkey by using data from FSIS sampling in slaughter and processing plants.

A related approach, comparative exposure assessment, combines sampling and testing with modeling of pathogen transmission routes. Models assessing *Campylobacter* exposure across multiple food exposure routes have been developed for the Netherlands (Evers et al., 2008) and New Zealand (McBride et al., 2005). Williams et al. (2010) constructed a monthly ground beef availability dataset to study relationships between the seasonal occurrence of *E. coli* O157:H7 in live cattle, ground beef, and humans in the United States. A lack of data on pathogen prevalence in different foods and disease reservoirs often limits the use of comparative exposure assessment. To develop their model, Williams et al. (2010) collected feces samples from five commercial feedlots over a 3-year period and relied on FSIS administrative data from sampling ground beef during processing-plant inspections.

Epidemiological Methods

Epidemiological approaches to source attribution include the use of case-control, cohort, case-series, and ecological studies to analyze surveillance data on sporadic cases and the analysis of outbreak investigation data. Case-control studies ask people with similar demographic characteristics who are ill and who are not ill about their exposure to known or suspected risk factors (Rothman et al., 2012). They use this information to estimate the impact of the exposure on whether people become ill. When a large number of individual case-control studies have been conducted, systematic review and meta-analysis provide a means of aggregating results from multiple studies (Domingues et al., 2012). Case-control studies are generally viewed as one of the stronger types of epidemiological evidence (Omair, 2015). They are designed to identify the specific exposures relevant to cases included in the study and are not generally designed to partition disease across all likely food exposure routes (Batz, 2005). In studying food exposures as risk factors, case-control studies rely on respondents' ability to recall their past food consumption. As noted above, dietary recall has proven difficult for individuals (Decker et al., 1986; Mann, 1981). Because case-control study surveys focus on known or suspected risk factors, another potential weakness is that they may not identify unsuspected risk factors. We are aware of only one national and two State-level case-control studies of campylobacteriosis in the United States (Friedman et al., 2004; Davis et al., 2013; Potter et al., 2003). Results of these studies are discussed below.

Analysis of outbreak investigation data has been used to partition foodborne illness across a wide range of food exposures (Painter et al., 2013). The purpose of outbreak investigations is to find the cause of the disease outbreak. For potentially foodborne pathogens, investigations must determine if the outbreak is foodborne and which specific foods are the exposure source. A strength of this method is that outbreak investigations provide direct evidence of association between food exposure and illness, but the method has limitations. Small outbreaks and outbreaks involving mild illness or illnesses with long incubation periods are less likely to be reported. In addition, as discussed above, most foodborne illnesses are sporadic, not outbreak-associated (Ebel et al., 2016), and the foods that cause outbreaks may be different from those that cause sporadic illnesses, particularly for campylobacteriosis. (Batz et al., 2005). Aggregate data from multiple years of U.S. outbreak investigations of pathogens, including *Campylobacter*, have been used to partition foodborne outbreak cases across multiple food exposure routes (Painter et al., 2013).

Our method, which relies on multivariate statistical analysis, is referred to as an "ecological study" in epidemiology.[2] We found a small number of ecological studies used to assess the risk factors influencing campylobacteriosis rates, but few that did food source attribution (Patrick et al., 2004; Kovats et al., 2005; Goldstein et al., 2016). Most studied the influence of regional differences and weather on campylobacteriosis rates (Goldstein et al., 2016; Soneja et al., 2016). Cha et al. (2016) performed an ecological study to examine differences in the food sources of campylobacteriosis in urban and rural areas of Michigan using data on food consumption collected since 2011 as part of a State campylobacteriosis surveillance program.

---

[2] The term "ecological study" is used in epidemiology to refer to studies of factors that affect health risks or outcomes based on populations that are defined either geographically or temporally or both. Economists think of these as multivariate regression analysis of the factors affecting health outcomes.

Intervention Studies

Intervention studies are used primarily to estimate the risk attributable to specific exposures. Interventions may be specifically designed treatments or trials, such as the Danish effort to reduce *Salmonella* prevalence in poultry flocks and swine herds (Pires et al., 2009), or they may be natural experiments created by a change in exposure or behavior. For example, the withdrawal of chicken and eggs from Belgium food markets in 1999 due to dioxin contamination of chicken feed provided a natural experiment that allowed estimation of the percent of campylobacteriosis attributable to chicken consumption in Belgium (Vellinga and Van Loock, 2002). We are not aware of any U.S. intervention studies used for foodborne disease source attribution.

Expert Elicitation Methods

Finally, structured expert elicitation is a means of eliciting and aggregating expert judgment and is used where there are significant data gaps or deficiencies (Cooke and Shrader-Frechette, 1991). Expert elicitations have been used for source attribution studies in the United Kingdom (Henson, 1997), the United States (Hoffmann et al., 2007), the Netherlands (Havelaar et al., 2008), New Zealand (Lake et al., 2010), and recently by the WHO in estimating the global burden of foodborne disease (Hoffmann et al., 2017). Expert elicitation provides a transparent, rigorous alternative to modelers using their judgments about critical model parameters but is not a replacement for primary data and research (Goldstein, 2014; EPA, 2012; Colson and Cooke, 2018). Expert elicitation can also identify areas where experts believe other methods provide biased assessments. A U.S. expert elicitation found a significant difference between outbreak investigation and expert judgment food-source attribution estimates for U.S. foodborne campylobacteriosis (Batz et al., 2012). According to outbreak investigations, 51 percent of U.S. foodborne outbreak-associated campylobacteriosis cases from 1999 through 2008 were attributed to consumption of (mostly unpasteurized) dairy and 18 percent to poultry consumption. In a formal elicitation study of experts' judgment, 72 percent of total foodborne campylobacteriosis cases were attributed to poultry, 7.8 percent to dairy, and 5.2 percent to produce (Batz et al., 2012).

Food Risk Factors

The question of which foods are the greatest risk factors for foodborne *Campylobacter* infections in the United States is not settled. A leading hypothesis has been that poultry is the primary source of foodborne *Campylobacter* infection and that vegetables are cross-contaminated during food preparation on kitchen surfaces or with utensils previously contaminated by raw poultry (Cools et al., 2005). In a recent analytical review of the past decade's research on the causes of *Campylobacter* infections, Nelson and Harris (2017) argue that foodborne *Campylobacter* exposure routes are more diverse than implied by the poultry hypothesis.

The principal method used to study food risks of sporadic campylobacteriosis illnesses has been case-control studies. Table 1 summarizes statistically significant findings on foods as risk factors for sporadic campylobacteriosis from U.S. and non-U.S. studies. These studies indicate that the type of food consumed, how it is processed, and where it is prepared all affect risk of campylobacteriosis. In interpreting the applicability of study results from outside the United States, it is worth noting that Skarp et al. (2016) found that estimated campylobacteriosis rates are much lower in the United States (13.5/100,000 population) than in Europe (28.9/100,000 to 104/100,000), or Australia or New Zealand (112.3/100,000 to 152.9/100,000). It is unknown whether this is due to differences in surveillance and health care or differences in foodborne or other exposures. In addition, Powell's 2016 analysis of trends in FoodNet surveillance data showed a sharp decline in U.S. cases of campylobacteriosis between 1996 and 2001, coincidental with implementation of Hazard and Analysis Critical Control Point (HACCP)[3], followed by relative stability during our study period (2000-06).

We look first at risk associated with poultry and non-poultry meat consumption. In a U.S. study of foodborne outbreak cases from 1997-2008, Taylor et al. (2013) found that 11 percent of cases were attributable to poultry and 2 percent to red meats. In European studies of sporadic illness, consumption of poultry was generally associated with increased campylobacteriosis risk (table 1). U.S. case-control studies found that the risk of sporadic campylobacteriosis increases with the consumption of meat, including poultry, if it is prepared in a restaurant, but not if it is prepared at home (table 1). Two U.S. studies found that handling raw poultry or consuming undercooked chicken increased risk. Freezing has been shown to decrease *Campylobacter* prevalence on chicken effectively enough that freezing is used as a means of controlling *Campylobacter* (Georgsson et al., 2006; Archer, 2004; Baker et al., 2006; Tustin et al., 2011). A Danish case-control study found that eating chicken that was not frozen when purchased greatly increased risk (Wingstrand et al., 2006). None of the case-control studies looked at the effect of freezing on campylobacteriosis risk. There is some indication from non-U.S. studies that consumption of cooked red meats (beef, pork, lamb/mutton) reduced campylobacteriosis risk and that eating undercooked or raw non-poultry meats increased it. *Campylobacter* is known to be adversely affected by oxygen, suggesting that ground meat should pose a lower risk than whole cuts. Vipham et al. (2012) found that *Campylobacter* prevalence in whole cuts of beef from U.S. retail stores was more than double that found in ground beef. Yet case-control studies in the United States and Europe show higher risk of campylobacteriosis associated with ground non-poultry meat and lower risk with whole cuts. Kuhn (2018) hypothesized that Norway's introduction of a packaging process that lowers the oxygen concentration in ground meat to extend shelf-life may have promoted *Campylobacter* survival.

Taylor et al. (2013) found that 5 percent of U.S. foodborne campylobacteriosis outbreak cases were attributable to produce. Studies of sporadic illness show mixed evidence about risk from produce. U.S. case-control studies found that consumption of strawberries and, more generally, of berries purchased at stores reduces the risk of campylobacteriosis, while European studies found that consumption of strawberries increased campylobacteriosis risk (table 1). European studies found that fruits like apples and pears, which tend to be eaten unpeeled, reduced risk. An Arizona study found that cantaloupe consumption increased campylobacteriosis risk. In a Danish study, daily consumption of raw vegetables reduced campylobacteriosis risk, but consumption of chives increased it. A Dutch risk assessment found *Campylobacter* prevalence levels in fruits and vegetables at retail were adequate to pose a meaningful risk given the amount of fruits and vegetables consumed (Verhoeff-Bakkenes et al., 2011). The Dutch study also found the prevalence of the *Campylobacter* in packaged raw vegetables was about 50 percent higher than in nonpackaged raw vegetables. A similar study in Canada did not find elevated *Campylobacter* prevalence on leafy greens or herbs (Denis et al., 2016).

---

[3] HACCP is a management system in which food safety is addressed through the analysis and control of biological, chemical, and physical hazards—from raw material production, procurement, and handling, to manufacturing, distribution, and consumption of the finished product (USDA, 1997). USDA has required HACCP systems for meat and poultry processing since 1999. FDA started supporting a voluntary program for HACCP in dairy processing in 1999 as well. Other foods came under HACCP requirements or guidance in the 2000s: fish and seafood processing in 2001, juice in 2004, and fresh-cut produce in 2007 (North Dakota State University, Food Law).

Pasteurization is a highly effective pathogen control. A study of U.S. campylobacteriosis outbreak investigation data found that 29 percent of foodborne outbreak-associated cases were caused by the consumption of unpasteurized milk (Taylor et al., 2013), while a Dutch case-control study found the consumption of pasteurized milk and dairy products associated with reduced campylobacteriosis risk (table 1). An Arizona case-control study found that consumption of queso fresco, an unpasteurized cheese, substantially increased sporadic campylobacteriosis risk.

Campylobacteriosis risk associated with the consumption of fish and seafood may depend on whether it is cooked. Taylor et al. (2013) found that 2 percent of U.S. foodborne campylobacteriosis outbreak cases were associated with eating seafood. European case-control studies of sporadic illnesses found the consumption of fish and seafood associated with reduced risk of campylobacteriosis (table 1). The U.S. national case-control study found that consumption of raw seafood was associated with increased risk.

Seasonal and regional differences in campylobacteriosis

The incidence of total campylobacteriosis cases in temperate climates, including the United States, shows distinct summer peaks (Nylen et al., 2002; Miller et al., 2004; Kovats et al., 2005; Tam et al., 2006; Weisent et al., 2010; Strachan et al., 2013; Patrick et al., 2018). There is also regional variation within and between countries (Miller et al., 2004; Louis et al., 2005). Despite substantial research, the reasons for this seasonal and regional variation are still undetermined.

Seasonality and Temperature

Season is broadly associated with temperature, but the influence of temperature on pathogen growth may occur at much smaller time scales. Season may also influence campylobacteriosis risk through seasonal variations in human behavior, food sourcing, or changes in natural ecosystems. The influences of season and temperature have not been clearly distinguished in studies of campylobacteriosis risk.

Table 1

Results from prior research on Campylobacteriosis food risk factors

	Location studied											
	U.S. (national)[a]	Arizona[b]	Washington[c]	Michigan[d]	Denmark[1]	Denmark[2]	Germany[3]	France[4]	Netherlands[5]	Netherlands[6]	Norway[7]	Australia[8]
Food consumed												
Non-poultry meat or chicken prepared at home	0.7											
Poultry prepared at a restaurant	2.2											
Eating poultry			0.2									
Handling raw poultry		4.88	0.3									
Fried chicken or turkey prepared at home	0.5											
Consumed any chicken							1.6		1.5		1.69	
Chicken bought unfrozen					5.8							
Chicken in January-March										3		
Chicken cooked												1.4
Undercooked chicken	2.1											4.7
Turkey					1.4							
Turkey bought fresh					1.75							
Undercooked meat									2.1	2	1.74	
Meat prepared at a restaurant	1.7											
Ground meat				1.4								
Beef							0.7	0.56				
Roast beef		0.1										
Undercooked beef								1.86				
Eating minced beef						2.6						
Steak tartare										1.5		
Pork prepared in large pieces					0.1							
Lamb/mutton							0.6					
White bread					3.21							
Produce												protective
Raw vegetables eaten daily					0.24							
Chives					2.78							
Unpeeled fruit							0.6		0.7			
Apples and pears					0.21							
Cantaloupe		7.64										

Continued—

Table 1

Results from prior research on Campylobacteriosis food risk factors—continued

	Location studied											
	U.S. (national)[a]	Arizona[b]	Washington[c]	Michigan[d]	Denmark[1]	Denmark[2]	Germany[3]	France[4]	Netherlands[5]	Netherlands[6]	Norway[7]	Australia[8]
Food consumed												
Fresh strawberries					1.69	5.3						
Fresh berries bought at a store	0.6											
Blueberries		0.15										
Pasteurized milk or dairy product									0.8 to 0.6			
Queso fresco		7.11										
Eggs and dairy												0.5
Seafood									0.5			
Raw seafood	1.9											
Fresh fish												0.7

Note: [a]Friedman et al. 2004; [b]Pogreba-Brown 2016; [c]Davis et al. 2013; [d]Cha et al. 2016. [1]Wingstrand et al. 2006; [2]Kuhn et al. 2018; [3]Rosner et al., 2017; [4]Gallay et al. 2008; [5]Mughini Gras et al. 2012; [6]Doorduyn et al., 2010 (case type not specified); [7]MacDonald et al., 2015; [8]Stafford et al., 2007 (case type not specified). These are case-control studies of sporadic cases unless otherwise indicated.

Source: USDA, Economic Research Service.

Higher temperatures may contribute to higher *Campylobacter* prevalence in animal populations or water—or to more temperature abuse in food transport, storage, or handling (Jore et al., 2010; Boysen, 2011). A small set of studies found that higher temperatures are associated with higher rates of campylobacteriosis. Louis et al. (2005) found that higher average weekly temperature in England and Wales between 1990 and 1999 correlated with higher incidence of campylobacteriosis but found no difference in the influence of average weekly temperature compared to a 1-, 2-, or 3-week lagged average weekly temperature. A second study of England and Wales found higher ambient temperature 2 weeks prior to illness was associated with increased campylobacteriosis (Djennad, 2017). In a multi-country study (European Union (E.U.), Canada, Australia, and New Zealand), Kovats et al. (2005) found only temperature 10-14 weeks prior to infection was significant. A Danish study found that a combination of the average and maximum ambient temperature 4 weeks before the illness provided the best model for predicting human campylobacteriosis incidence (Patrick et al., 2004). In contrast, Arsenault (2012) found that warmer temperatures decreased campylobacteriosis risk in Quebec.

Seasonality could play an independent role from temperature since human activities that increase exposure to *Campylobacter* also vary seasonally. Travel, swimming in untreated water, playing in playgrounds, and direct contact with livestock, other animals, and flies tend to vary seasonally, and all are associated with increased rates of campylobacteriosis (Whiley et al., 2013; Neal et al., 1995; Mullner et al., 2010; Ekhald et al., 2005; Friedman et al., 2004; Kuhn et al., 2018; Schonberg-Norio et al., 2004; Doorduyn et al., 2001; Domingues et al., 2012; Nichols, 2005;Vereen et al., 2007). Method or location of food preparation that affects foodborne *Campylobacter* exposure also vary seasonally. Cooking meat on outdoor grills was associated with increased risk of campylobacteriosis in several studies of primary data and a meta-analysis of case-control studies (Domingues et al., 2012; Kuhn et al., 2018; Mughini Gras et al., 2012; Doorduyn et al., 2010; MacDonald et al., 2012). However, a Canadian study found that attending a barbecue was associated with lowered risk of campylobacteriosis (Ravell et al., 2016).

Two studies that tried to distinguish between the influence of temperature and seasonality on the temporal pattern of campylobacteriosis produced differing results. In testing for alternative specification of temperature lags in a time-series analysis, Tam et al. (2006) found that after controlling for season and year, average temperature during the 6 weeks prior to infection had the greatest influence on campylobacteriosis risk in England and Wales during the 1990s. Soneja et al. (2016) found that campylobacteriosis increased in summer but did not find an association between monthly extreme heat or precipitation events and monthly campylobacteriosis cases once seasonality was accounted for in Maryland during 2000-12.

Williams et al. (2015) found evidence that seasonal increases in chicken contamination levels may not explain the seasonal pattern of human *Campylobacter* cases in the United States. David et al. (2017) concluded that the summer increase in campylobacteriosis in Canada was driven more by changes in human activities, such as increased outdoor recreational activities, than increases in either food or water contamination. A global review of studies in wealthy countries suggests that both humans and chickens acquire *Campylobacter* from a common, possibly environmental, source (Skarp et al., 2015) that increases *Campylobacter* prevalence during summer.

Regional Variation

There is substantial variation in sporadic campylobacteriosis incidence between FoodNet sites (Patrick et al., 2018). Ailes et al. (2012) found no statistically significant differences across FoodNet sites in medical care-seeking or stool sample submission, actions that lead to a case being reported in FoodNet. They did find differences across FoodNet sites in exposure to four risk factors (eating chicken in a restaurant, contact with animal stool, drinking untreated water, and contact with a farm animal), but these exposure differences were not associated with differences in campylobacteriosis rates across FoodNet sites. A number of studies using FoodNet data have found that the incidence of campylobacteriosis is higher in rural areas (Cha et al., 2016; Pasturel et al., 2013; Geissler et al., 2017). Proximity to broiler and dairy operations have been linked to higher campylobacteriosis rates, as have contact with ruminants and use of well water, all of which are higher in rural areas (Pasturel et al., 2013; Goldstein et al., 2016). Considering both their findings regarding FoodNet sites and other studies of spatial variation in campylobacteriosis, Ailes et al. (2012) concluded that geographic variation in campylobacteriosis in the United States is real—not an artifact of differences in disease surveillance—but is not well understood and needs further study.

Methods

This section describes the method developed in our study. We first describe the data the study builds on. We then present the statistical model we use to analyze this data.

Data

We use two main sources: data on sporadic cases of campylobacteriosis from FoodNet and data on household purchases of food from retail stores, generally intended for at-home consumption, collected by Nielsen Homescan©. Each dataset is described in this section, along with a description of how we paired them for analysis.

FoodNet Data

The Foodborne Diseases Active Surveillance Network (FoodNet) is a collaborative effort of the CDC, 10 State departments of public health, FSIS, and FDA (CDC, 2013a) that conducts population-based active surveillance of laboratory-diagnosed cases of illness caused by eight major pathogens commonly transmitted through food.[4] FoodNet collects information on the pathogen identified, the date a stool specimen is submitted, and whether a case was associated with an outbreak. FoodNet does not determine whether an infection was acquired through food. While these eight pathogens are leading causes of foodborne illness, they also can be transmitted through other exposure routes. FoodNet data has been used extensively in case-control and cohort studies (Friedman et al., 2004; Fullerton et al., 2007; Kimura, 2004; Kassenborg, 2004; Voetsch, 2007). In our analysis, we use only data on sporadic (non-outbreak-associated) cases.

FoodNet surveillance, which is county-based, grew gradually across the country, beginning in 1996 in Minnesota, Oregon, and select counties in California, Connecticut, and Georgia. Colorado joined FoodNet in 2000 and New Mexico joined in 2004 (table 2). By 2000, the number of counties participating within each participating State had stabilized, and the surveillance area has remained unchanged since 2004 (table 2).

---

[4] In active surveillance systems, public health officials proactively contact laboratories and health care providers on a regular basis to identify new cases of illness. This contrasts with the far more widely used passive surveillance, which relies on care providers to voluntarily report cases of illness to local health authorities. Active surveillance is designed to decrease the underreporting seen in passive surveillance systems but is still an undercount of total illness because only ill individuals who seek health care are identified. FoodNet routinely conducts periodic audits to ensure that all cases seeking care in each FoodNet catchment area are reported (CDC, 2018).

Table 2

Foodborne Diseases Active Surveillance Network (FoodNet) Surveillance Area, by State and county, 1996–2015

State	County	Year								
		1996	1997	1998	1999	2000	2001	2002	2003	2004-15
California	Original counties (Alameda and San Francisco)	●	●	●	●	●	●	●	●	●
	Added county (Contra Costa)					●	●	●	●	●
Colorado	Original counties (Adams, Arapahoe, Denver, Douglas, and Jefferson)						●	●	●	●
	Added counties (Boulder and Broomfield)							●	●	●
Connecticut	Original counties (Hartford and New Haven)	●	●	●	●	●	●	●	●	●
	Rest of State			●	●	●	●	●	●	●
Georgia	Original counties (Clayton, Cobb, DeKalb, Douglas, Fulton, Gwinnett, Newton, and Rockdale)	●	●	●	●	●	●	●	●	●
	Added counties (Barrow, Bartow, Carroll, Cherokee, Coweta, Fayette, Forsyth, Henry, Paulding, Pickens, Spalding, and Walton)		●	●	●	●	●	●	●	●
	Rest of State				●	●	●	●	●	●
Maryland	Orginal counties (Anne Arundel, Baltimore, Baltimore City, Carroll, Harford, and Howard)			●	●	●	●	●	●	●
	Added counties (Montgomery and Prince George's)						●	●	●	●
	Rest of State							●	●	●
Minnesota	All counties	●	●	●	●	●	●	●	●	●
New Mexico	All counties									●
New York	Original sites (Genesee, Livingston, Monroe, Ontario, Orleans, Wayne, and Yates)			●	●	●	●	●	●	●
	Added counties (Albany, Columbia, Greene, Montgomery, Rensselaer, Saratoga, Schenectady, and Schoharie)				●	●	●	●	●	●
	Added counties (Erie, Niagara, and Wyoming)							●	●	●
	Added counties (Allegany, Cattaraugus, Chautauqua, Chemung, Schuyler, Seneca, Steuben, Warren, and Washington)								●	●
	Added counties (Clinton, Delaware, Essex, Franklin, Fulton, Hamilton, and Otsego)									●
Oregon	All counties	●	●	●	●	●	●	●	●	●
Tennessee	Original counties (Cheatham, Davidson, Dickson, Hamilton, Knox, Robertson, Rutherford, Shelby, Sumner, Williamson, and Wilson)					●	●	●	●	●
	Rest of State								●	●

Source: U.S. Centers for Disease Control and Prevention.

Food Purchase Data and Food Categories

Our empirical approach relies on having detailed data on daily food purchases as a proxy for food consumption. This detail allows us to aggregate data on food purchases into categories that are relevant to studying food source attribution. We obtain this data from the Nielsen Homescan© panel. Households in the panel are asked to report all their food purchases from all retail outlets, including farmers' markets and convenience stores. Participants enter information on purchases either by using a hand-held scanner to scan package barcodes or manually entering information for items without barcodes. The final data contain details about each item purchased, including a detailed description of the food, date, and quantity purchased, package size, form when purchased (e.g., canned, fresh, or frozen), and other descriptive characteristics. A key advantage to the Homescan© data is that between 1998 and 2006, Nielsen collected detailed information about foods purchased in varying weights (random-weight items), such as fresh meats, produce, and some deli items (potential sources of foodborne pathogens).[5] The dataset includes information on the location of each household at the ZIP code level. A limitation of the data is that it collects data only on food purchases taken home; it does not collect data on food consumed away from home (Muth et al., 2020).

Homescan© provides population weights to allow users to estimate food purchases that are representative in a particular market. We assume all counties within a Homescan© market, including all FoodNet counties in the market, have the same per capita food purchases. *For each food category, w*e use Homescan© weights to estimate total purchases in a specific market and then divide this by the market population to get average per capita purchases of the food in the market.

Households in Nielsen panels are recruited continuously based on their demographic characteristics. Only households that report data for at least 10 of the 12 months each calendar year are included in the final weighted sample that can be used to estimate national and market-level purchases. This reporting requirement results in a considerable decline in participation in the final 2 months of each year.[6] Although the survey design methods differ from most nationally representative Federal surveys, an ERS-funded study concluded that "the overall accuracy of self-reported data by Homescan© panelists seems to be in line with other commonly used (Government-collected) economic datasets" (Einav et al., 2008).

Homescan© food purchase data is an imperfect proxy for consumption for several reasons. First, some food is not consumed soon after being purchased (Buzby et al., 2014). We expect the purchase-to-consumption lag to be smallest for perishable items that are not typically frozen, such as dairy products, fresh fruits, and fresh vegetables. In addition, Homescan© data do not capture information about food prepared outside of the home, such as food prepared in restaurants, which accounts for about one-third of calories consumed in the United States (Lin and Guthrie, 2012).

---

[5] ERS purchased Nielsen Homescan© data from 1998 until its merger with IRI InfoScan in 2010, and since 2010 has purchased IRI InfoScan data (National Consumer Panel 2013). In 2012, IRI resumed collecting data on expenditures, but not the quantity, of foods sold by random weight. As a result, we cannot use this more recent IRI data in our analysis. ERS researchers are working on research that would impute the quantity of random-weight food sold from this IRI expenditure data. This imputation may make IRI random weight data useful for food source attribution research at a future date.

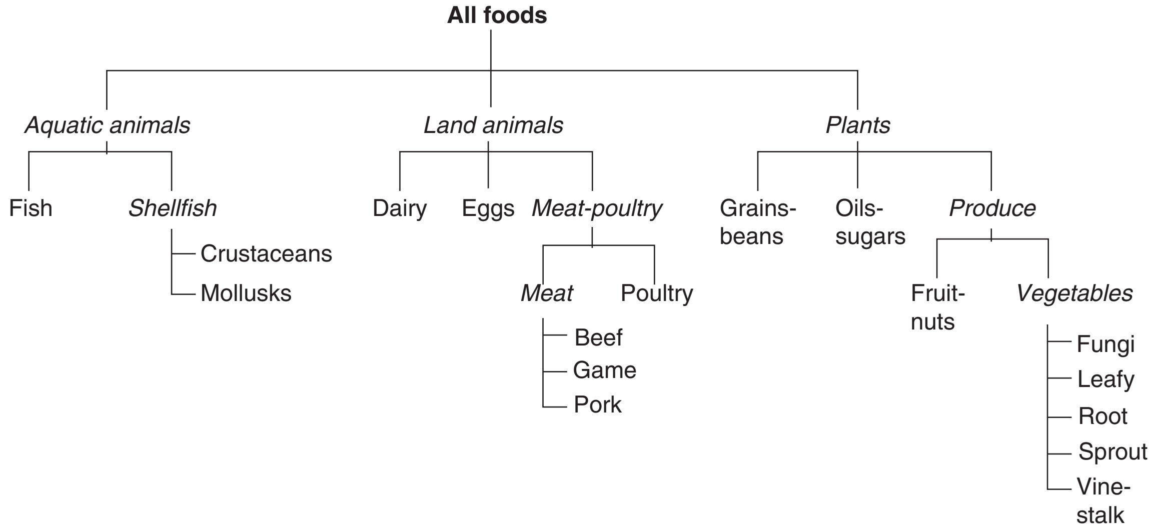
[6] Although households are brought into the sample continuously, those that enter after February and stay on at least 10 continuous months will not be included in their entry-year dataset because they report only for 9 of the 12 calendar-year months. In contrast, those that begin in January (or the previous year) and report purchases through October will appear in the data, even though they do not report in November or December. Those that leave prior to October will not be included at all. Some households participate in Homescan© panels for multiple years.

Food Categories

We developed a food categorization scheme informed by our review of the types of food associated with increased risk of campylobacteriosis, as well as prior categorization schemes developed for use with outbreak investigation data (figure 1). Previous categorization reflected the strengths and limitations of the types of data used in previous studies, as well as existing understanding of factors influencing foodborne disease risk (Richardson et al., 2017; Painter et al., 2013; DeWaal et al., 2006; Batz et al.; 2012). In some cases, the infrequency of some food purchases limited our ability to separate foods into their own category. For example, there is not enough fresh turkey sold in the United States in a year to be able to put it in a separate category from frozen turkey. Similarly, we are unable to find reports of unpasteurized cheese and milk.

Table 3 lists the disaggregated and aggregated food categories that we defined by the type of food (Painter et al., 2013; DeWaal et al., 2006); processing and handling practices (e.g., frozen versus fresh); form (e.g., sliced versus block cheese); and consumption practices (cooked or raw) that can influence the presence or growth of pathogens on foods (Richardson et al., 2017). According to USDA food labeling rules, chicken labeled "fresh" cannot have been frozen prior to sale (FSIS, 2019). We include fresh chicken as a separate category because the literature indicates its consumption increases the risk of sporadic campylobacteriosis, while frozen chicken is a separate category because freezing is recognized as an effective way to reduce the prevalence of *Campylobacter* on food. Chicken sold as fresh may be frozen once it is taken home.

Figure 1
Painter et al. 2013 food categorization for food source attribution of outbreak disease data



Italics indicate commodity groups.

Source: Painter et al., 2013

Table 3

Food categories developed for this study

Aggregate categories	Disaggregated food categories
Canned	Canned fruits and vegetables Canned meat Canned seafood
Cereal	Cereal
Dairy	Milk Block cheese (random weight) Block cheese (BC) Processed block cheese (BC) Processed sliced cheese (BC) Sliced cheese (random weight) Sliced cheese (BC) Other dairy (random weight) Other dairy (BC)
Deli/Sliced/Precooked	Mixed deli meat (BC) Precooked beef sausages (BC) Precooked beef sausages (random weight) Precooked mixed sausages (BC) Precooked mixed sausages (random weight) Precooked pork sausages (BC) Precooked pork sausages (random weight) Sliced beef (random weight) Sliced beef (BC) Sliced mixed meat (random weight) Sliced mixed meat (BC) Sliced pork (random weight) Sliced pork (BC) Sliced turkey (BC) Sliced turkey (random weight)
Eggs	Eggs (BC)

Continued—

Table 3

Food categories developed for this study—continued

Aggregate categories	Disaggregated food categories
Fresh vegetables, herbs, and roots	Ready-to-eat carrots (BC)
	Ready-to-eat celery (BC)
	Beets (random weight)
	Broccoli (random weight)
	Brussels sprouts (BC)
	Brussels sprouts (random weight)
	Carrots (BC)
	Carrots (random weight)
	Cauliflower (random weight)
	Celery (BC)
	Celery (random weight)
	Corn (random weight)
	Cucumbers (random weight)
	Eggplant (random weight)
	Greens (BC)
	Greens (random weight)
	Head of cabbage (random weight)
	Herbs (BC)
	Herbs (random weight)
	Mixed vegetables (BC)
	Mixed vegetables (random weight)
	Mushrooms (BC)
	Mushrooms (random weight)
	Onions and scallions (random weight)
	Peas (BC)
	Peas in the pod (BC)
	Peppers (BC)
	Pepper (random weight)
	Potatoes (BC)
	Potatoes (random weight)
	Radishes (BC)
	Shredded cabbage (BC)
	Sprouts (BC)
	Squash (BC)
	Squash (random weight)
	String beans (BC)
	String beans (random weight)
	Tomatoes (BC)
	Tomatoes (random weight)
	Other root vegetables (not carrots, onions and scallions, potatoes, or radishes)
	Other ready-to-eat vegetables (BC)
	Other vegetables (not listed above)

Continued—

Table 3

Food categories developed for this study—continued

Aggregate categories	Disaggregated food categories
Leafy greens	Leafy lettuce (random weight) Lettuce head (BC) Lettuce head (random weight) Ready-to-eat lettuce (BC) Ready-to-eat spinach (BC) Spinach (random weight)
Frozen fruits and vegetables	Frozen fruits and vegetables (BC)
Fruits eaten without peeling (not peeled fruits)	Grapes (random weight) Grapes (BC) Peaches (random weight) Pears (random weight) Plums (random weight) Prunes (random weight) Apples (random weight) Apples (BC) Raisins Dry dates Other dry fruit (not raisins or dates)
Berries	Blueberries (BC) Raspberries (BC) Strawberries (BC) Other berries (not blueberries, raspberries, or strawberries) (BC)
Fruits eaten peeled (peeled fruits)	Bananas (random weight) Grapefruit (BC) Kiwi (BC) Lemons (BC) Limes (BC) Mangos (random weight) Melons (random weight) Oranges (BC) Papayas (random weight) Pineapples (random weight) Tangerines (BC) Avocado (BC)
Juice	Pasteurized citrus juice (BC) Pasteurized grape juice (BC) Pasteurized pineapple juice (BC) Pasteurized vegetable juice (BC) Other pasteurized juice (BC) Other juice (BC)

Continued—

Table 3

Food categories developed for this study—continued

Aggregate categories	Disaggregated food categories
Whole Meat	Fresh whole beef (random weight) Fresh whole beef (BC) Fresh whole lamb (random weight) Fresh whole lamb (BC) Fresh whole pork (random weight) Fresh whole pork (BC) Frozen whole beef (random weight) Frozen whole pork (random weight)
Ground meat (no beef)	Frozen ground pork Fresh ground lamb (random weight) Fresh ground lamb (BC) Fresh ground pork (random weight) Fresh ground pork (BC)
Ground beef	Fresh ground beef (random weight) Fresh ground beef (BC) Frozen ground beef (BC)
Frozen chicken	Frozen ground chicken (BC) Frozen whole chicken (random weight) Frozen whole chicken (BC)
Fresh chicken	Fresh whole chicken (random weight) Fresh whole chicken (BC) Fresh ground chicken (random weight) Fresh ground chicken (BC)
Turkey	Fresh ground turkey (random weight) Fresh ground turkey (BC) Fresh whole turkey (random weight) Fresh whole turkey (BC) Frozen ground turkey (random weight) Frozen ground turkey (BC) Frozen whole turkey (random weight)
Seafood, fish, etc.	Fresh crustaceans (random weight) Fresh fish (random weight) Fresh mollusks (random weight) Fresh oysters (random weight) Frozen crustaceans (BC) Frozen fish (BC) Frozen mixed seafood (BC) Frozen mollusks (BC) Ready-to-eat fish and seafood (random weight) Ready-to-eat fish and seafood (BC)

Continued—

Table 3

Food categories developed for this study—continued

Aggregate categories	Disaggregated food categories
Nuts and seeds	Raw seeds (BC) Raw seeds (random weight) Raw shelled mixed nuts (BC) Raw shelled peanuts (BC) Raw shelled peanuts (random weight) Raw shelled tree nuts (BC) Raw shelled tree nuts (random weight) Raw unshelled mixed nuts (BC) Raw unshelled mixed nuts (random weight) Raw unshelled peanuts (BC) Raw unshelled peanuts (random weight) Raw unshelled tree nuts (BC) Raw unshelled tree nuts (random weight) Roasted seeds (BC) Roasted seeds (random weight) Roasted shelled mixed nuts (BC) Roasted shelled mixed nuts (random weight) Roasted shelled pecan (BC) Roasted shelled pecan (random weight) Roasted shelled tree nuts (BC) Roasted shelled tree nuts (random weight)
Snacks	Snacks (BC)

BC = bar-coded. These foods are prepackaged and sold in uniform weights.

Lamb, pork (specifically that cooked in large pieces), and beef sold as whole cuts were associated with lower campylobacteriosis risk in non-U.S. case-control studies.[7] Roast beef was associated with lower campylobacteriosis risk in the Arizona case-control study. As a result, we aggregate beef, lamb, and pork sold as whole cuts into a single category. Ground beef was identified as a risk factor in both U.S. and non-U.S. case-control studies. The grinding process introduces opportunities for cross-contamination and increased surface area for pathogen growth—both factors that could increase risk. The grinding process also increases the exposure of *Campylobacter* to oxygen, which could decrease risk (Kuhn et al., 2018). For these reasons, we separate ground meats from whole cuts. Since ground beef is widely consumed in the United States, we separate it from other ground meats.

The results on produce are mixed. Fresh berries were associated with lower campylobacteriosis risk in the national U.S. case-control study as were blueberries in the Arizona case-control study (Pogreba Brown et al., 2016), while strawberries were identified as a risk factor in non-U.S. case-control studies. Purchases of individual types of fresh (non-frozen) berries were not frequent enough in our dataset to allow us to disaggregate by specific berries, so we include an aggregate category for fresh berries.

---

[7] The reasons these foods are associated with lower risks are unclear. The value of these studies is in pointing to factors that may increase or decrease disease risk, estimating how large and significant that association is, and identifying needs for further research to understand causes.

Because the literature suggests differences in risk associated with peeled versus unpeeled fruits, we separated non-frozen fruits into those that are typically eaten without being peeled and those with peels not typically eaten. Because leafy-green vegetables have caused a number of foodborne disease outbreaks in the United States and are typically eaten raw, we separated leafy greens from all other vegetables, which are more often consumed after cooking. We separated frozen fruits and vegetables because, all else equal, freezing should reduce the prevalence of *Campylobacter* on frozen produce compared to raw.

Reasons for other categories varied. Several categories of food were included because they are known to have effective "kill steps" in their processing coupled with limited opportunities for later recontamination (i.e., canned foods, packaged cereals, pasteurized juices, and processed snacks). Eggs, seafood, and fresh fish were all associated with lower campylobacteriosis risk in non-U.S. case-control studies but have also been found to increase risk when consumed raw or undercooked. We included these foods as separate categories but have no way to identify how much was consumed raw or undercooked in the home. Pasteurized milk and dairy products were associated with lower campylobacteriosis risk in a European case-control study. Raw milk and some raw milk cheese have been found to increase the risk of campylobacteriosis; we are unable to identify raw milk or raw milk cheese in the Homescan© data. The amount of raw dairy products in Homescan© data is likely quite small.

We converted purchase quantities of each item to kilograms, summed the total of each item purchased by each household per day, then estimated the market-level total purchases of the item using the household weights. Using county-level population data from the U.S. Census Bureau, we then calculated the per capita daily amounts purchased of each food category in each market by dividing the estimated total amount of the item purchased by the market's population.

Linking FoodNet and Homescan© Datasets

We looked at how well FoodNet counties and Homescan© market areas overlap over time to determine which counties in FoodNet have sufficient overlap with a Homescan© market for our analysis (table 4). In total, 17 Homescan© markets also have FoodNet counties (table 4).[8] We performed sensitivity analysis on the impact of excluding markets that have less than 30 percent of coverage, i.e., percentage of Homescan© population in the active FoodNet counties. We did not find a significant impact on our estimates from excluding such markets and therefore include all FoodNet counties in each of these 17 Homescan© markets in our analysis.

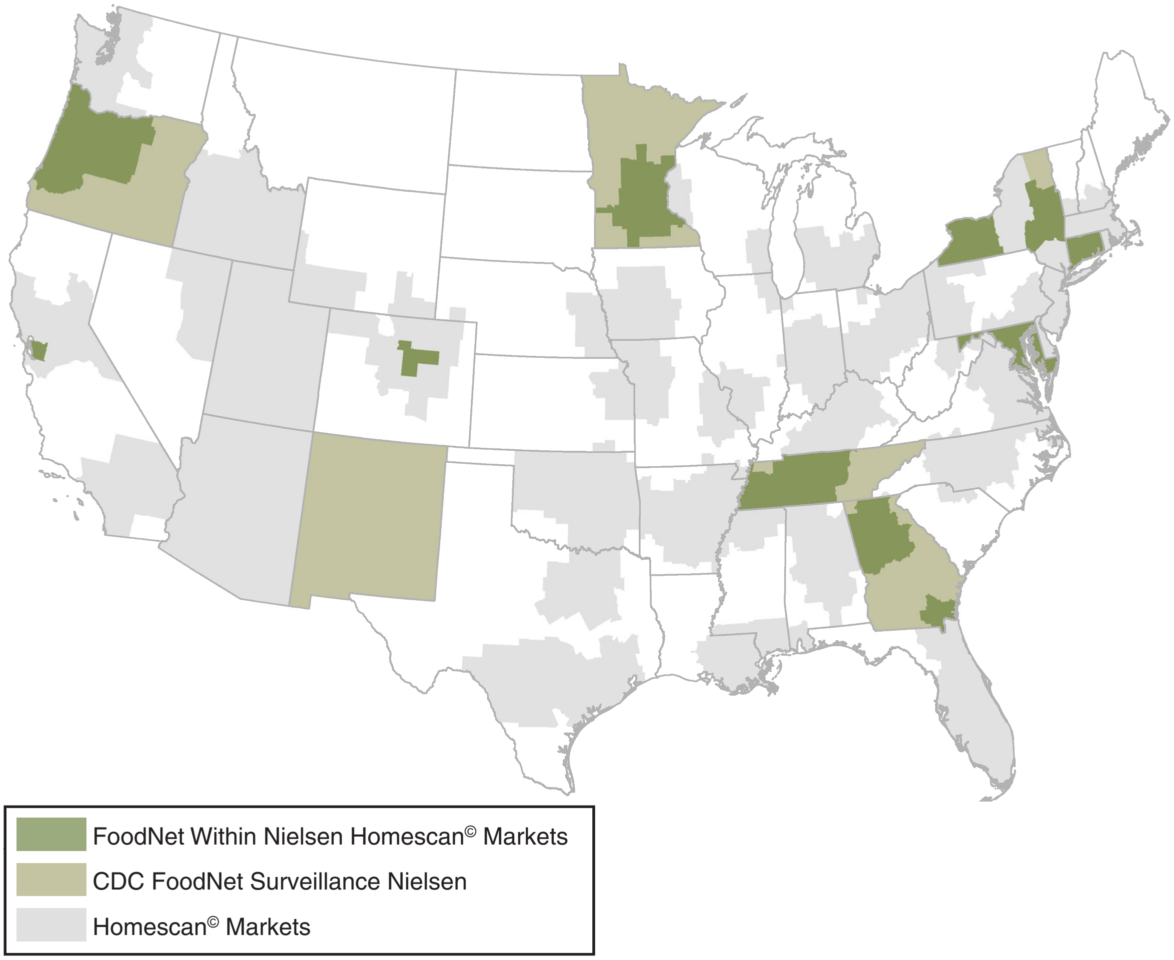
To be explicit, our disease variable is daily cases of illness per 100,000 population in the FoodNet counties within a particular Homescan© market. Our food purchase variable is lagged and aggregated average daily purchases per capita of a particular food in each Homescan© market. Because Homescan© data are population-weighted to be representative at the market—not the household or county level—we assume that food purchases are the same in all FoodNet counties within a particular Homescan© market.

---

[8] We excluded the data from FoodNet counties that were not within a Homescan© market (e.g., all counties in New Mexico) (figure 2).

Figure 2

Overlap between FoodNet sites and Homescan© markets



Source: Centers for Disease Control and Prevention (CDC) - Foodborne Diseases Active Surveillance Network (FoodNet) and Nielsen Co US, LLC - Homescan© Retail Measurement.

Table 4

Relationship between Homescan© and FoodNet geographic and temporal coverage

Markets	Number of counties that are active in FoodNet	Coverage[1]	Overlap[2]	First year all FoodNet counties were active
		Percent		
Baltimore	12	100	100	2002
Atlanta	57	98	92	1999
Buffalo-Rochester	13	96	81	2003
Minneapolis	38	93	83	1998
Portland	24	86	83	1998
Nashville	41	82	69	2003
Hartford-New Haven	6	78	67	1998
Albany	12	62	71	2004
Denver	7	62	23	2002
Memphis	16	55	30	2003
San Francisco	3	46	27	2000
Washington, DC	11	39	25	2002
NY Exurban	1	33	25	1998
Syracuse	6	14	30	2004
Jacksonville	8	12	40	1999
Boston	1	1	5	1998
Pittsburgh	1	1	3	2002

[1] Percentage of Homescan© population in the active FoodNet counties.

[2] FoodNet counties as percentage of Homescan© counties.

Note that Homescan© markets frequently cross state boundaries. Thus the Washington, DC, Homescan© market includes counties in Maryland; the Jacksonville market includes counties in Georgia; the Boston market includes counties in Connecticut; and the Pittsburgh market includes counties in Maryland.

Source: USDA, Economic Research Service.

Other Data

Temperature has been implicated as a factor that influences *Campylobacter* incidence (Louis et al., 2005; Tam, 2005). Our analysis uses National Oceanic and Atmospheric Administration (NOAA) temperature data on the daily average Fahrenheit temperature by market (University of Dayton, 2019).

Descriptive Statistics

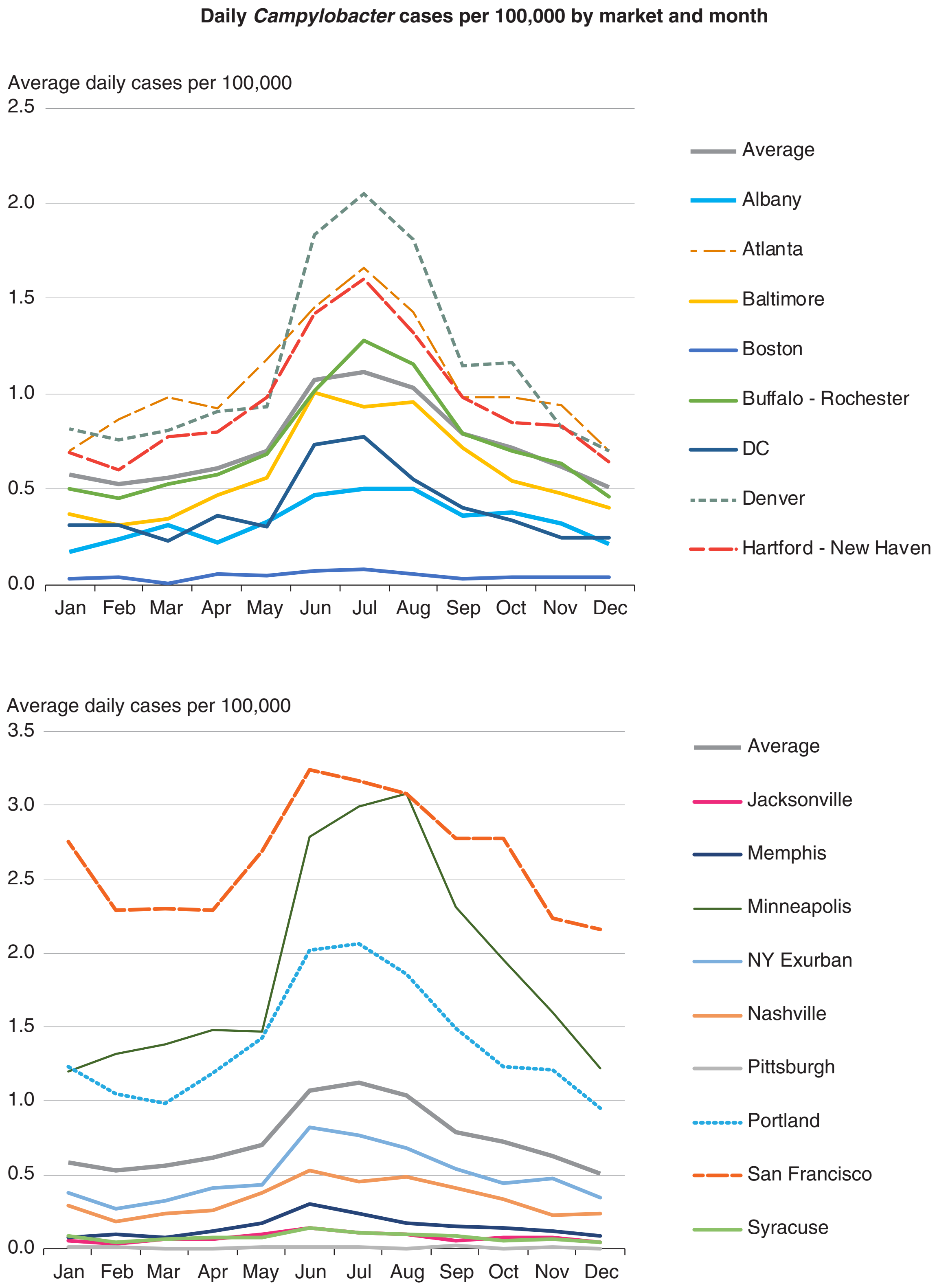
We graph monthly *Campylobacter* cases per 100,000 persons in each Homescan© market and see a strong mid-summer peak in sporadic campylobacteriosis case rates in most market areas (figures 3a and 3b). The exceptions were the Hartford and Pittsburgh markets,[9] which have multiple peaks. Looking at incidence rates across markets and years shows there is variation over time and across Homescan© markets; the San Francisco area has the highest rate, while Memphis has the lowest (figures 4a, 4b).

---

[9] Analysis of the Homescan© Pittsburgh market includes only counties in western Maryland. These counties are also in FoodNet.

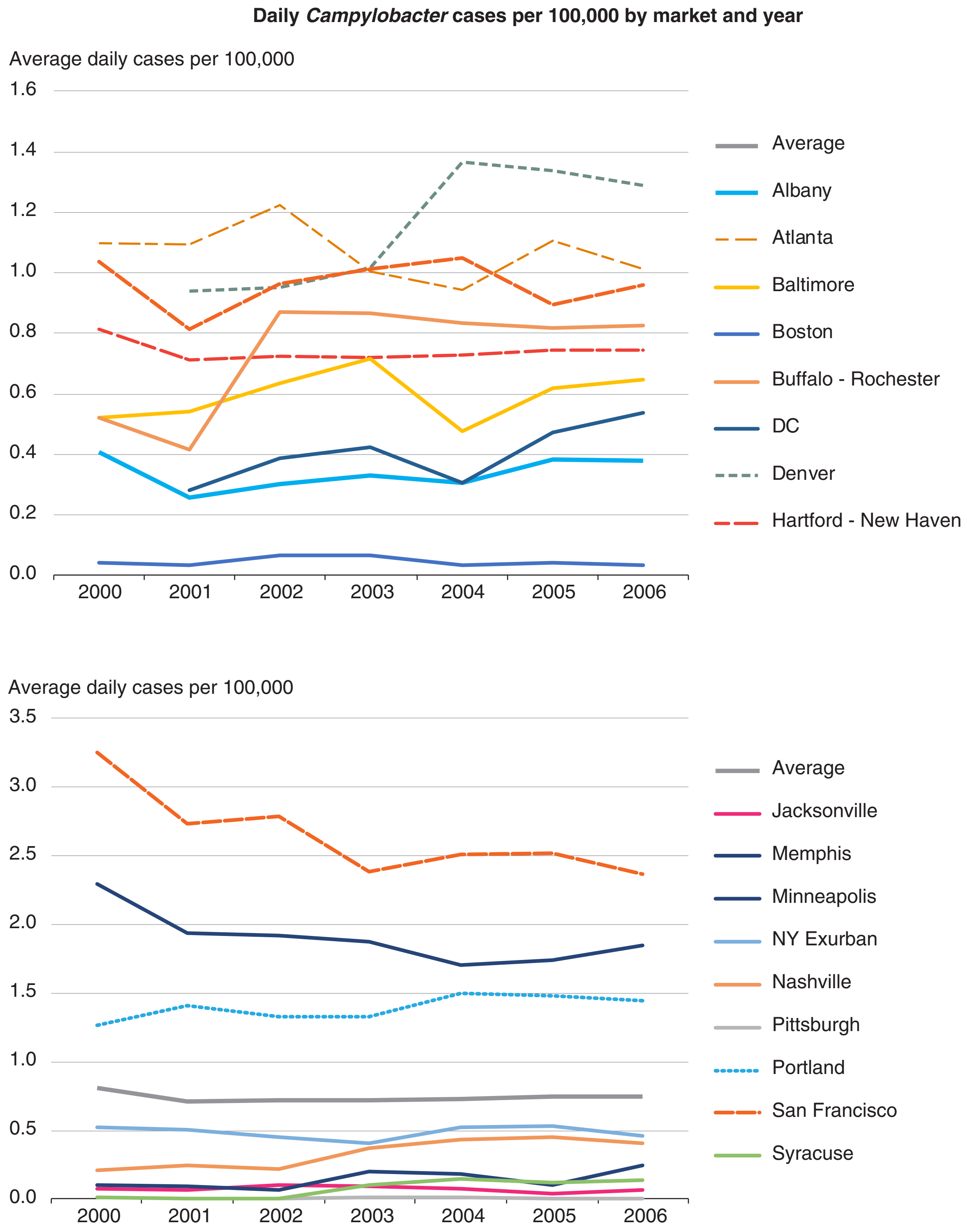
Aggregating purchases across all years in our study period and averaging by month shows there is considerable variation across months and markets in food purchases by food categories. Figures 5a, 5b, and 5c display the monthly variation in each market in per capita kilograms purchased of fresh chicken, berries, and dairy, respectively. There is variation across markets in per capita purchases of fresh chicken, with Syracuse and Pittsburgh having above-average purchase levels, while Denver and Minneapolis fall well below average (figure 5a). While chicken and dairy purchases (figure 5c) show little variation across the year, purchases of fresh berries show a strong summer seasonal peak (figure 5b). The declines observed in November and December likely reflect the lower rate of reporting in those months, as described above in our discussion of Homescan© data. Time plots of purchases of all food categories, by market, are provided in Appendix 1. Table 5 reports average per capita food purchases by food category across all Homescan© markets.

Figure 3
Seasonality in *campylobacteriosis* rates by Homescan© market



Source: USDA, Economic Research Service.

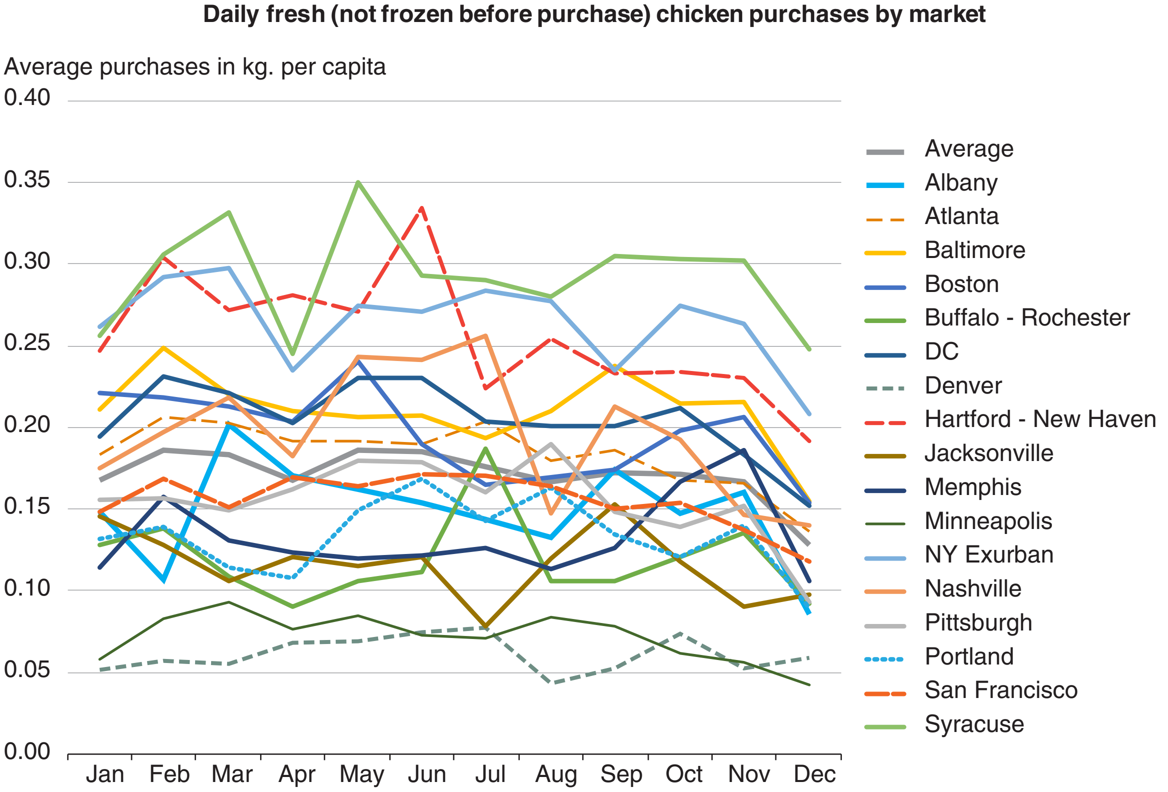
Figure 4
Campylobacteriosis rates by market and year

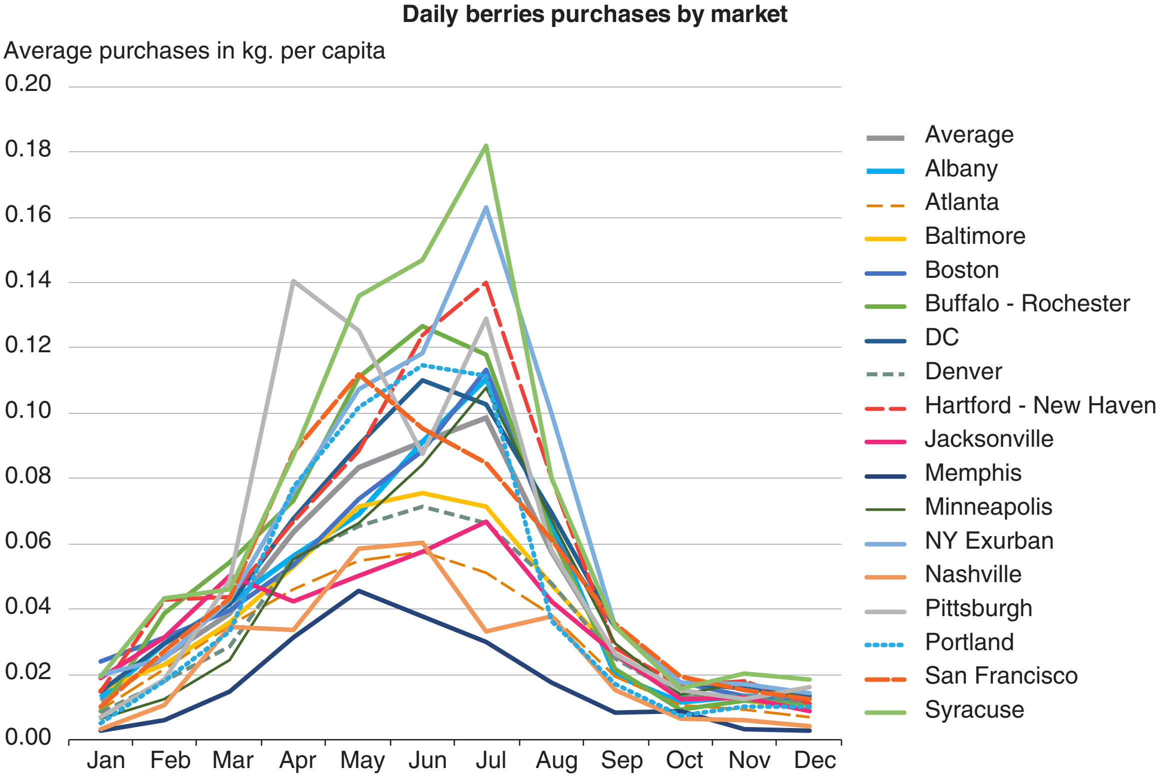


Source: USDA, Economic Research Service.

Figure 5

Average monthly fresh (not frozen before purchase) chicken and berry purchases by market (Homescan© data 2000-06)





Source: USDA, Economic Research Service.

Table 5

Summary statistics on food purchases across 17 Homescan© markets included in study, 2000-06

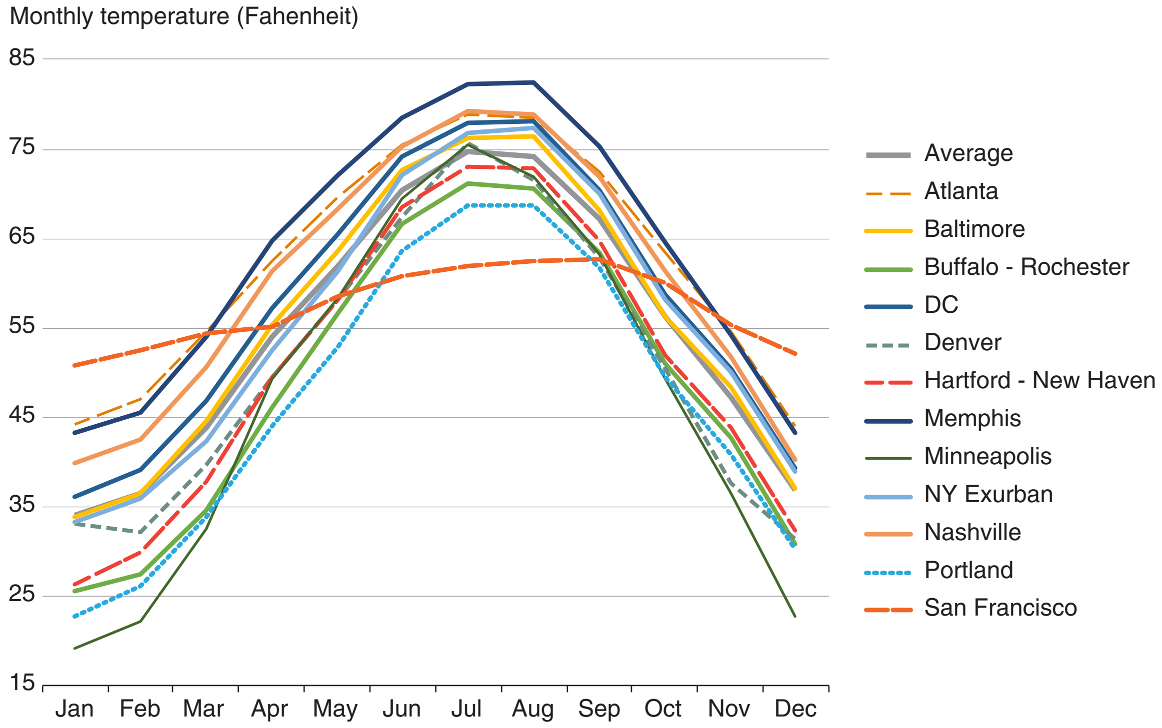
	Obs*	Mean	S.D.	Min.	Max.
Food: Total kgs. sold per capita (lagged t=5 to t=18 days)					
Ground beef	41,666	0.145	0.087	0	0.949
Berries	41,666	0.045	0.046	0	0.415
Canned goods	41,666	0.736	0.330	0.055	3.479
Cereal	41,666	0.160	0.059	0.002	0.662
Frozen chicken	41,666	0.043	0.053	0	1.088
Not-frozen chicken	41,666	0.171	0.121	0	1.430
Dairy	41,666	1.851	0.607	0.188	6.340
Deli meat (all)	41,666	0.227	0.116	0	1.633
Eggs	41,666	0.143	0.054	0	0.516
Frozen fruits and vegetables	41,666	0.152	0.068	0	0.585
Fruits not typically eaten peeled	41,666	0.108	0.080	0	0.824
Fruits eaten peeled	41,666	0.332	0.159	0	1.564
Juice	41,666	0.494	0.215	0	2.319
Leafy greens	41,666	0.131	0.089	0	2.015
Ground meat (excl. beef)	41,666	0.003	0.006	0	0.123
Whole cuts of meat (excl. poultry)	41,666	0.267	0.152	0	2.427
Nuts	41,666	0.055	0.038	0	0.792
Seafood	41,666	0.027	0.020	0	0.259
Turkey	41,666	0.067	0.145	0	2.654
Snacks	41,666	0.485	0.148	0.054	1.517
Fresh vegetables (excl. leafy greens)	41,666	0.703	0.298	0.032	3.353

*Number of weeks X number of markets

Source: USDA, Economic Research Service.

As one would expect, weekly average temperature varies across markets and over the year, generally peaking in mid-July (figure 6). The exception is San Francisco, where temperature peaks in September. July peaks range from below 70 in Portland to over 80 in Memphis. Low temperatures range from about 20 degrees in Minneapolis to about 50 in San Francisco in early January.

Figure 6
Average weekly temperature by Homescan© market 2000-06



Source: USDA, Economic Research Service.

Empirical Model

Multiple methods are needed to gain a full picture of the risk factors driving potentially foodborne diseases like campylobacteriosis. In the United States most "source attribution" research either uses outbreak data or uses case-control studies to analyze surveillance data on sporadic illnesses. Our study develops a new approach to source attribution research that uses multi-regional, cross-sectional time series analysis of data on sporadic illnesses and data on daily food purchases. This approach uses observational data on food purchase behavior, rather than food recall. This makes it possible to test for a wider range of possible food exposure risks. The multi-regional, multi-year nature of the data also allows us to simultaneously contribute to understanding of the relative roles of food exposure, region, seasonality, and ambient temperature, which has not been possible using existing source attribution approaches. In so doing the approach enables us to provide additional insight into challenging questions about what is driving regional variation in campylobacteriosis in the United States.

We estimate the relationship between daily sporadic cases of campylobacteriosis and lagged food purchases over the previous 2 weeks, temperature, and fixed effects using a Negative Binomial regression model, one of a class of models used to estimate count data. The Negative Binomial model is preferred to a Poisson model because the mean and variance of daily cases per capita are not equal (Greene, 2017). As a robustness check, we also estimated our model using a Poisson estimator with robust errors and found little difference in results.

Specifically, our model is:

$$C_m^t = a + \sum_i \beta_1^i F_m^{i,t} + \beta_2 T_m^{i,t} + \sum_j \beta_3^j Z + e_m^t$$

where *C* are the number of daily cases of illness in each Homescan© market (this assumes the date of specimen collection by FoodNet as the date of onset of the illness), with *i* indexing each of *m* markets (*m)*, and *t* indexing date starting with the first day of 2000 and ending with the last day of 2006. ***F*** is the total kilograms per capita of food *i* purchased in market *m* between 5 and 18 days before the illness was confirmed. We chose this lag structure to account both for food storage and the incubation period between consumption of *Campylobacter*-contaminated food and onset of symptoms, which is typically 2 to 5 days (CDC, 2018. *Campylobacteriosis.*). Since we do not have information on the lag between when food is purchased and when it is consumed, we tested both a 1- and a 2-week lag specification and found no statistically significant differences in the resulting models. We use a 2-week aggregation for food purchases because it better reflects both the frequency of U.S. household food shopping trips seen in the American Time Use Survey and allows for food storage.

T is a vector of lagged average temperature for each market for each day. Based on prior literature, we tested performance of different temperature averaging periods: 1 week, 2 weeks, 4 weeks, 6 weeks, and 10-14 weeks. In each case, we also lagged the average temperature by 4 days to account for the normal disease incubation period. Based on this testing, our final specification uses a 6-week period (i.e., the average of temperature on days t-5 to t-46).

Z is a matrix of *j* fixed effects including market, year, and season. Market fixed effects are included to control for unobserved differences between markets that could affect the risk of campylobacteriosis. These may include differences in food preparation practices, differences in care-seeking or medical treatment practices; regional differences in population age structure; level and types of outdoor activities; the prevalence of consumption of food from farmers' markets or home gardens; or pathogen prevalence in livestock, poultry, wildlife, or recreational waters. The year fixed effects control for broader time-specific effects common across all markets, such as changes in Homescan© and FoodNet data collection or nationwide shifts in food demand. Season fixed effects account for seasonal disease patterns, seasonal cooking and food consumption patterns, and seasonal patterns in behavior unrelated to food purchased for home consumption as well as seasonal changes in the Homescan© sample. We explore two different approaches to modeling season: one using conventional 3-month seasons with winter excluded, the other using 12 calendar months with January excluded. Finally, we include measurement error, *e*, for each Homescan© market and day of the study period, and a constant term, *a*.

Results

Regression results are reported in table 6, with coefficients converted to incidence rate ratios (IRRs) and their standard errors.[10] These IRRs are the ratio of the daily incidence (cases per 100,000 people) expected if the corresponding variable was increased by one unit relative to the original expected daily incidence. An IRR of 1 indicates that an increase in the variable made no difference to the incidence of disease. IRRs less than 1 indicate a reduction in incidence, while those over 1 indicate an increase in incidence. As an example, an IRR of 1.5 for ground beef would indicate that a 1-kilogram increase in beef purchases per capita would increase campylobacteriosis incidence by 50 percent.

Table 6 presents the results of six specifications that show how the estimated relationship between daily campylobacteriosis cases and food purchases change as we add controls to the model. Model 1 presents the results when only lagged food purchases are included. Model 2 adds market fixed effects (Albany omitted). In a robustness check, our results were unaffected when markets with less than 30 percent coverage were excluded (table 4). Model 3 adds year fixed effects (the year 2000 omitted). Model 4 adds the average temperature variable. Model 5 adds season dummies, defined as 3-month periods (winter omitted). Model 6 replaces the season dummies with month fixed effects (January omitted).

The average daily campylobacteriosis incidence rate is 0.739 per 100,000 people. As expected, coefficients and patterns of significance change as confounding effects are accounted for but are reasonably stable once models account for market and annual fixed effects (models 4-6). Our preferred specifications are model 5 (3-month season dummies) and model 6 (month fixed effects). Each model has strengths and provides different insights into factors that influence campylobacteriosis rates. Model 5 has relatively low correlation between season, temperature, and other variables in the model. Although the Variance Inflation Factors (VIFs) for season dummies (summer VIF 7.63) and lagged temperature (VIF 5.72) are higher than for other variables in model 5, they are still well below a level of concern of 10. As a result, season and temperature should be viewed as having independent impacts on campylobacteriosis rates. In model 6, because temperature in our model is defined as 6-week average lagged temperature, there is a strong enough relationship between average 6-week lagged temperature (VIF of 20) and month (VIF from 11 to 15 for July through September) that month and temperature cannot be viewed as independent. However, none of the food variables have a VIF high enough to be of concern, indicating that they are not strongly multi-collinear with other variables in the model and that the multi-collinearity between month and 6-week lagged average temperature does not bias the regression coefficients on foods.[11] The added flexibility allowed by using month rather than 3-month season fixed effects contributes to slightly better overall fit than model 5 and more efficient estimates for about half the food variables, most notably berries (table 6).

---

[10] An incidence risk ratio (IRR) is the ratio of two incidence rates. In our study these are the incidence rates for those who do and do not face a higher level of the risk factor. IRRs are used when there are data on person-time at risk, i.e., the time period during which people are at risk (not something case-controls have) is known. Table 1 presents case-control study results as odds ratios (OR). ORs are used in case-control studies to compare the risk in exposed and unexposed groups. For relatively rare disease outcomes, the OR will approximate the IRR; so it is still appropriate to use the ORs as a comparison for our findings (Greenland et al., 1986).

[11] The average VIF for all food variables in model 5 is 2.46; that in model 6 is 2.55—both well below a level of concern.

Table 6

Negative binomial regression results: incidence rate ratios for Campylobacter regressions

Dependent variable: daily cases of sporadic campylobacteriosis from FoodNet in 17 Homescan© Markets						
	Model					
	(1)	(2)	(3)	(4)	(5)	(6)
Variables	Food purchases	+ Market FE	+ Year FE	Temperature L6	Model (4) + Season FE	Model (4) + Month FE
Food: Total kgs. purchased per capita (t=5 to t=18 days prior to laboratory confirmation of case)						
Ground beef	0.553***	1.840***	1.599***	1.494***	1.508***	1.383***
	(0.0478)	(0.154)	(0.136)	(0.133)	(0.135)	(0.124)
Berries	11.38***	7.235***	8.454***	5.123***	3.109***	1.771***
	(1.403)	(0.836)	(0.999)	(0.645)	(0.459)	(0.296)
Canned goods	0.743***	0.823***	0.843***	0.922**	1.006	1.023
	(0.0251)	(0.0271)	(0.0274)	(0.0305)	(0.0350)	(0.0358)
Cereal	4.751***	0.831	1.074	1.148	1.011	0.962
	(0.841)	(0.151)	(0.197)	(0.222)	(0.196)	(0.189)
Frozen chicken	2.202***	0.929	0.882	0.897	0.815	0.699**
	(0.273)	(0.131)	(0.124)	(0.130)	(0.120)	(0.106)
Not-frozen chicken	0.770***	1.062	1.078	1.106*	1.091	1.024
	(0.0446)	(0.0623)	(0.0629)	(0.0653)	(0.0641)	(0.0613)
Dairy	1.252***	0.960**	0.961**	0.953**	0.960**	0.961**
	(0.0189)	(0.0181)	(0.0183)	(0.0191)	(0.0191)	(0.0191)
Deli meat (all)	0.785***	0.964	1.142**	1.076	1.068	1.041
	(0.0400)	(0.0513)	(0.0637)	(0.0634)	(0.0631)	(0.0617)
Eggs	0.434***	0.871	0.876	0.971	0.933	1.203
	(0.0668)	(0.140)	(0.140)	(0.159)	(0.152)	(0.200)
Frozen fruits and vegetables	0.127***	0.910	0.891	1.048	1.097	1.143
	(0.0152)	(0.117)	(0.114)	(0.138)	(0.144)	(0.150)
Fruits not typically eaten peeled	4.341***	2.354***	2.252***	1.078	0.765***	0.870
	(0.328)	(0.183)	(0.175)	(0.0981)	(0.0747)	(0.0913)
Fruits eaten peeled	1.429***	0.545***	0.516***	0.824***	0.839***	0.821***
	(0.0671)	(0.0311)	(0.0299)	(0.0495)	(0.0509)	(0.0510)
Juice	0.602***	0.810***	0.837***	0.910*	0.909*	0.908*
	(0.0244)	(0.0386)	(0.0396)	(0.0449)	(0.0448)	(0.0451)
Leafy greens	1.598***	0.934	1.004	0.772*	0.788*	0.718**
	(0.158)	(0.114)	(0.122)	(0.111)	(0.112)	(0.107)
Ground meat (excl. beef)	0.487	0.106**	0.116*	0.160*	0.154*	0.157*
	(0.522)	(0.120)	(0.130)	(0.174)	(0.168)	(0.169)
Whole cuts of meat (excluding poultry)	0.944	1.052	1.005	1.064	1.060	1.113*
	(0.0484)	(0.0547)	(0.0545)	(0.0575)	(0.0581)	(0.0611)
Nuts	3.104***	0.688**	0.812	0.927	0.855	1.180
	(0.442)	(0.119)	(0.138)	(0.161)	(0.151)	(0.214)
Seafood	0.0431***	0.159***	0.253***	0.623	0.499*	0.577
	(0.0173)	(0.0590)	(0.0907)	(0.221)	(0.177)	(0.207)

Table 6

Negative binomial regression results: incidence rate ratios for Campylobacter regressions—continued

Dependent variable: daily cases of sporadic campylobacteriosis from FoodNet in 17 Homescan© Markets						
	Model					
	(1)	(2)	(3)	(4)	(5)	(6)
Variables	Food purchases	+ Market FE	+ Year FE	Temperature L6	Model (4) + Season FE	Model (4) + Month FE
Food: Total kgs. purchased per capita (t=5 to t=18 days prior to laboratory confirmation of case)						
Turkey	0.998 (0.0490)	0.952 (0.0467)	0.964 (0.0470)	0.912* (0.0447)	0.923 (0.0474)	0.987 (0.0542)
Snacks	0.623*** (0.0574)	1.454*** (0.131)	1.204** (0.112)	0.989 (0.0988)	0.977 (0.0982)	0.939 (0.0947)
Fresh vegetables (excl. leafy greens)	1.164*** (0.0434)	1.207*** (0.0501)	1.152*** (0.0485)	1.188*** (0.0517)	1.202*** (0.0526)	1.193*** (0.0524)
Market fixed effects:						
Atlanta		0.762*** (0.0246)	0.768*** (0.0247)	0.717*** (0.0238)	0.713*** (0.0236)	0.710*** (0.0236)
Baltimore		0.822*** (0.0292)	0.833*** (0.0294)	0.778*** (0.0281)	0.780*** (0.0281)	0.779*** (0.0282)
Boston		1.263*** (0.0941)	1.281*** (0.0955)	1.215** (0.0943)	1.218** (0.0945)	1.236*** (0.0960)
Buffalo-Rochester		1.193*** (0.0421)	1.215*** (0.0425)	1.122*** (0.0406)	1.132*** (0.0409)	1.133*** (0.0411)
District of Columbia		0.694*** (0.0287)	0.715*** (0.0295)	0.656*** (0.0280)	0.668*** (0.0284)	0.668*** (0.0286)
Denver		1.476*** (0.0518)	1.496*** (0.0528)	1.480*** (0.0538)	1.481*** (0.0536)	1.464*** (0.0531)
Hartford-New Haven		1.237*** (0.0456)	1.254*** (0.0459)	1.185*** (0.0438)	1.211*** (0.0447)	1.219*** (0.0453)
Jacksonville		1.246*** (0.0778)	1.256*** (0.0782)	1.142** (0.0753)	1.135* (0.0748)	1.118* (0.0737)
Memphis		0.543*** (0.0271)	0.551*** (0.0274)	0.540*** (0.0271)	0.528*** (0.0265)	0.523*** (0.0262)
Minneapolis		1.571*** (0.0527)	1.538*** (0.0515)	1.490*** (0.0514)	1.504*** (0.0517)	1.518*** (0.0523)
New York Exurban		1.661*** (0.0664)	1.675*** (0.0669)	1.584*** (0.0644)	1.629*** (0.0662)	1.641*** (0.0673)
Nashville		0.726*** (0.0292)	0.754*** (0.0302)	0.696*** (0.0285)	0.678*** (0.0279)	0.682*** (0.0282)
Pittsburgh		0.734 (0.173)	0.775 (0.182)	0.724 (0.179)	0.724 (0.179)	0.735 (0.182)
Portland		1.547*** (0.0563)	1.591*** (0.0589)	1.440*** (0.0555)	1.438*** (0.0553)	1.417*** (0.0548)
San Francisco		2.259*** (0.0728)	2.291*** (0.0737)	2.128*** (0.0702)	2.181*** (0.0721)	2.190*** (0.0729)

Table 6

Negative binomial regression results: incidence rate ratios for Campylobacter regressions—continued

Dependent variable: daily cases of sporadic campylobacteriosis from FoodNet in 17 Homescan© Markets						
	Model					
	(1)	(2)	(3)	(4)	(5)	(6)
Variables	Food purchases	+ Market FE	+ Year FE	Temperature L6	Model (4) + Season FE	Model (4) + Month FE
Food: Total kgs. purchased per capita (t=5 to t=18 days prior to laboratory confirmation of case)						
Syracuse		1.476*** (0.0963)	1.530*** (0.0997)	1.421*** (0.0925)	1.470*** (0.0958)	1.491*** (0.0972)
Year fixed effects						
2001			0.904*** (0.0169)	0.899*** (0.0170)	0.897*** (0.0169)	0.895*** (0.0169)
2002			0.880*** (0.0178)	0.877*** (0.0192)	0.878*** (0.0192)	0.888*** (0.0196)
2003			0.841*** (0.0171)	0.854*** (0.0181)	0.858*** (0.0182)	0.857*** (0.0181)
2004			0.855*** (0.0175)	0.859*** (0.0177)	0.867*** (0.0178)	0.865*** (0.0178)
2005			0.875*** (0.0179)	0.866*** (0.0178)	0.874*** (0.0180)	0.877*** (0.0182)
2006			0.861*** (0.0177)	0.841*** (0.0174)	0.851*** (0.0177)	0.859*** (0.0181)
Average 6-week temperature lagged (average of t-5 to t-46)				1.009*** (0.000521)	1.007*** (0.000857)	1.005*** (0.00159)
Month fixed effects						
February						0.941** (0.0276)
March						0.949* (0.0289)
April						0.924** (0.0336)
May						1.076 (0.0492)
June						1.272*** (0.0718)
July						1.240*** (0.0819)
August						1.115 (0.0760)
September						0.990 (0.0618)
October						0.921* (0.0456)

Table 6

Negative binomial regression results: incidence rate ratios for Campylobacter regressions—continued

Dependent variable: daily cases of sporadic campylobacteriosis from FoodNet in 17 Homescan© Markets						
	Model					
	(1)	(2)	(3)	(4)	(5)	(6)
Variables	Food purchases	+ Market FE	+ Year FE	Temperature L6	Model (4) + Season FE	Model (4) + Month FE
Food: Total kgs. purchased per capita (t=5 to t=18 days prior to laboratory confirmation of case)						
November						0.868*** (0.0364)
December						0.850*** (0.0271)
Season Fixed Effects***						
Spring (March-May)					1.005 (0.0200)	
Summer (June-August)					1.187*** (0.0375)	
Fall (September-November)					0.974 (0.0255)	
Constant	1.81e-05*** (4.07e-07)	1.51e-05*** (5.70e-07)	1.73e-05*** (7.24e-07)	1.02e-05*** (5.50e-07)	1.09e-05*** (6.32e-07)	1.22e-05*** (9.08e-07)
Observations	41,666	41,666	41,666	38,871	38,871	38,871
Average daily campylobacteriosis incidence cases per 100,000 population	0.739	0.739	0.739	0.739	0.739	0.739
Pseudo R-squared	0.0389	0.0832	0.0842	0.0871	0.0888	0.0902

Notes: Robust standard errors in parentheses. *** p<0.01, **p<0.05, *p<0.1.

In model 5, ground beef (IRR 1.5), berries (IRR 3.1), and fresh vegetables other than leafy greens (IRR 1.2) are all associated with increased risk of campylobacteriosis. Many foods are also associated with a decreased risk of campylobacteriosis, including dairy (IRR 0.96), fresh fruits other than berries that are typically eaten with their peel (IRR 0.765), fresh fruits other than berries that are typically eaten after being peeled (IRR 0.839), pasteurized juice (IRR 0.909), leafy greens (IRR 0.788), ground meat (excluding beef) (IRR 0.154), and fish and seafood (IRR 0.499).

Shifting from a 3-month season (model 5) to month (model 6) fixed effects does affect some of our results. Higher frozen chicken (IRR 0.699) purchases are associated with lower incidence of campylobacteriosis in model 5, but the effect is statistically significant only in model 6. Higher seafood purchases are also associated with lower campylobacteriosis incidence in both models but lose their statistical significance in model 6. Whole cuts of meat are a risk factor in both models 5 and 6, but statistically significant only in model 6. Berries are a statistically significant risk factor in both models 5 and 6, but the IRR for berries is much lower and the accuracy of the estimate much higher in model 6 (IRR 1.77, s.e. 0.296) than in model 5 (IRR 3.11, s.e. 0.459).

Our analysis also allows us to look at annual variation and the influence of temperature and season on campylobacteriosis. We find no systematic yearly influence on campylobacteriosis rates over the study period once the influences of food purchases, region, season, and temperature are held constant, other than rates being estimated to be higher in 2000 than in other study years. Powell (2016) found substantial year-to-year variation in FoodNet campylobacteriosis cases but no overall trend since about 2000-01. Model 5 allows us to assess the relative roles of season and temperature on daily campylobacteriosis incidence (table 6). An increase in the average daily temperature in the 6-week period 5 days prior to laboratory confirmation of the case is associated with a slight, but statistically significant, increase in the daily campylobacteriosis rate (IRR 1.007) (table 6, model 5). Summer was associated with a higher campylobacteriosis rate (IRR 1.187) (table 6, model 5). Comparing models 5 and 6, the substitution of months for 3-month seasons has little impact on the size or significance of the coefficient on temperature (table 6).

Discussion

There have been calls to develop new attribution methods, particularly those making innovative use of existing datasets (IFSAC, 2017a). In this study, we develop a new approach for studying food source attribution that makes use of time-series data on food purchases not previously used in food source attribution research. We test the approach by studying sporadic campylobacteriosis in the United States as measured using FoodNet surveillance data. Our finding shows that the use of FoodNet illness data paired with food purchase data can provide us not only with additional insights into the roles of specific foods in causing foodborne disease but also on the relative roles of food, season, temperature, and geographic location.

We find results that sometimes support, sometimes conflict with, and sometimes identify risk factors not identified by previous studies. This should not be surprising. Approaching the same question using multiple methods should help us determine when results are robust and identify areas that require further study (Evans et al., 2003).

There are a number of areas where our findings on food sources agree with prior U.S. and European case-control studies. In particular, we find that increases in ground beef purchases increase campylobacteriosis risk. Risk increases are similar in size in our study (IRR 1.5) and a Michigan case-control study (OR 1.4). We find that fruits (other than berries) are associated with slightly lower campylobacteriosis risks (IRR 0.77, 0.84), as do European case-control studies (RR 0.7 to 0.2).[12] The only U.S. national case-control study on eating turkey at home finds it to be associated with lower campylobacteriosis risk (OR 0.5); we find it not to be significant. U.S. case-control studies found that eating non-poultry meats at home (OR 0.7) or eating roast beef (OR 0.15) were also associated with lower campylobacteriosis risk; we find purchases of whole cuts of meat (non-poultry) for home use not significant.

Our results support a finding in the U.S. national case-control study that chicken prepared at home is not a major risk factor for campylobacteriosis (IRR 0.7) (Friedman et al., 2004). Increased purchases of frozen chicken for use at home are expected to be associated with lower incidence of campylobacteriosis. Frozen chicken purchases were not significant in model 5 but were significant and associated with a slightly lower risk of campylobacteriosis in model 6 (IRR 0.7). Purchases of fresh chicken were not significant; this may in part reflect storage practices, such as freezing chicken at home. The findings that chicken consumption or purchase for home use is associated with decreased campylobacteriosis risk suggests there may be value in research aimed at understanding why chicken at home would pose a different risk than chicken eaten away from home. Differences in food handling and storage are possible reasons (National Chicken Council, 2012).

There were also areas of disagreement. The most marked was that we found fresh berry purchases increased risk (IRR 3.1 in model 5, 1.8 in model 6), which is consistent with European studies but different from previous U.S. studies that found lower risk associated with berry consumption. This is a significant difference and indicates further research is needed. We found increased purchases of leafy greens were associated with a lower risk of campylobacteriosis (IRR 0.79), but other fresh vegetable purchases were associated with increased risk (IRR 1.2). An Australian and Danish case-

---

[12] Note that an Arizona case-control study found that eating cantaloupe substantially increased campylobacteriosis risk (OR 7.64).

control study found consumption of produce or eating raw vegetables daily to be associated with lower campylobacteriosis risk.

Homescan© and other scanner data allow identification of detailed information about how food was processed prior to sale. Our results provide insight into the influence of some processing practices on campylobacteriosis risks. As discussed above, freezing can reduce *Campylobacter* prevalence and has been used to help control *Campylobacter* in chicken. In model 6, we find purchases of frozen chicken associated with a reduced risk of campylobacteriosis. In our results, coefficients on frozen fruits and vegetables are not significant. Pasteurization and canning are both widely recognized as generally effective means of controlling bacterial contamination in food. No raw milk was reported in the Homescan© data we analyzed. Most dairy and juice sold in U.S. retail stores has been pasteurized and reduces risk in our models. Increased purchases of canned foods were not significant. Neither pasteurized dairy, juice, or canned foods were included in U.S. case-control studies.

Because Homescan© and FoodNet have substantial regional variation as well as provide daily data, we are able to explore the impact of season, temperature, and geography on disease while controlling for food consumption patterns. Models 5 and 6 each provide valuable findings on these explanatory factors.

Use of quarterly seasons allows independent interpretation of daily fluctuations in lagged average temperature and seasonal change. Our results confirm that a finding in England, which showed temperature and season each have an independent impact on sporadic campylobacteriosis incidence, also holds in the United States (Tam, 2005). Our estimates show that a 1-degree increase in average lagged temperature increased daily campylobacteriosis incidence very slightly (IRR 1.007). This result is robust to model specification. We find that higher daily campylobacteriosis rates during the summer persist even after controlling for daily temperature fluctuations, food purchases, market, and year (IRR 1.87). Prior U.S. research found that human activities that vary seasonally (excluding food consumption and preparation)—such as swimming in lakes and rivers, drinking untreated water from streams, playing in playgrounds contaminated by bird feces, or travel—are all risk factors for campylobacteriosis. A Danish study explored the hypothesis that rapid increase in fly populations in the late spring may play a role (Hald et al., 2007).

Replacing quarterly seasons with month fixed effects leads to improvements in model fit and changed the size and significance of coefficients on food purchases. This suggests new hypotheses about the causes of foodborne disease. Most significantly, estimates of the risk posed by berries and fruits typically eaten with peels on change. One possibility is that month may be correlated with factors not included in the model, such as the location of food production. A recent study suggests that regional changes in where produce is grown were a significant factor in at least four recent STEC outbreaks in the United States (Astill et al., 2020). Coupling data used in this study with data on changes in the location of food production through the year might provide additional insights into what drives foodborne disease incidence.

This study's results add evidence to our understanding of the causes of regional (market) variation in campylobacteriosis in the United States (Geissler et al., 2017). Ailes et al. (2012) concluded that regional differences in sporadic campylobacteriosis across FoodNet sites in the United States were not explained by differences in medical care or stool sample submission and were unlikely to be due to differences in the virulence of *Campylobacter* strains. They suggested that regional differences in campylobacteriosis rates might be explained by differences in fresh (never frozen) chicken consumed somewhere other than a commercial establishment. Using national passive surveillance of both sporadic cases and outbreaks, Geissler et al., (2017) found that campylobacteriosis incidence rates are higher in the West and rural counties than in the South and metropolitan counties. We find that regional differences in human *Campylobacter* incidence persist even after controlling for fresh chicken purchases for preparation and consumption at home. We also find they persist after controlling for season and temperature. Unfortunately, with only 17 markets, it is not possible to test statistically for specific factors that may be driving variation among markets. These could include things as diverse as regional differences in the prevalence of pathogens on farms, regional differences in immune status due to age or chronic illness rates, or regional differences in outdoor activities.

Strengths and Limitations. No currently available data related to food consumption are ideal for studying the food exposure sources of foodborne disease. The geographic coverage of Homescan© data is extensive compared to the consumption data collected through the "What We Eat in America" (WWEIA) component of the CDC's National Health and Nutrition Examination Survey (NHANES), which collects 2 days of food intake data from only about 5,000 Americans in 15 counties each year. ERS's Loss-Adjusted Food Availability data provide annual national estimates of the food available for consumption, after adjusting for food loss at different points in the production and distribution chain in the United States but does not provide subnational or sub-annual estimates. Store scanner data are daily and geographically detailed but do not capture all retailers or informal markets in a region or provide a reliable means of defining where purchased food is consumed. The Nielsen Homescan© household purchase data provide information about daily purchases tied to the household that uses the food, and broad geographic coverage, but include only food purchased for use at home and only data on the quantity of random-weight foods purchased through 2006. A new ERS survey of household food acquisition and purchases (FoodAPS) collects data on both foods purchased for home use and food consumed away from home, but it too is only nationally representative and is a 1-time survey of food consumption over a 1-week period. Since 2012, IRI household panel purchase data, which replaces the Nielsen Homescan© panel data, has collected data on random-weight food purchases but collects only data on food expenditures, not the quantity of food purchased. ERS has begun research to impute the quantity of food purchased from food expenditures, which could make IRI household panel data usable in studies similar to ours. Finally, food purchase data is an imperfect proxy for food consumption/exposure because of unobserved variation in food storage behavior. Trying to develop food-specific storage lags would complicate the model significantly and would be based on very uncertain judgments about food storage behavior. ERS provides an overview of these and other food data sources on its website.

FoodNet provides the best available data on sporadic gastrointestinal illness, like campylobacteriosis, in the United States; but even so, it has limitations. FoodNet includes only 9 pathogens and surveillance in 10 States, sites not randomly chosen to represent the entire country. In addition, because of the relatively small number of Homescan© markets in the United States in which there is active surveillance of gastrointestinal disease, it is not possible to use our approach to explore whether demographic, behavioral, or biological factors are drivers behind regional differences in campylobacteriosis rates. Our approach also relies on illnesses being relatively frequent; we use *Campylobacter* to explore use of our approach because campylobacteriosis has the second-highest annual incidence rate of disease in FoodNet. Further research is needed to assess how useful our approach is for studying rarer foodborne diseases.

Despite the limitations just discussed, our approach has many strengths. Like case-control studies, our approach allows us to study the determinants of sporadic disease incidence. This is preferable to using outbreak data to study foods associated with campylobacteriosis because most *Campylobacter* infections are sporadic. While using food purchase data as a proxy for consumption has limitations, they are different from those posed by the food consumption recall inherent in case-control studies. Thus the two methods provide robustness checks on each other. In addition, because we do not have to take respondent fatigue into account as case-control studies must, we can look at the influence of all foods on campylobacteriosis, not just the few that are deemed most likely to be risk factors based on prior research. Because we can make use of all cases of illness in a time period, not just a sample, we have enough observations to statistically assess the impact of temperature, season, region, and annual variation on campylobacteriosis in addition to the influence of foods.

This study shows that time-series data on daily food purchases can be used to gain greater insight into the causes of common foodborne illnesses. We show how existing data can be put to new uses in food source attribution to help test the robustness of prior research findings and generate additional insights and new hypotheses. Our results on chicken purchased for consumption at home are consistent with major findings from the single national case-control study of campylobacteriosis in the United States and add to a growing body of research indicating that campylobacteriosis is associated with foods in addition to poultry. We were able to provide new evidence on the influence of season and temperature on sporadic *Campylobacter* incidence in the United States. We also show that regional differences in sporadic campylobacteriosis persist even after controlling for season, temperature, and food purchase patterns.

References

Ailes, E., E. Scallan, R. Berkelman, D. Kleinbaum, R. Tauxe, and C. Moe. 2012. "Do Differences in Risk Factors, Medical Care Seeking, or Medical Practices Explain the Geographic Variation in Campylobacteriosis in Foodborne Diseases Active Surveillance Network (FoodNet) Sites?" *Clinical Infectious Diseases* 54, no. suppl_5: S464-S471.

Archer, D. 2004. "Freezing: an Underutilized Food Safety Technology?" *International Journal of Food Microbiology* 90(2): 127-138.

Arnade, C., L. Calvin, and F. Kuchler. 2009. "Consumer Response to a Food Safety Shock: The 2006 Food-Borne Illness Outbreak of *E. coli* O157:H7 Linked to Spinach," *Review of Agricultural Economics* 31(4): 734-50.

Arsenault, J., O. Berke, P. Michel, A. Ravel, and P. Gosselin. 2012. "Environmental and Demographic Risk Factors for Campylobacteriosis: Do Various Geographical Scales Tell the Same Story?" *BMC Infectious Diseases* 12(1): 318.

Astill, G., F. Kuchler, J. Todd, and E. Page. Forthcoming 2020. "Shiga Toxin–Producing Escherichia coli (STEC) O157:H7 and Romaine Lettuce: Source Labeling, Prevention, and Business," *American Journal of Public Health* 110(3): 322-328, Feb. 2020.

Baker, M., N. Wilson, R. Ikram, S. Chambers, P. Shoe Mack, and G. Cook. 2006. "Regulation of Chicken Contamination Urgently Needed to Control New Zealand's Serious Campylobacteriosis Epidemic," *The New Zealand Medical Journal* 119(1243):U2264.

Batz, M., M. Doyle, J. Morris Jr., J. Painter, R. Singh, R. Tauxe, M. Taylor, M. Danilo. F. Wong, and Food Attribution Working Group. 2005. "Attributing Illness to Food," *Emerging Infectious Diseases* 11(7): 993.

Batz, M., S. Hoffmann, and J. Morris Jr. 2012. "Ranking the Disease Burden of 14 Pathogens in Food Sources in the United States Using Attribution Data from Outbreak Investigations and Expert Elicitation," *Journal of Food Protection* 75(7): 1278-1291.

Cha, W., T. Henderson, J. Collins, and S. Manning. 2016. "Factors Associated with Increasing Campylobacteriosis Incidence in Michigan, 2004–2013," *Epidemiology and Infection* 144(15): 3316-3325.

Colson, A., and R. Cooke. "Cross Validation for the Classical Model of Structured Expert Judgment," *Reliability Engineering and System Safety* 163 (2017): 109-120.

Cooke, R., and K. Shrader-Frechette. 1991. Experts in Uncertainty: Opinion and Subjective Probability in Science. New York, NY. Oxford University Press.

Cools, I., M. Uyttendaele, J. Cerpentier, E. D'haese, H. Nelis, and J. Debevere. 2005. "Persistence of *Campylobacter jejuni* on Surfaces in a Processing Environment and on Cutting Boards," *Letters in Applied Microbiology* 40(6): 418-423.

David, J., F. Pollari, K. Pintar, A. Nesbitt, A. J. Butler, and A. Ravel. 2017. "Do Contamination of and Exposure to Chicken Meat and Water Drive the Temporal Dynamics of *Campylobacter* Cases?" *Epidemiology and Infection* 145(15): 3191-3203.

Davis, M., D. Moore, K. Baker, N. French, M. Patnode, J. Hensley, K. MacDonald, and T. Besser. 2013. "Risk Factors for Campylobacteriosis in Two Washington State Counties with High Numbers of Dairy Farms," *Journal of Clinical Microbiology* 51(12): 3921-3927.

Decker, M., A. Booth, M. Dewey, R. Fricker, R. Hutcheson, and W. Schaffner. 1986. "Validity of Food Consumption Histories in a Foodborne Outbreak Investigation," *American Journal of Epidemiology* 124: 859– 863.

Denis, N., H. Zhang, A. Leroux, R. Trudel, and H. Bietlot. 2016. "Prevalence and Trends of Bacterial Contamination in Fresh Fruits and Vegetables Sold at Retail in Canada," *Food Control* 67: 225-234.

Dewaal, C., G. Hicks, K. Barlow, L. Alderton, and L. Vegosen. 2006. "Foods Associated with Foodborne Illness Outbreaks from 1990 through 2003," *Food Protection Trends* 26(7): 466-473.

Dingle, K., F. Colles, D. Wareing, R. Ure, A. Fox, F. Bolton, H. Bootsma, R. Willems, R. Urwin, and M. Maiden. 2001. "Multilocus Sequence Typing System for *Campylobacter jejuni*," *Journal of Clinical Microbiology 39*(1):14-23.

Djennad, A., G. Nichols, G. Loiacono, L. Fleming, A. Kessel, S. Kovats, I. Lake, et al. 2017. "The Seasonality and Effects of Temperature and Rainfall on *Campylobacter* Infections," *International Journal of Population Data Science* 1(1).

Domingues, A., S. Pires, T. Halasa, and T. Hald. 2012. "Source Attribution of Human Campylobacteriosis Using a Meta-analysis of Case-control Studies of Sporadic Infections," *Epidemiology and Infection* 140(6): 970-981.

Doorduyn, Y., W. van den Brandhof, Y. van Duynhoven, B. Breukink, J. Wagenaar, and W. van Pelt. 2010. "Risk Factors for Indigenous *Campylobacter jejuni* and *Campylobacter coli* Infections in The Netherlands: a Case-control Study," *Epidemiology and Infection 138*(10): 1391-1404.

Ebel, E., M. Williams, D. Cole, C. Travis, K. Klontz, N. Golden, and R. Hoekstra. 2016. "Comparing Characteristics of Sporadic and Outbreak-associated Foodborne Illnesses, United States, 2004–2011," *Emerging Infectious Diseases* 22(7): 1193.

Einav, L., E. Leibtag, and A. Nevo. Dec. 2008. *On the Accuracy of Nielsen Homescan© Data*. Economic Research Report. No. 69. U.S. Department of Agriculture, Economic Research Service.

Ekdahl, K., B. Normann, and Y. Andersson. 2005. "Could Flies Explain the Elusive Epidemiology of Campylobacteriosis?" *BMC Infectious Diseases* 5(1): 11.

European Food Safety Authority (EFSA). 2008. "Overview of Methods for Source Attribution for Human Illness from Foodborne Microbiological Hazards-Scientific Opinion of the Panel on Biological Hazards," *EFSA Journal* 6(7): 764.

European Food Safety Authority (EFSA). 2014. “Guidance on Expert Knowledge Elicitation in Food and Feed Safety Risk Assessment,” *EFSA Journal* 12(6): 3734.

Evans, M., C. Ribeiro, and R. Salmon. 2003. “Hazards of Healthy Living: Bottled Water and Salad Vegetables as Risk Factors for *Campylobacter* Infection,” *Emerging Infectious Diseases* 9(10): 1219.

Evers, E., H. van der Fels-Klerx, M. Nauta, J. Schijven, and A. Havelaar. 2008. “Campylobacter Source Attribution by Exposure Assessment,” *International Journal of Risk Assessment and Management* 8(1): 174.

French, N., A. Midwinter, B. Holland, J. Collins-Emerson, R. Pattison, and P. Carter. 2007. “Molecular Epidemiology of *Campylobacter jejuni* Isolated from Wild Bird Faecal Material in Children’s Play Areas,” In *Zoonoses and Public Health* 54-52. Hoboken, NJ. Wiley-Blackwell.

Friedman, C., R. Hoekstra, M. Samuel, R. Marcus, J. Bender, B. Shiferaw, S. Reddy, D. Ahuja, D. Helfrick, F. Hardnett, and M. Carter. 2004. “Risk Factors for Sporadic *Campylobacter* Infection in the United States: a Case-control Study in FoodNet Sites,” *Clinical Infectious Diseases 38*(Supplement_3): S285-S296.

Fullerton, K., L. Ingram, T. Jones, B. Anderson, P. McCarthy, S. Hurd, B. Shiferaw, D. Vugia, N. Haubert, T. Hayes, and S. Wedel. 2007. “Sporadic *Campylobacter* Infection in Infants: a Population-based Surveillance Case-control Study,” *The Pediatric Infectious Disease Journal 26*(1): 19-24.

Gallay, A., V. Bousquet, V. Siret, V. Prouzet-Mauléon, H. de Valk, V. Vaillant, F. Simon, Y. Le Strat, F. Mégraud, and J. Desenclos. 2008. “Risk Factors for Acquiring Sporadic *Campylobacter* Infection in France: Results from a National Case-control Study,” *The Journal of Infectious Diseases* 197(10): 1477-1484.

Geissler, A., F. Bustos Carrillo, K. Swanson, M. Patrick, K. Fullerton, C. Bennett, K. Barrett, and B. Mahon. 2017. “Increasing Campylobacter Infections, Outbreaks, and Antimicrobial Resistance in the United States, 2004–2012,” *Clinical Infectious Diseases* 65 (10): 1624-1631.

General Accounting Office. 1992. “Uniform, Risk-based Inspection System Needed to Ensure Safe Food Supply,” Washington, DC.

Georgsson, F., A. Þorkelsson, M. Geirsdottir, J. Reiersen, and N. Stern. 2006. “The Influence of Freezing and Duration of Storage on *Campylobacter* and Indicator Bacteria in Broiler Carcasses,” *Food Microbiology* 23(7): 677-683.

Goldstein, R., E. Rosenberg, R. Cruz-Cano, C. Jiang, A. Palmer, D. Blythe, P. Ryan, B. Hogan, et al. 2016. “Association between Community Socioeconomic Factors, Animal Feeding Operations, and Campylobacteriosis Incidence Rates: Foodborne Diseases Active Surveillance Network (FoodNet), 2004–2010,” *BMC Infectious Diseases* 16(1): 354.

Guo, C., R. Hoekstra, C. Schroeder, S. Pires, K. Ong, E. Hartnett, A. Naugle, J. Harman, P. Bennett, P. Cieslak, and E. Scallan. 2011. “Application of Bayesian Techniques to Model the Burden of Human Salmonellosis Attributable to US Food Commodities at the Point of Processing: Adaptation of a Danish Model,” *Foodborne Pathogens and Disease 8*(4): 509-516.

Gould, L., K. Walsh, A. Vieira, K. Herman, I. Williams, A. Hall, and D. Cole. 2013. "Surveillance for Foodborne Disease Outbreaks – United States, 1998-2008," *Surveillance Summaries* 62(SS02): 1-34.

Greenland S., D.C. Thomas, and H. Morgenstern. December 1986. "The Rare-disease Assumption Revisited. A Critique of "Estimators of Relative Risk for Case-control Studies," *American Journal of Epidemiology* 124(6): 869–83.

Hald, B., H. Sommer, and H. Skovgård, 2007. "Use of Fly Screens to Reduce *Campylobacter* spp. Introduction in Broiler Houses," *Emerging Infectious Diseases* 13(12): 1951–1953.

Hald, T., D. Vose, H. Wegener, and T. Koupeev. 2004. "A Bayesian Approach to Quantify the Contribution of Animal food Sources to Human Salmonellosis," *Risk Analysis: an International Journal* 24(1): 255-269.

Havelaar, A., A. Vargas Galindo, D. Kurowicka, and R. Cooke. 2008. "Attribution of Foodborne Pathogens Using Structured Expert Elicitation," *Foodborne Pathogens and Disease* 5(5): 649-659.

Henson, S., 1997. "Estimating the Incidence of Food-borne *Salmonella* and the Effectiveness of Alternative Control Measures Using the Delphi Method," *International Journal of Food Microbiology* 35(3): 195-204.

Hoffmann, S., P. Fischbeck, A. Krupnick, and M. McWilliams. 2007. Using Expert Elicitation to Link Foodborne Illnesses in the United States to Foods," *Journal of Food Protection 70*(5): 1220-1229.

Hoffmann, S., B. McCulloch, and M. Batz. 2015. *Economic Burden of Major Foodborne Illnesses Acquired in the United States,* EIB-140, U.S. Department of Agriculture, Economic Research Service.

Interagency Food Safety Analytics Collaboration (IFSAC). Feb. 2011. Interagency Food Safety Analytics Collaboration (IFSAC): Charter.

Interagency Food Safety Analytics Collaboration (IFSAC). Jan. 2012. IFSAC: Strategic Plan for Foodborne Illness Source Attribution.

Interagency Food Safety Analytics Collaboration (IFSAC). June 2016. Interagency Food Safety Analytics Collaboration (IFSAC): Charter.

Interagency Food Safety Analytics Collaboration (IFSAC). 2017a. IFSAC: Strategic Plan—Calendar Year 2017-2021.

Interagency Food Safety Analytics Collaboration (IFSAC). 2017b. IFSAC: 2017-2021 Action Plan.

Jore, S., H. Viljugrein, E. Brun, B. Heier, B. Borck, S. Ethelberg, M. Hakkinen, M. Kuusi, J. Reiersen, I. Hansson, and E. Engvall. 2010. "Trends in *Campylobacter* Incidence in Broilers and Humans in Six European Countries, 1997–2007," *Preventive Veterinary Medicine 93*(1): pp.33-41.

Kassenborg, H., C. Hedberg, M. Hoekstra, M. Evans, A. Chin, R. Marcus, D. Vugia, K. Smith, S. Ahuja, L. Slutsker, and P. Griffin. 2004. "Farm Visits and Undercooked Hamburgers as Major Risk Factors for Sporadic *Escherichia coli* O157:H7 Infection: Data from a Case-control Study in 5 FoodNet Sites," *Clinical Infectious Diseases 38*(Supplement_3): S271-S278.

Kimura, A., V. Reddy, R. Marcus, P. Cieslak, J. Mohle-Boetani, H. Kassenborg, S. Segler, F. Hardnett, T. Barrett, D. Swerdlow, and Emerging Infections Program FoodNet Working Group. 2004. "Chicken Consumption is a Newly Identified Risk Factor for Sporadic *Salmonella enterica* Serotype Enteritidis Infections in the United States: a Case-control Study in FoodNet Sites," *Clinical Infectious Diseases 38*(Supplement_3): S244-S252.

Kovats, R., S. Edwards, D. Charron, J. Cowden, R. D'Souza, K. Ebi, C. Gauci, P. Gerner-Smidt, S. Hajat, S. Hales, and G. Pezzi. 2005. "Climate Variability and *Campylobacter* Infection: an International Study," *International Journal of Biometeorology 49*(4): 207-214.

Kuhn, K. Gaardbo, E. Møller Nielsen, K. Mølbak, and Steen Ethelberg. 2018. "Determinants of Sporadic Campylobacter Infections in Denmark: a Nationwide Case-control Study among Children and Young Adults," *Clinical Epidemiology* 10: 1695.

Lake, R., P. Cressey, D. Campbell, and E. Oakley. 2010. "Risk Ranking for Foodborne Microbial Hazards in New Zealand: Burden of Disease Estimates," *Risk Analysis: an International Journal* 30(5): 743-752.

Lal, A., S. Hales, N. French, and M. Baker. 2012. "Seasonality in Human Zoonotic Enteric Diseases: a Systematic Preview," *PLoS One* 7(4): e31883.

Lin, B.-H., and J. Guthrie. 2012. *Nutritional Quality of Food Prepared at Home and Away from Home, 1977-2008*, EIB No. 105, U.S. Department of Agriculture, Economic Research Service.

Louis, V., I. Gillespie, S. O'Brien, E. Russek-Cohen, A. Pearson, and R. Colwell. 2005. "Temperature-driven *Campylobacter* Seasonality in England and Wales," *Applied and Environmental Microbiology* 71(1): 85-92.

MacDonald, E., R. White, R. Mexia, T. Bruun, G. Kapperud, H. Lange, K. Nygård, and L. Vold. 2015. "Risk Factors for Sporadic Domestically Acquired *Campylobacter* Infections in Norway 2010–2011: A National Prospective Case-control Study," *PLoS One* 10(10): e0139636.

McBride, G., M. Meleason, C. Skelly, R. Lake, P. VanDerLodgt, and R. Collins. 2005. *Preliminary relative risk assessment for Campylobacter exposure in New Zealand*: *1. National Model for Four Potential Human Exposure Routes 2*.

Mann, J. 1981. "A Prospective Study of Response Error in Food History Questionnaires: Implications for Foodborne Outbreak Investigation," *American Journal Public Health* 71: 1362– 1366.

Miller, G., G. Dunn, A. Smith-Palmer, I. D. Ogden, and N. J. C. Strachan. 2004. "Human Campylobacteriosis in Scotland: Seasonality, Regional Trends and Bursts of Infection," *Epidemiology and Infection* 132(4): 585-593.

Morgan, M., M. Henrion, and M. Small. 1992. *Uncertainty: a Guide to Dealing with Uncertainty in Quantitative Risk and Policy Analysis*. Cambridge, UK, New York, NY. Cambridge University Press.

Mughini Gras, L., J. Smid, J. Wagenaar, A. de Boer, A. Havelaar, I. Friesema, N. French, L.Busani, and W. van Pelt. 2012. "Risk Factors for Campylobacteriosis of Chicken, Ruminant, and Environmental Origin: a Combined Case-Control and Source Attribution Analysis," *PloS one* 7(8): e42599.

Mullner, P., T. Shadbolt, J. Collins-Emerson, A. Midwinter, S. Spencer, J. Marshall, P. Carter, D. Campbell, D. Wilson, S. Hathaway, and R. Pirie. 2010. "Molecular and Spatial Epidemiology of Human Campylobacteriosis: Source Association and Genotype-related Risk Factors," *Epidemiology and Infection* 138(10): 1372-1383.

Muth, M., A Okrent, C. Zhen, and S. Karns. 2020. *Using Scanner Data for Food Policy Research*. London, UK, San Diego, CA, Cambridge, MA, Oxford, UK. Academic Press, Elsevier.

National Academy of Sciences. 1985. *Meat and Poultry Inspection: The Scientific Basis of the Nation's Program*. Washington, DC

National Academy of Sciences. 1987. *Poultry Inspection: The Basis for a Risk Assessment Approach*. Washington, DC.

National Academy of Sciences. 2003. *Scientific Criteria to Ensure Safe Food*. Washington, DC.

National Academies of Sciences. 2009. *Letter Report on the Review of the Food Safety and Inspection Service Proposed Risk-Based Approach to and Application of Public-Health Attribution*. Washington, DC.

National Chicken Council. 2012. Consumers Speak about Chicken Breast Meat/Breast Tenders: Survey Results 2012.

National Consumer Panel. 2013. "National Consumer Panel: a Nielsen/Symphony IRI Joint Venture," IRI

Neal, K. R., and R. Slack. 1995. "The Autumn Peak in Campylobacter Gastro-enteritis. Are the Risk Factors the Same for Travel-and UK-acquired Campylobacter Infections?" *Journal of Public Health* 17(1): 98-102.

Nelson, W., and B. Harris. 2017. "Campylobacteriosis–the Problem with Chicken-as-source." doi:10.5281/zenodo.853494.

Nylen, G., F. Dunstan, S. Palmer, Y. Andersson, F. Bager, J. Cowden, G. Feierl, Y. Galloway, G. Kapperud, F. Megraud, and K. Molbak. 2002. "The Seasonal Distribution of *Campylobacter* Infection in Nine European Countries and New Zealand," *Epidemiology and Infection* 128(3): 383-390.

Omair, A. 2015. "Selecting the Appropriate Study Design for Your Research: Descriptive Study Designs," *Journal of Health Specialties 3*(3), 153.

Painter, J., R. Hoekstra, T. Ayers, R. Tauxe, C. Braden, F. Angulo, and P. Griffin. 2013. "Attribution of Foodborne Illnesses, Hospitalizations, and Deaths to Food Commodities by Using Outbreak Data, United States, 1998–2008," *Emerging Infectious Diseases* 19(3): 407.

Pasturel, B., R. Cruz-Cano, R. Rosenberg Goldstein, A. Palmer, D. Blythe, P. Ryan, B. Hogan, C. Jung, S. Joseph, M. Wang, and M. Ting Lee. 2013. "Impact of Rurality, Broiler Operations, and Community Socioeconomic Factors on the Risk of Campylobacteriosis in Maryland," *American Journal of Public Health* 103(12): 2267-2275.

Patrick, M., L. Engbo Christiansen, M. Wainø, S. Ethelberg, H. Madsen, and H. Caspar Wegener. 2004. "Effects of Climate on Incidence of *Campylobacter* spp. in Humans and Prevalence in Broiler Flocks in Denmark," *Applied Environmental Microbiology* 70(12): 7474-7480.

Patrick, M., O. Henao, T. Robinson, A. Geissler, A. Cronquist, S. Hanna, S. Hurd, F. Medalla, J. Pruckler, and B. Mahon. 2018. "Features of Illnesses Caused by Five Species of *Campylobacter*, Foodborne Diseases Active Surveillance Network (FoodNet)–2010–2015," *Epidemiology and Infection* 146(1): 1-10.

Pires, S., E. Evers, W. van Pelt, T. Ayers, E. Scallan, F. Angulo, A. Havelaar, and T. Hald. 2009. "Attributing the Human Disease Burden of Foodborne Infections to Specific Sources," *Foodborne Pathogens and Disease* 6: 417-424.

Pires, S., A. Vieira, T. Hald, and D. Cole. 2014. "Source Attribution of Human Salmonellosis: an Overview of Methods and Estimates," *Foodborne Pathogens and Disease 11*(9): 667-676.

Pogreba-Brown, K., K. Ernst, and R. Harris. 2014. "Case-case Methods for Studying Enteric Diseases: a Review and Approach for Standardization," *OA Epidemiology* 2(1): 7.

Pogreba-Brown, K., A. Baker, K. Ernst, J. Stewart, R. B. Harris, and J. Weiss. 2016. "Assessing Risk Factors of Sporadic *Campylobacter* Infection: a Case-control Study in Arizona," *Epidemiology and Infection* 144(4): 829-839.

Potter, R., J. Kaneene, and W. Hall. 2003. "Risk Factors for Sporadic *Campylobacter jejuni* Infections in Rural Michigan: a Prospective Case–control Study," *American Journal of Public Health* 93(12): 2118-2123.

Powell, M. 2016. "Trends in Reported Foodborne Illness in the United States; 1996–2013," *Risk Analysis: an International Journal* 36(8):1589-1598.

Ravel, A., K. Pintar, A. Nesbitt, and F. Pollari. 2016. "Non-food-related Risk Factors of Campylobacteriosis in Canada: a Matched Case-control Study," *BMC Public Health* 16(1): 1016.

Richardson, L., M. Bazaco, C. Parker, D. Dewey-Mattia, N. Golden, K. Jones, K. Klontz, C. Travis, J. Zablotsky Kufel, and D. Cole. 2017. "An Updated Scheme for Categorizing Foods Implicated in Foodborne Disease Outbreaks: a Tri-agency Collaboration," *Foodborne Pathogens and Disease* 14(12): 701-710.

Rosner, B., A. Schielke, X. Didelot, F. Kops, J. Breidenbach, N. Willrich, G. Gölz, et al. 2017. "A Combined Case-Control and Molecular Source Attribution Study of Human Campylobacter Infections in Germany, 2011–2014," *Scientific Reports* 7(1): 5139.

Rothman, K. 2012. *Epidemiology: an Introduction*. New York, NY. Oxford University Press.

Scallan, E., R. Hoekstra, F. Angulo, R. Tauxe, M. Widdowson, S. Roy, J. Jones, and P. Griffin. 2011. "Foodborne Illness Acquired in the United States—Major Pathogens," *Emerging Infectious Diseases* 17(1): 7.

Schönberg-Norio, D., J. Takkinen, M. Hänninen, M. Katila, S. Kaukoranta, L. Mattila, and H. Rautelin. 2004. "Swimming and Campylobacter Infections," *Emerging Infectious Diseases* 10(8): 1474.

Skarp, C., M. Hänninen, and H. Rautelin. 2016. "Campylobacteriosis: the Role of Poultry Meat," *Clinical Microbiology and Infection* 22(2): 103-109.

Soneja, S., C. Jiang, C. Upperman, R. Murtugudde, C. Mitchell, D. Blythe, A. Sapkota, and A. Sapkota. 2016. "Extreme Precipitation Events and Increased Risk of Campylobacteriosis in Maryland, USA," *Environmental Research* 149: 216-221.

Strachan, N., O. Rotariu, A. Smith-Palmer, J. Cowden, S. Sheppard, S. O'Brien, M. Maiden, et al. 2013. "Identifying the Seasonal Origins of Human Campylobacteriosis," *Epidemiology and Infection* 141(6): 1267-1275.

Stafford, R., P. Schluter, M. Kirk, A. Wilson, L. Unicomb, R. Ashbolt, J. Gregory, and OzFoodNet Working Group. 2007. "A Multi-centre Prospective Case-control Study of *Campylobacter* Infection in Persons Aged 5 Years and Older in Australia," *Epidemiology and Infection* 135(6): 978-988.

Tam, C., L. Rodrigues, S. O'brien, and S. Hajat. 2006. "Temperature Dependence of Reported *Campylobacter* Infection in England, 1989–1999," *Epidemiology and Infection* 134(1): 119-125.

Taylor, E., K. Herman, E. Ailes, C. Fitzgerald, J. Yoder, B. Mahon, and R. Tauxe. 2013. "Common Source Outbreaks of *Campylobacter* Infection in the USA, 1997–2008," *Epidemiology and Infection* 141(5): 987-996.

Tustin, J., K. Laberge, P. Michel, J. Reiersen, S. Dađadóttir, H. Briem, H. Harđardóttir, K. Kristinsson, E. Gunnarsson, V. Friđriksdóttir, and F. Georgsson. 2011. "A National Epidemic of Campylobacteriosis in Iceland, Lessons Learned," *Zoonoses and Public Health 58*(6):440-447.

Tyson, G., H. Tate, J. Abbott, T. Tran, C. Kabera, E. Crarey, S. Young, P. McDermott, G. Sprague, M. Campbell, and O. Adeyemo. 2016. "Molecular Subtyping and Source Attribution of *Campylobacter* Isolated from Food Animals," *Journal of Food Protection* 79(11): 1891-1897.

U.S. Centers for Disease Control and Prevention (CDC). 2000. "Foodborne Disease Active Surveillance Network (FoodNet) 2000 Surveillance Report."

U.S. Centers for Disease Control and Prevention (CDC). 2006. "Foodborne Disease Active Surveillance Network (FoodNet) 2006 Surveillance Report."

U.S. Centers for Disease Control and Prevention (CDC). 2013a. "FoodNet 2011 Surveillance Report," Centers for Disease Control and Prevention, Atlanta.

U.S. Centers for Disease Control and Prevention (CDC). 2008. "Summary of Notifiable Diseases – United States, 2006," *Mortality and Morbidity Weekly Report* 55(3): March 21, 2008.

U.S. Centers for Disease Control and Prevention (CDC). 2013d. "Attribution of Foodborne Illness: Methods and Data Sources," Centers for Disease Control and Prevention, Atlanta.

U.S. Centers for Disease Control and Prevention (CDC). 2019. "Foodborne Illness Analytics Collaboration," Centers for Disease Control and Prevention, Atlanta.

U.S. Centers for Disease Control and Prevention (CDC). 2018 "Foodborne Diseases Active Surveillance Network (FoodNet)," Centers for Disease Control and Prevention, Atlanta.

U.S. Centers for Disease Control and Prevention (CDC). 2018. "*Campylobacter* (Campylobacteriosis) Symptoms," Centers for Disease Control and Prevention, Atlanta.

U.S. Department of Agriculture, Economic Research Service (ERS). What We Eat in America.

U.S. Department of Agriculture, Economic Research Service (ERS). 2019. Food Availability (Per Capita) Data System: Overview. Data Product.

U.S. Department of Agriculture, Economic Research Service (ERS). FoodAPS National Household Food Acquisition and Purchase Survey.

U.S. Department of Agriculture, Economic Research Service (ERS). Food Data Sources.

U.S. Department of Agriculture, Food Safety and Inspection Service (FSIS). "Meat and Poultry Labeling Terms."

U.S. Department of Agriculture, Food Safety and Inspection Service (FSIS). July 25, 1996. "Pathogen Reduction/Hazard Analysis and Critical Control Point System: Final Rule," *Federal Register* 61 (144): 38806-38989.

U.S. Department of Agriculture, Food Safety and Inspection Service (FSIS). 2017a. FSIS Strategic Plan for FY2017 to FY2021.

U.S. Department of Agriculture, Food Safety and Inspection Service (FSIS). 2017b. FSIS Annual Plan for FY2017.

U.S. Department of Agriculture, Food Safety and Inspection Service (FSIS). April 18, 2008. "Public Health Risk-Based Inspection System of Processing and Slaughter. Technical Report." Washington, DC.

U.S. Department of Agriculture, National Advisory Committee on Microbiological Criteria for Foods. 1997. HACCP Principles and Application Guidelines.

U.S. Environmental Protection Agency (EPA), Scientific Advisory Board. 2012. Expert Elicitation White Paper Review.

U.S. Food and Drug Administration (FDA). Jan. 19, 2001. "Hazard Analysis and Critical Control Point (HAACP); Procedures for the Safe and Sanitary Processing and Importing of Juice; Final Rule," *Federal Register* 66(13): 6138-6202.

U.S. Food and Drug Administration (FDA). July 12, 2011. “FSMA Facts: Background on the FDA Food Safety Modernization Act (FSMA).”

University of Dayton--Environmental Protection Agency Average Daily Temperature Archive.

Vellinga, A., and F. Van Loock. 2002. “The Dioxin Crisis as Experiment to Determine Poultry-related *Campylobacter enteritis*,” *Emerging Infectious Diseases* 8(1): 19.

Vereen, E., R. Lowrance, D. Cole, and E. Lipp. 2007. “Distribution and Ecology of Campylobacters in Coastal Plain Streams (Georgia, United States of America),” *Applied and Environmental Microbiology* 73(5)): 1395-1403.

Verhoeff-Bakkenes, L., H Jansen, R. Beumer, M. Zwietering, and F. Van Leusden. 2011. “Consumption of Raw Vegetables and Fruits: a Risk Factor for *Campylobacter* Infections,” *International Journal of Food Microbiology* 144(3): 406-412.

Vipham, J., M. Brashears, G. Loneragan, A. Echeverry, J. Chance Brooks, W. Evan Chaney, and M. Miller. 2012. “*Salmonella* and *Campylobacter* Baseline in Retail Ground Beef and Whole-muscle Cuts Purchased during 2010 in the United States,” *Journal of Food Protection* 75(12): 2110-2115.

Voetsch A., M. Kennedy, W. Keene, K. Smith, T. Rabatsky-Ehr, S. Zansky, S. Thomas, J. Mohle-Boetani, P. Sparling, M. Mcgavern, and P. Mead. 2007. “Risk Factors for Sporadic Shiga toxin-producing *Escherichia coli* O157 Infections in FoodNet Sites, 1999–2000,” *Epidemiology and Infection* 35: 993–1000.

Weisent, J., W. Seaver, A. Odoi, and B. Rohrbach. 2010. “Comparison of Three Time-series Models for Predicting Campylobacteriosis Risk,” *Epidemiology and Infection* 138(6): 898-906.

Whiley, H., B. van den Akker, Steven Giglio, and R. Bentham. 2013. “The Role of Environmental Reservoirs in Human Campylobacteriosis,” *International Journal of Environmental Research and Public Health* 10(11): 5886-5907.

Williams, M., J. Withee, E. Ebel, N. Bauer Jr., W. Schlosser, W. Disney, D. Smith, and R. Moxley. 2010. “Determining Relationships between the Seasonal Occurrence of *Escherichia coli* O157 in Live Cattle, Ground Beef, and Humans,” *Foodborne Pathogens and Disease* 7(10): 1247-1254.

Williams, M., N. Golden, E. Ebel, E. Crarey, and H. Tate. 2015. “Temporal Patterns of *Campylobacter* Contamination on Chicken and Their Relationship to Campylobacteriosis C in the United States,” *International Journal of Food Microbiology* 208: 114-121.

Wingstrand, A., J. Neimann, J. Engberg, E. Møller Nielsen, P. Gerner-Smidt, H. Wegener, and K. Mølbak. 2006. “Fresh Chicken as Main Risk Factor for Campylobacteriosis, Denmark,” *Emerging Infectious Diseases* 12(2): 280.

World Health Organization (WHO), Food and Agriculture Organization of the United Nations (FAO) and World Organization for Animal Health (OAH). 2012. *The Global View of Campylobacteriosis: Report of Expert Consultation. Utrecht, Netherlands, 9-11 July 2012.* World Health Organization, Geneva, Switzerland.