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The effects of ambient temperature changes on foodborne illness outbreaks associated with the restaurant industry

Abstract

Foodborne illness outbreaks generate serious socioeconomic costs in the United States. Among many causes, the effects of weather change and the habit of frequently dining out at restaurants are very important topics for researchers, because ambient temperature change may influence the entire process of food consumption from farms to tables, and restaurants are considered to be the most predominant single location responsible for foodborne illness outbreaks. However, few studies have examined both factors simultaneously, although empirical findings support a significant relationship between each factor and foodborne illness outbreaks. Therefore, the objective of this study is to link the effects of ambient temperature change with foodborne illness outbreaks in restaurant business settings. Furthermore, this study aims to identify how restaurant firms have performed compared with others in regard to foodborne illness outbreaks. Finally, this study intends to suggest how restaurant firms can reduce or prevent the prevalence of foodborne illness outbreaks.

Keywords: ambient temperature; foodborne illnesses; foodborne hospitalizations; restaurants; Norovirus; Salmonella

1. Introduction

Foodborne illnesses generate serious socioeconomic costs in the United States. Every year, approximately 47.8 million people in the U.S. become ill (1 out of 6) and 128,000 people are hospitalized due to foodborne pathogens (Scallan et al., 2011a, 2011b). Among them, the Centers for Disease Control and Prevention (CDC) estimates that only 20% (9.4 million) of illnesses and approximately 44% (55,961) of hospitalizations are from known pathogens, which impose an economic burden that exceeds $15.5 billion annually (Hoffmann, Maculloch, & Batz, 2015).

Although most foodborne illnesses cause relatively minor symptoms (Dominianni et al., 2018), a single foodborne illness outbreak can also cost millions of dollars for a restaurant firm in lost revenue, fines, lawsuits, and employee retraining (Bartsch et al., 2018). In severer cases, an outbreak can ruin the restaurant's reputation and harshly devalue its worth, thus making the firm take a much longer time to fully recover from the negative impacts. For example, the consequences of the multiple foodborne illness outbreaks at Chipotle Mexican Grill in October and November 2015 slashed nearly 25% off of the firm's stock price, thereby diminishing the firm's value by $5.75 billion (from $23 billion to $17.25 billion) in just two months. Therefore, the prevention and precise diagnosis of foodborne illness outbreaks are very significant topics not only for government health authorities but also for the restaurant industry.

To reduce the socioeconomic burden from foodborne illnesses, an enhanced monitoring system and a structured farm-to-table approach, such as the Hazard Analysis and Critical Control Points (HACCP) approach, have been adopted during the last 20 years, and all sectors of the food chain are encouraged to follow enhanced food safety practices (Newell et al., 2010). However, despite the continuous efforts of government, industry, and academia, preventing foodborne illness outbreaks is still an ongoing public health problem, and the challenges persist. The responsibility may be embedded in the fact that such implementations are heavily based on the findings from substantial research efforts in diagnosing intestinal diseases and in detecting foodborne pathogens.

A serious limitation of the empirical findings to date is that the vast majority of foodborne illness outbreaks (80% of illnesses and 56% of hospitalizations) are caused by unknown pathogens (Hoffmann et al., 2015). In addition, most foodborne illnesses are not even reported to the health authorities. In the National Outbreak Reporting System (NORS), the average annual number of reported foodborne illnesses and hospitalizations were 14,475 and 840, respectively, from 2009 to 2016. That is to say that the proportion of reported illnesses in NORS was less than 0.03% of an expected 47.8 million cases, and the share of informed hospitalizations in NORS was approximately 0.7% of an estimated 128,000 cases (Hoffmann et al., 2015, p. 2). This lack of data makes it difficult for public health authorities and academia to verify the causes of foodborne illness outbreaks precisely. For the same reason, the analysis may not be proficient in preventing potential foodborne illness outbreaks because it relies only on the confirmed or suspected foodborne illnesses in the NORS database, even though there are many unidentified causes.

Even with those limitations, the effects of climate change and variability on foodborne illness outbreaks have been extensively investigated by researchers (Uyttendaele et al., 2015; Tirado et al., 2010; Miraglia et al., 2009; Lake, 2017; D’souza et al., 2004; Martinez-Urtaza et al., 2010). The subject has been a significant focus for study because changes in the climate, such as changes in ambient temperature and precipitation, may have direct and indirect impacts on various stages of the food chain, from production to consumption (Tirado et al., 2010). According to Uyttendaele et al. (2015, p. 1), “Climate change has an impact not only on crop production or food security (Fischer, Shah, Tubiello, & Van Velhuizen, 2005; Gregory, Ingram,

& Brklacich, 2005), but also on food safety, incidence and prevalence of foodborne diseases (Lal et al., 2012; Miraglia et al., 2009; Tirado, Clarke, Jaykus, McQuatters-Gollop, & Frank, 2010)."

Another important research topic for foodborne illness outbreaks has been dedicated to the restaurant environment, because restaurants have been proven to be the most predominant single location responsible for foodborne illness outbreaks (Bartsch et al., 2018; Dewey-Mattia et al., 2018). According to the National Restaurant Association (2016), the average American dined out five times per week and spent 47% of his or her food dollars for food away from home in 2016. In that context, restaurant food is an essential part of the everyday diet in the United States. At the same time, restaurant food has been blamed as a most likely source for foodborne illness outbreaks: According to the CDC's 2016 annual report, restaurants were involved in approximately 61% of the total reported foodborne illness outbreaks (Dewey-Mattia et al., 2018).

Therefore, it is undeniable that climate change and restaurant settings are important factors in foodborne illness outbreaks. Nonetheless, few studies have examined both factors simultaneously, which raises two indispensable questions for understanding the causes of foodborne illness outbreaks. The first question that arises is "How does ambient temperature change influence the foodborne illness outbreaks at restaurants?" The second question is based on the fact that Americans consume almost half of their food from restaurants. Therefore, how many foodborne illness outbreaks would be too many for them? Accordingly, the second, two-part question is "Does the restaurant industry really cause major foodborne illness outbreaks? If so, how can restaurant firms decrease the prevalence of the foodborne illness outbreaks?" In the context of these queries, this study has connected two critical questions and aimed to suggest a better way to reduce the socioeconomic burdens caused by foodborne illness outbreaks.

To achieve those objectives, this study linked the monthly weather data from the National Centers for Environmental Information (NCEI) for all 50 states with the NORS data, which included not only food-related illness outbreaks but also all other enteric disease outbreaks including unknown disease sources from 2009 to 2016. Then, the outcomes of the impacts of weather change on foodborne illness outbreaks were compared with all other enteric disease outbreaks and restaurant associated foodborne illnesses. In that way, this study should provide enhanced, robust findings to add to the extant literature.

2. Literature review

2.1 The effects of ambient temperature change on foodborne illnesses

Whereas the impacts of climate change have been investigated intensively across broad areas of research, the interdisciplinary link between ambient temperature change and food safety remains thin even though the topic has gradually been receiving growing attention from researchers and policymakers (Miraglia et al., 2009; Uyttendaele et al., 2015).

Nonetheless, the NORS data from 2009 to 2016 clearly show that enteric disease outbreaks from all sources, including from food, water, animal, environmental, person-to-person, and indeterminate/unknown sources, had a very strong seasonality. Among the total reported enteric disease outbreaks, January (15.4%), February (15.0%), March (13.7%), and December (12.0%) had the most frequent outbreaks. For those four months, the respective numbers of illnesses (18.6%, 18.3%, 14.3%, and 14.0%) and hospitalizations (14.9%, 14.2%, 12.6%, and 9.8%) were also the highest. However, when the data included only foodborne disease outbreaks, without considering other sources, the strength of seasonality in the frequency of outbreaks and the number of illnesses disappeared: March (9.7%), May (10.2%), June (9.5%), and December (9.4%) showed the most frequent outbreaks, but the number of illnesses was the highest in April (9.7%), May (9.4%), June (9.6%), and December (10.2%). Furthermore, the number of hospitalizations for foodborne illnesses was the highest in June (15.2%) and July (10.7%), and that trend was contradictory to the pattern of overall enteric disease outbreaks. These conflicts between all enteric disease outbreaks and foodborne illness outbreaks cast doubt on the true (or general) effects of ambient temperature on outbreaks of foodborne illnesses.

(Insert Table 1 here)

Semenza et al. (2012) suggested that changes in climate conditions can influence the prevalence and reproduction of foodborne diseases and, among several climate parameters, they felt that ambient temperature provided the best available climate data. A number of studies have shown that the ambient temperature positively influences the incidence of certain enteric diseases, including from Salmonella, with the highest number of illnesses occurring during the summer months in different countries (D'souza et al., 2004; Fleury et al., 2006; Semenza et al., 2012; Lake et al., 2009). Tirado et al. (2010) also advocated that the changes in temperature and precipitation have an impact on the prevalence of foodborne diseases because they are indispensably influential elements for the growth of pathogens. Martinez-Urtaza et al. (2010) expanded the other studies by investigating the potential effects of climate anomalies on seafood-borne illnesses caused by *Vibrio parahaemolyticus* and *Vibrio vulnificus* that occurred outside the normal geographic and seasonal ranges. They found evidence that the greatest *Vibrio* abundance and risk occurred during climate anomalies, and thus, they proposed more rigorous post-harvest time-temperature controls in response to the vulnerability of raw seafood consumption (Martinez-Urtaza et al., 2010).

Higher ambient temperatures may increase the frequency of occurrence of foodborne illness outbreaks for several reasons. First, increased ambient temperatures can accelerate the reproduction of certain enteric pathogens within a food at various points in the food chain (Kovats et al., 2004). Second, high ambient temperatures may change the consumer's eating patterns (Lake et al., 2009). For example, when the temperature is extremely hot, people are especially likely to eat uncooked or raw foods that face relatively higher risks of cross-contamination. Last, high outdoor temperatures also may inspire people to engage in outdoor activities and travel, thus exposing them more frequently to potentially hazardous food resources (Lake et al., 2009). Knowing these issues, how can the seasonality trend of overall enteric disease outbreaks be explained? The most frequent occurrence of overall enteric disease outbreaks, including illnesses and hospitalizations, has appeared in winter months (December, January, February, and March). All of the empirical evidence has serious limitations to answering the question why. Therefore, more robust evidence from the bigger picture should be provided to clarify the adversarial effects of ambient temperature change on foodborne illnesses.

2.2 The effects of ambient temperature change on foodborne illness outbreaks originating at restaurants

According to the CDC's annual report "Surveillance for Foodborne Disease Outbreaks: United States, 2016," restaurants were associated with 459 outbreaks that represented 54.7% of the total of 839 reported foodborne illness outbreaks (Dewey-Mattia et al., 2018). The majority were from sit-down restaurants (363 outbreaks, 43.3% of the total reported foodborne illness outbreaks, and 79.1% of all reported res outbreaks from restaurants) (Dewey-Mattia et al., 2018, p. 1). However, the reports may not illustrate the whole picture of foodborne illness outbreaks originating at restaurants, because they were based on only the small portion that had a confirmed etiology or food vehicle. In addition, the 54.7% share of restaurant-associated outbreaks in the total number of reported foodborne illness outbreaks was not surprisingly high, considering the public's frequency of dining out (five times per week), the proportion of food dollars spent for food away from home (47%), and the probability of under-reporting of foodborne illnesses caused by the consumption of foods at home. Furthermore, if the data include all of the foodborne illnesses and hospitalizations estimated by Hoffmann et al. (2015), the proportion of reported foodborne illnesses associated with restaurants becomes even more trivial. The proportion of reported illnesses from dining out at the restaurants would be only 0.016% (7,869/47,800,000 cases) of the total expected illnesses (47.8 million), and the proportion of reported hospitalizations after eating out at restaurants would be just 0.3% (384/2,625 cases) of the total expected number of hospitalizations (127,839 cases) in 2016.

Despite the data limitations, there is no doubt that restaurants are an important single location for causing foodborne illness outbreaks (Batsch et al., 2018; Hedberg et al., 2006; Gould et al., 2013). More importantly, the dominance of foodborne illness outbreaks at sit-down restaurants indicates that the different food preparation procedures between the sit-down and fast-food restaurants is a distinctive factor for restaurant-associated foodborne illness outbreaks. Using a different approach, Hedberg et al. (2006) compared 22 restaurants that had experienced foodborne illness outbreaks from 2002 to 2003 with 347 restaurants that had no associated foodborne illness outbreak during that period. The researchers found no substantial environmental differences between the two groups – not in the number of meals served, the employee training, or the policy for sick leave benefits. The single exception was that the non-outbreak restaurants had a greater presence of a certified kitchen manager. Furthermore, Jones et al. (2004) did not identify any significant difference in mean restaurant inspection scores between restaurants associated with foodborne illness outbreaks and those with no reported associated outbreaks. In addition, the most common contributing factors for foodborne illness outbreaks had been verified to be the practices of food handling and preparation (61% of all contributors) during the period between 1998 and 2013 (Angelo et al., 2017). The healthiness and hygiene of restaurant employees were also among the most important factors found for different restaurant settings (Angelo et al., 2017; Gould et al., 2013; Hedberg et al., 2006). However, neither the prevalence of foodborne illness outbreaks associated with the sit-down restaurants nor the concurrent evidence of restaurant employees' inappropriate food preparation practices, such as food preparation by ill employees or food preparation with bare hands, can directly explain the strong seasonality of foodborne illness outbreaks in restaurant settings.

One noticeable phenomenon associated with recent foodborne illnesses has been the increasing occurrence of foodborne illness outbreaks from consuming fruits and fresh produce (Sivapalasingam et al., 2004; Lynch et al., 2009; Callejón et al., 2015). Nowadays that increased prevalence is a growing public concern, because fruits and fresh produce have important nutritional benefits for the public's diet, but, paradoxically, they also have become an important contributor to foodborne illness outbreaks. The proportion of reported foodborne illness outbreaks from consuming fresh produce, such as radish sprouts, prepackaged spinach, raspberries, strawberries, green onions, and lettuce, has been increasing in the United States (Sivapalasingam et al., 2004). Over the same time period, vegetable row crops, fruits, and seeded vegetables were the most frequent sources of restaurant-associated foodborne illnesses (15%, 10%, and 11%, respectively) and hospitalizations (17%, 3%, and 14%, respectively) in the United States during 1998 and 2013 (Angelo et al., 2017). The seriousness of the issue lies in the fact that fruits and fresh produce can be contaminated at any point in the food chain, from farm to table, and that the contamination cannot be fully washed off with water, sanitizer, or any post-harvest decontamination processes (Lynch et al., 2009; Berger et al., 2010). Thus, prevention in the first place, and improved traceability, will be more effective solutions for reducing foodborne illness outbreaks that originate at restaurants than better preparation practices can be. One obvious fact of the findings is that fresh fruits and vegetables are important potential vehicles for transmission of pathogens, and they can be contaminated externally or even internally at various stages before they arrive at restaurant tables. Certainly, at the point of arrival, at least some of those foods are contaminated (e.g., Sivapalasingam et al., 2004). Therefore, the strengths and variability of potential pathogens that survive on or within fresh fruits and produce can be influenced by ambient temperature change before the foods arrive at restaurants and also can be altered by time-temperature controls after they have been received at restaurants. Those are important assumptions of this study.

3. Methodology

3.1 Samples and data

This study combined the NCEI's monthly weather data for all states in the United States with the data from NORS. From the available weather information, the study used the monthly data for ambient temperature, temperature anomalies, precipitation, and precipitation anomalies in each state from 2009 to 2016. The sample included the NORS data only after 2009 because in that year the Foodborne Disease Outbreak Surveillance System was newly incorporated into the web-based platform, which also included details about all other gastroenteritis outbreaks, such as those from water-borne, person-to-person, and even unknown modes of transmission. The NORS data were collected on December 10, 2018, and included data on foodborne illness outbreaks and all other enteric disease outbreaks including unknown resources from 2009 to 2016.

3.2 Variables and statistical models

For dependent variables, this study used the natural log of all illnesses, hospitalizations, illnesses from Norovirus and Salmonella, and hospitalizations for Norovirus and Salmonella. The study included the natural log of the 1) foodborne illnesses and of the 2) foodborne-illness-related hospitalizations, and compared them with the 3) foodborne illnesses acquired at restaurants, and the 4) hospitalizations for foodborne illnesses acquired at restaurants. In addition, the study separated the natural log of foodborne illnesses caused by 5) Norovirus and by 6) Salmonella, and also foodborne hospitalizations caused by 7) Norovirus and by 8) Salmonella. Then, those were compared with foodborne illnesses caused by 9) Norovirus and by 10) Salmonella acquired at restaurants, and also hospitalizations for foodborne illnesses caused by 11) Norovirus and 12) Salmonella acquired at restaurants. Finally, the study used the natural log of the ratio of 13) foodborne illnesses acquired at restaurants over the total number of all foodborne illnesses, 14) hospitalizations for foodborne illnesses acquired at restaurants over all foodborne-illness-related hospitalizations, 15) foodborne illnesses from Salmonella acquired at restaurants over all foodborne illnesses from Salmonella, 16) foodborne illnesses from Norovirus acquired at restaurants over all foodborne illnesses from Norovirus, 17) hospitalizations for foodborne illnesses caused by Norovirus acquired at restaurants over all hospitalizations for foodborne illnesses caused by Norovirus, and 18) hospitalizations for foodborne illnesses caused by Salmonella acquired at restaurants over hospitalizations for all foodborne illnesses caused by

Salmonella. For analytic models, the study compared all results obtained from linear regression and from Bayesian linear regression. For an independent variable (X_1), the study used the ambient temperature. For control variables, the anomalies of the ambient temperature (X_2), the amount of precipitation (X_3), and the anomalies of the amount of precipitation (X_4) were included.

- Log(Y) = β_0 + β_1*ambient temperature (X_1) + β_2*temperature anomaly (X_2) + β_3*precipitation (X_3) + β_4*precipitation anomaly (X_4) + ε (Linear Regression Model)

For Bayesian analysis, the study used Random-walk Metropolis-Hastings samplings. For dependent variables (Y), we used the natural log of the ratio of 1) foodborne illnesses acquired at restaurants over all foodborne illnesses, 2) foodborne illnesses from Norovirus acquired at restaurants over all foodborne illnesses from Norovirus, 3) foodborne illnesses from Salmonella acquired at restaurants over all foodborne illnesses from Salmonella, 4) hospitalizations for foodborne illnesses acquired at restaurants over all foodborne-illness-related hospitalizations, 5) hospitalizations for foodborne illnesses caused by Norovirus acquired at restaurants over all hospitalizations for foodborne illnesses caused by Norovirus, and 6) hospitalizations for foodborne illnesses caused by Salmonella acquired at restaurants over all hospitalizations for foodborne illnesses caused by Salmonella. For the independent variable and control variables, the study used the same variables as in the linear regression models. The algorithm starts with $X^{(0)} := (X_1^{(0)}, \ldots \ldots X_p^{(0)})$ and uses a symmetric random walk proposal g, iterates for t = 1, 2, …..

1. Draw $\varepsilon \sim$ g and set X = $X^{(t-1)} + \varepsilon$

2. Compute

$\alpha(X|X^{(t-1)}) = \min\{1, \frac{f(X)}{f(X^{(t-1)})}\}$

3. With probability $\alpha(X|X^{(t-1)})$ set $X^{(t)} = X$, otherwise set $X^{(t)} = X^{(t-1)}$

The models used the independent normal priors with zero mean and a variance of 10,000 for regression coefficients and the inverse gamma (0.01, 0.01) for the variance parameter.

- $P(\beta|Log(Y), X) = \frac{P(Log(Y)|\beta, X) * P(\beta|X)}{P(Log(Y)|X)}$ (Bayesian Linear Regression Model)

4. Results

4.1 Descriptive analysis

As shown in Figure 1, the effect of ambient temperature appeared to have a negative relation to overall gastroenteritis outbreaks. The highest number of illnesses was reported at 31°F (-0.6°C) and the largest number of hospitalizations was at 36°F (2.2°C), which were quite cold temperatures. Both types of occurrence were the highest in January. Interestingly, there was a slightly positive relationship between ambient temperature and foodborne illness outbreaks. Foodborne illnesses were reported most frequently at 65°F (18.3°C) and foodborne-illness-related hospitalizations peaked at 66°F (18.9°C), which were warmer ambient temperature than those in the cases of overall enteric disease outbreaks. The foodborne-illness-related hospitalizations showed the highest records in July and June, but the trends for the foodborne illnesses was not clear across the months.

(Insert Figure 1 here)

The discrepancies in the effect of ambient temperature between overall enteric disease outbreaks and foodborne illness outbreaks seemed to be caused by the different etiologies. As shown in Figure 2, the majority of overall enteric illnesses were caused by person-to-person Norovirus transmission (e.g., Dewey-Mittia et al., 2018), which had a strong negative relationship with the ambient temperature. However, although foodborne illnesses from Norovirus food contamination seemed to have a similarly negative trend with the ambient temperature, the number of occurrences was relatively trivial compared with the number of overall enteric illnesses. On the contrary, the foodborne illnesses were mainly caused by consuming Salmonella-contaminated foods (e.g., Dewey-Mittia et al., 2018) and showed a strongly positive relationship with the ambient temperature. However, there was almost no overall enteric illness that was caused by person-to-person Salmonella transmission. As a result, the ambient temperature showed a negative relationship with the overall enteric illnesses but a positive relationship with foodborne illnesses. The phenomena were the same in the number of hospitalizations. The majority of overall enteric-pathogen-caused hospitalizations were caused by person-to-person Norovirus spread, but the foodborne-illness-related hospitalizations were caused by Salmonella-contaminated food consumption.

(Insert Figure 2 here)

The seasonality of other foodborne illness outbreaks (foodborne illness outbreaks excluding those in restaurant settings) seemed to be similar: Other foodborne illnesses showed a negative relation to the ambient temperature, and other foodborne-illness-related hospitalizations followed a rather positive trend. However, the effect of ambient temperature on foodborne-illness-related hospitalizations seemed to be stronger and more volatile in other areas than it was for restaurants. In addition, the ambient temperature's effects on all foodborne illnesses seemed to be very similar in other areas to its effects on those illnesses in restaurant settings.

(Insert Figure 3 here)

4.2 Linear regression analysis

The results from the ordinary least squares regression models confirmed that a significant relationship existed between the ambient temperature and gastroenteritis disease outbreaks. More specifically, the ambient temperature had a significant negative impact on gastroenteritis illnesses from Norovirus (e.g., Hall et al., 2013; Wikswo et al., 2015): The coefficient was -0.0365, with a *p*-value of less than 0.01. On the other hand, the effect of the ambient temperature on gastroenteritis illnesses from Salmonella was significantly positive, with a coefficient of 0.0130 and a *p*-value of less than 0.01 (e.g., Hall et al., 2013; Wikswo et al., 2015). Despite the opposite directions of two different etiologies, the ambient temperature showed a negative impact (-0.0320, with $p < 0.01$) on the overall number of gastroenteritis illnesses, due to the dominant gastroenteritis outbreaks from Norovirus: The coefficient changed by only +0.0045 from -0.0365 (for Norovirus). The influence of the ambient temperature on gastroenteritis-related hospitalizations showed similar trends: It had a significantly negative relationship (-0.0222, with $p < 0.01$) with the number of hospitalizations for Norovirus but showed a weakly positive impact (0.0035, with $p < 0.1$) on the number of hospitalizations for Salmonella. There was no dominant effect from ambient temperature on the number of Norovirus cases (it changed by +0.0132 from -0.0222 (Norovirus)), but ambient temperature had a slightly stronger impact on the number of all gastroenteritis hospitalizations (-0.0090, with $p < 0.01$).

(Insert Table 2 here)

For the next analysis, we examined the effect of the ambient temperature on foodborne illness outbreaks at restaurants and its impact on overall foodborne illness outbreaks. Consistently with the evidence for all gastroenteritis illnesses, the ambient temperature had a significantly negative impact (-0.0093, with $p < 0.01$) on the foodborne illnesses caused by Norovirus acquired at restaurants, but it had a significantly positive effect (0.0067, with $p < 0.05$) on the foodborne illnesses caused by Salmonella acquired at restaurants. The effects of the ambient temperature on the foodborne illnesses caused by Norovirus were very similar between Norovirus illnesses acquired at restaurants and those from all other eating places (-0.0093 vs. -0.0096). However, the ambient temperature influenced the number of cases of foodborne illnesses caused by Salmonella acquired at restaurants less strongly than it affected the number acquired at all other eating places (0.0067 vs. 0.0106). As a result, the ambient temperature showed a significantly negative impact on foodborne illnesses acquired at restaurants (-0.0048, with $p < 0.01$), but it had no significant impact on such illnesses acquired at all other eating places including restaurants (-0.0019, $p > 0.1$). In other words, the (negative) impact of ambient temperature on foodborne illnesses caused by Norovirus was still stronger than the ambient temperature's (positive) impact was on foodborne illnesses caused by Salmonella acquired at restaurant settings. However, they had similar strengths in overall foodborne illness settings.

(Insert Table 3 here)

Interestingly, the impact of ambient temperature on hospitalizations for foodborne illnesses caused either by Norovirus (-0.0019, with $p > 0.1$) or Salmonella (-0.0001, with $p > 0.1$) was not statistically significant, which was inconsistent with the findings of previous studies. Nonetheless, ambient temperature had a significant positive effect on the overall number of hospitalizations for foodborne illnesses acquired both at restaurants (0.0069, with $p < 0.01$) and at all eating places including restaurants (0.0080, with $p < 0.01$). These findings indicate that even though Norovirus and Salmonella were the major etiologies of foodborne illness outbreaks associated with restaurants and with all other eating places, the foodborne-illness-related hospitalizations were also caused by other sources that were positively influenced by the ambient temperature.

(Insert Table 4 here)

In the following analysis our findings are contrary to the public's concerns, because the restaurant firms showed better performance than other eating places did, in terms both of the number of foodborne illnesses and of hospitalizations for those illnesses. As is shown in Table 5, a significant negative relationship was found between the ambient temperature and the proportion of foodborne illnesses acquired at restaurants over the total number of foodborne illnesses (-0.0039, with $p < 0.01$). The major difference between the effect of ambient temperature on foodborne illnesses at restaurants and its effect on all foodborne illnesses was explained by Salmonella: The proportion of foodborne illnesses caused by Salmonella acquired at restaurants, relative to the total number of all foodborne illnesses, was -0.0040, with $p < 0.01$. The influence of the ambient temperature on foodborne illnesses caused by Norovirus was not significantly different between the number of cases acquired at restaurant settings and the number at all other eating places. Similarly, the impact of the ambient temperature on the ratio of hospitalizations for foodborne illnesses associated with restaurants, over the total number of foodborne-illness-related hospitalizations, was negatively significant (-0.0040, with $p < 0.01$). Although the impact of the ambient temperature on hospitalizations for foodborne illnesses caused by Norovirus was not statistically significant, its impact on hospitalizations for foodborne illnesses caused by Salmonella was significant (-0.0034, with $p < 0.01$), and that also explained most of the differences in the number of hospitalizations for foodborne illnesses associated with restaurants and those associated with all other eating places. Both findings clearly indicated that in response to ambient temperature changes, restaurant firms had done relatively well in preventing foodborne illnesses and their related hospitalizations, compared with the success of all other eating places.

(Insert Table 5 here)

4.3 Bayesian regression analysis

The Bayesian regression models clearly showed that the negative relationship between the ambient temperature and the proportion of foodborne illnesses acquired at restaurants over the total number of foodborne illnesses was caused by foodborne illnesses from Salmonella. As is shown in Table 6, when the ambient temperature went up by 1 degree (°F), the proportion of foodborne illnesses acquired at restaurants over the total number of foodborne illnesses decreased by 0.4% (mean and median), or between 0.64% and 0.16%, in the 95% confidence interval. When the ambient temperature increased by 1 degree (°F), the proportion of foodborne illnesses from Salmonella acquired at restaurants over all foodborne illnesses caused by Salmonella decreased by 0.4% (mean and median), or between 0.7% and 0.1%, in the 95% confidence interval. On the contrary, when the ambient temperature decreased by 1 degree (°F), the proportion of foodborne illnesses caused by Norovirus acquired at restaurants, over the total number of foodborne illnesses from Norovirus, also decreased by 0.21% (mean) or 0.2% (median), or between 0.07% and -0.52% (increased), in the 95% confidence interval. Nonetheless, the overall effect of the ambient temperature on the proportion of restaurant associated foodborne illnesses over all foodborne illnesses was quite similar to the case of foodborne illnesses from Salmonella (-0.0040 vs. -0.0040). Therefore, this study concluded that restaurant firms had performed better than all other eating places had, especially with regard to preventing foodborne illnesses from Salmonella, because the ambient temperature showed a consistent, positive impact on all foodborne illnesses from Salmonella and a negative impact on all foodborne illnesses from Norovirus. Although restaurant firms also had performed better than other eating places did with regard to foodborne illnesses from Norovirus that difference was not significant compared with their performance in terms of foodborne illnesses from Salmonella.

(Insert Table 6 here)

Besides, the trace plots of "foodborne illnesses acquired at restaurants over all foodborne illnesses: ambient temperature," "foodborne illnesses from Norovirus acquired at restaurants over all foodborne illnesses from Norovirus," and "foodborne illnesses from Salmonella acquired at restaurants over all foodborne illnesses from Salmonella" illustrated well-mixed parameters that presented the dense drawn lines looking almost vertical. Furthermore, the autocorrelations decreased continuously and became very small after some lag numbers. The density plots also proved that there was a good convergence between the first half and the second half. The models showed that the Markov (MCMC) efficiency of all regression coefficients was larger than 0.01 and smaller than 0.1.

(Insert Figure 4 here)

The results for foodborne-illness-related hospitalizations revealed very similar results to the cases of foodborne illnesses. The Bayesian regression models appeared to indicate that the ambient temperature had a negative effect on the proportion of foodborne illnesses acquired at restaurants over the total number of foodborne illnesses, and that negative effect was mainly caused by foodborne-illness-related hospitalizations for Salmonella. A 1-unit (°F) increase in the ambient temperature decreased the proportion of hospitalizations for foodborne illnesses acquired at restaurants over the total number of foodborne-illness-related hospitalizations by 0.41% (mean and median), or between 0.67% and 0.15%, in the 95% confidence interval. Similarly, a 1-degree (°F) higher ambient temperature decreased the ratio of the number of foodborne-illness-related hospitalizations for Salmonella acquired at restaurants to the total number of foodborne-illness-related hospitalizations due to Salmonella by 0.31% (mean) or 0.32% (median), or between 0.62% and 0.00% in the 95% confidence interval. On the other hand, as the ambient temperature decreased by 1 unit (°F), the share of the number of foodborne-illness-related hospitalizations for Norovirus acquired at restaurants decreased by 0.13% (mean and median), or between 0.14% and -0.39% (increased), in the 95% confidence interval. In these models, the overall effect of the ambient temperature on the proportion of restaurant associated foodborne-illness-related hospitalizations over all foodborne-illness-related hospitalizations was explained primarily by the foodborne-illness-related hospitalizations for Salmonella (-0.0041 vs. -0.0031). Therefore, the findings revealed that, in general, restaurant firms also had responded better than all other eating places had to the influence that changes in ambient temperature exerted on foodborne-illness-related hospitalizations, especially those from Salmonella but also those from Norovirus, even though the improvement in the number of foodborne-illness-related hospitalizations for Norovirus was not sufficiently large compared with that from Salmonella.

(Insert Table 7 here)

The diagnostics of the Bayesian regression models did not show any significant issues with the models. The trace plots of “foodborne-illness-related hospitalizations associated with restaurants, over all foodborne-illness-related hospitalizations: ambient temperature,” “foodborne-illness-related hospitalizations for Norovirus acquired at restaurants over all foodborne-illness-related hospitalizations for Norovirus,” and “foodborne-illness-related hospitalizations for Salmonella acquired at restaurants over all foodborne-illness-related hospitalizations for Salmonella,” indicated well-mixed parameters with almost vertical and dense trends. In addition, the autocorrelations decreased constantly, and the first half and the second half density plots looked very similar. In addition, the MCMC efficiency of all regression coefficients was between 0.01 and 0.1.

(Insert Figure 5 here)

4.4 Food sources of restaurant-associated foodborne illness outbreaks

Restaurants have been considered to be the primary locations responsible for foodborne illness outbreaks (e.g., Angelo et al., 2017; Dewey-Mittia et al., 2018; Hedberg et al., 2006). In this context, it would be meaningful to compare the causes of foodborne illness outbreaks at restaurants with those at other places. Among all foodborne illness outbreaks reported during the time period we studied, restaurant-associated illnesses consisted of approximately 42.6% (171,666/403,111) and restaurant-associated hospitalizations entailed approximately 41% (6,766/16,517) from 2009 and 2016. In terms of the Interagency Food Safety Analytics Collaboration (IFSAC) category, foodborne illnesses were caused more frequently at restaurants than at other eating places, and the food sources that were responsible were eggs, fish, mollusks, and vegetable row crops. Among them, eggs showed the biggest difference between the two types of locations: eggs caused 2.5 times more illnesses (2,511) at restaurants than at other places. In addition, seeded vegetables (4,403) and eggs (4,198) were the most frequent sources of restaurant-associated foodborne illnesses. On the contrary, beef, chicken, fruits, pork, seeded vegetables, and turkey caused far fewer illnesses at restaurants than at other places. The foodborne-illness-related hospitalizations showed similar patterns. Eggs, mollusks, and sprouts were more frequent sources for foodborne illnesses acquired at restaurants than at other places, while beef, chicken, fruits, and seeded vegetables were less frequent sources for illnesses acquired at restaurants than at other places. Furthermore, seeded vegetables (438) and vegetable row crops (325) were the most serious sources of foodborne-related-illnesses that were acquired at restaurants and that led to hospitalization. However, there were many unknown food sources that caused foodborne illness outbreaks, and that gap limited the implications of our findings.

(Insert Table 7 here)

5. Discussion and conclusions

5.1 Summary of findings

One objective of this study was to identify the effects of ambient temperature change on the foodborne illness outbreaks in restaurant settings. The issue is important because, despite the substantial efforts of government authorities, industry, and academia to prevent foodborne illness outbreaks, such outbreaks do not show any downward trend and are persistently responsible for substantial economic and sociological costs.

Unquestionably, previous evidence suggested that the ambient temperature had a significant impact on gastroenteritis disease outbreaks and also on foodborne illness outbreaks. Interestingly, the previous findings specifically showed that the seasonality for gastroenteritis disease outbreaks varied by different etiologies, such as with the strong winter seasonality of

Norovirus and the strong summer seasonality of Salmonella. However, few studies had examined the variant relationships between the ambient temperature and foodborne illness outbreaks by different etiologies and in restaurant business settings.

Another predominant proposition form past research was that restaurants were the single most important source location for foodborne illness outbreaks. However, before 2009, the NORS data included only foodborne illness outbreaks and were plagued by many unidentified causes and under-reported outbreaks. For those reasons, it has not been appropriate to find the benchmark and to draw the whole picture for the prevalence of foodborne illness outbreaks. Thus, it has been problematic to find effective ways to prevent foodborne illness outbreaks in the restaurant environment. To overcome those limitations, this study examined the trend in overall gastroenteritis outbreaks and then compared it with the cases not only of overall foodborne illness outbreaks but also of the restaurant-associated foodborne illness outbreaks.

First, this study identified that ambient temperature has a negative impact on foodborne illness outbreaks from Norovirus at restaurants, a finding that was consistent with previous evidence that had shown the negative relationship between the ambient temperature and the overall gastroenteritis outbreaks from Norovirus (D'souza et al., 2004; Fleury et al., 2006; Hall et al., 2013; Wikswo et al., 2015). Second, this study identified that ambient temperature has a positive impact on foodborne illness outbreaks from Salmonella, a finding that also corresponded to other, empirical evidence of seasonality in foodborne illness outbreaks from Salmonella (Pui et al., 2011; Kovats et al., 2004; Wikswo et al., 2015). In addition, this study presented evidence that the effect of ambient temperature was stronger on foodborne illnesses than on foodborne-illness-related hospitalizations, in both overall foodborne-illness situations and restaurant-associated foodborne-illness situations. Finally, temperature had a strong negative impact on both overall foodborne and restaurant-associated foodborne illnesses from Norovirus, but it had a strong positive impact on both overall foodborne and restaurant-associated foodborne illnesses from Salmonella.

Furthermore, this study suggested that restaurant firms have achieved better records than other eating places have in preventing both foodborne illnesses and their related hospitalizations, in response to ambient temperature changes. The improvement was substantial in regard to foodborne illnesses and hospitalizations for Salmonella, whereas it was not as extensive in regard to foodborne illnesses and hospitalizations for Norovirus. The findings indicated that the prevention of foodborne illnesses and hospitalizations for person-to-person illness transmission was not as effective in restaurant business settings as it was in other eating places. However, the restriction of foodborne illnesses and hospitalizations for contaminated foods was fairly efficient at restaurants, compared with other eating places. Those inferences endorsed this study to examine better ways to prevent foodborne illness outbreaks in restaurant business settings.

The last findings of this study revealed that restaurant firms should take precautions for foodborne illnesses when they prepare foods from eggs and vegetable row crops. In addition, this study found that eggs caused more frequent foodborne hospitalizations at restaurants than at other eating places. In both cases, eggs were the shared risk factor for foodborne illness outbreaks in restaurant business settings.

5.2 Implications

This study is the first-ever attempt to understand the effects of ambient temperature on restaurant-associated foodborne illness outbreaks, through comparing temperature data with overall foodborne illness outbreaks and with the foodborne illness outbreaks at other eating places. The approach is unique and valuable because it enables us to verify the strengths and weaknesses of the restaurant industry with regard to foodborne illness outbreaks. In recent years, the American people have spent nearly half of their food budget for restaurant foods, and the role of restaurant foods in the daily diet of Americans is expected to continue to increase due to anticipated changes in economic and sociodemographic factors (e.g., household income, employment, size of the household, and ethnic composition) (Stewart et al., 2004; Liu, Kasteridis, & Yen, 2012). Thus, food safety in the restaurant industry is an important issue not only for the restaurant industry but also for government health authorities and other food-related industries. In fact, growing public concerns about the effects of climate change on people's daily lives are very serious and challenging, regardless of the industry. Therefore, the findings of this study are relevant and provide several practical implications.

First, despite the limitations of the data because of unknown pathogens and under-reported foodborne illness outbreaks, this study strongly suggests that the food industry, including the restaurant industry, should develop a better method of identifying contaminated eggs in order to reduce the prevalence of foodborne illness outbreaks, and using pasteurized eggs instead of fresh eggs would be one solution. Otherwise, when fresh eggs are used, the restaurant industry should find a better way to prevent cross-contamination from eggshells or the eggs themselves. Furthermore, it is much more difficult to prevent foodborne illness outbreaks when fresh eggs are used for uncooked foods, such as mayonnaise and other egg-based sauces.

Another practical implication of this study is that the food industry should improve the methods it uses to detect contaminated vegetable row crops and fresh vegetables, because those foods are ready to eat and their inherent pathogens cannot be eliminated by heat or other cooking procedures. The evidence of increasing foodborne illness outbreaks from consuming fresh vegetables supports that implication (Berger et al., 2010; Lynch et al., 2009; Sivapalasingam et al., 2004).

Finally, even with those important implications from our work, many sources of foodborne illness outbreaks remain unknown and foodborne illness outbreaks are largely under-reported – two inherent limitations of our findings.

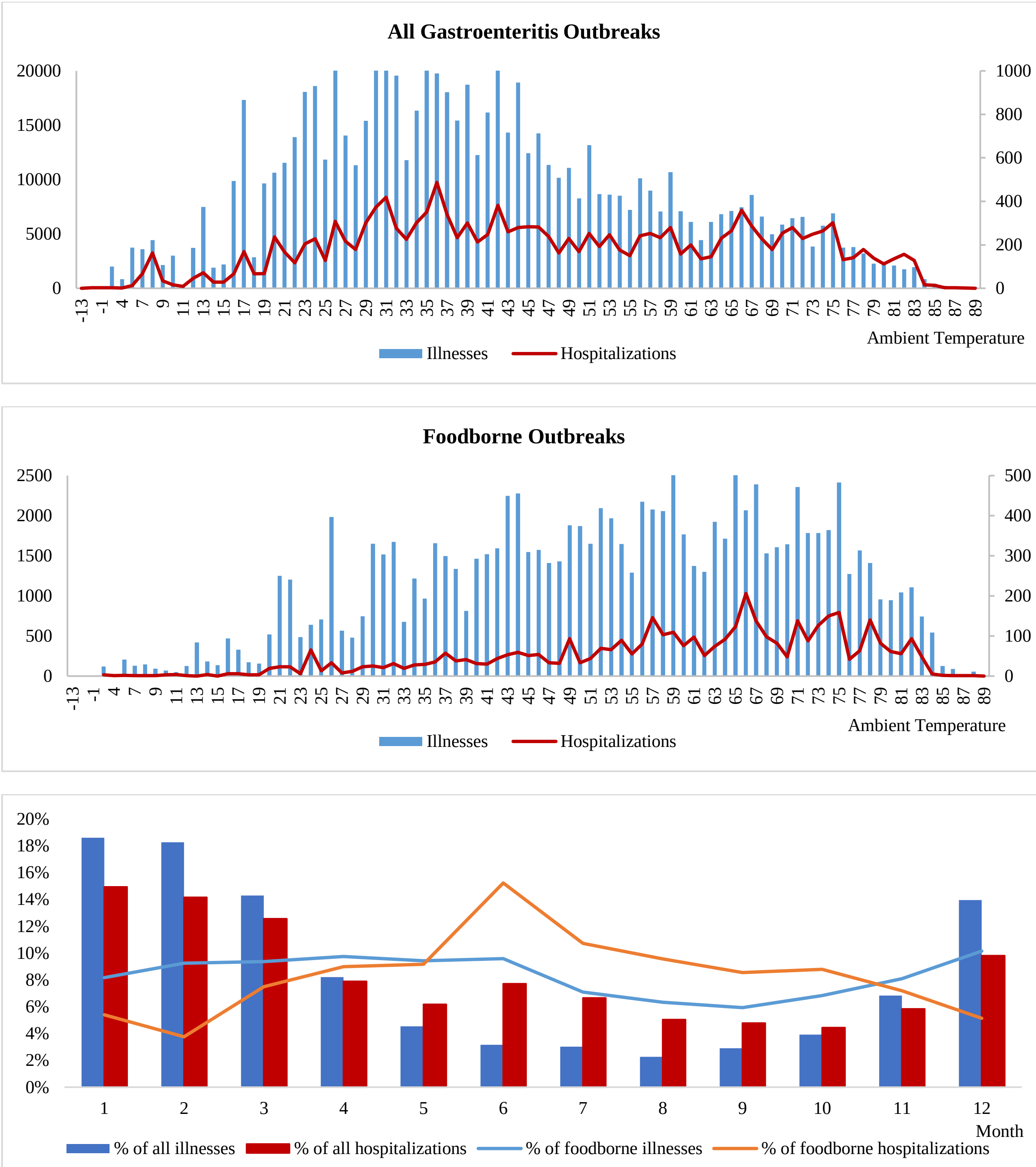

Figure 1. Seasonality of all gastroenteritis illness outbreaks vs. foodborne illness outbreaks reported in NORS (from 2009 to 2016)

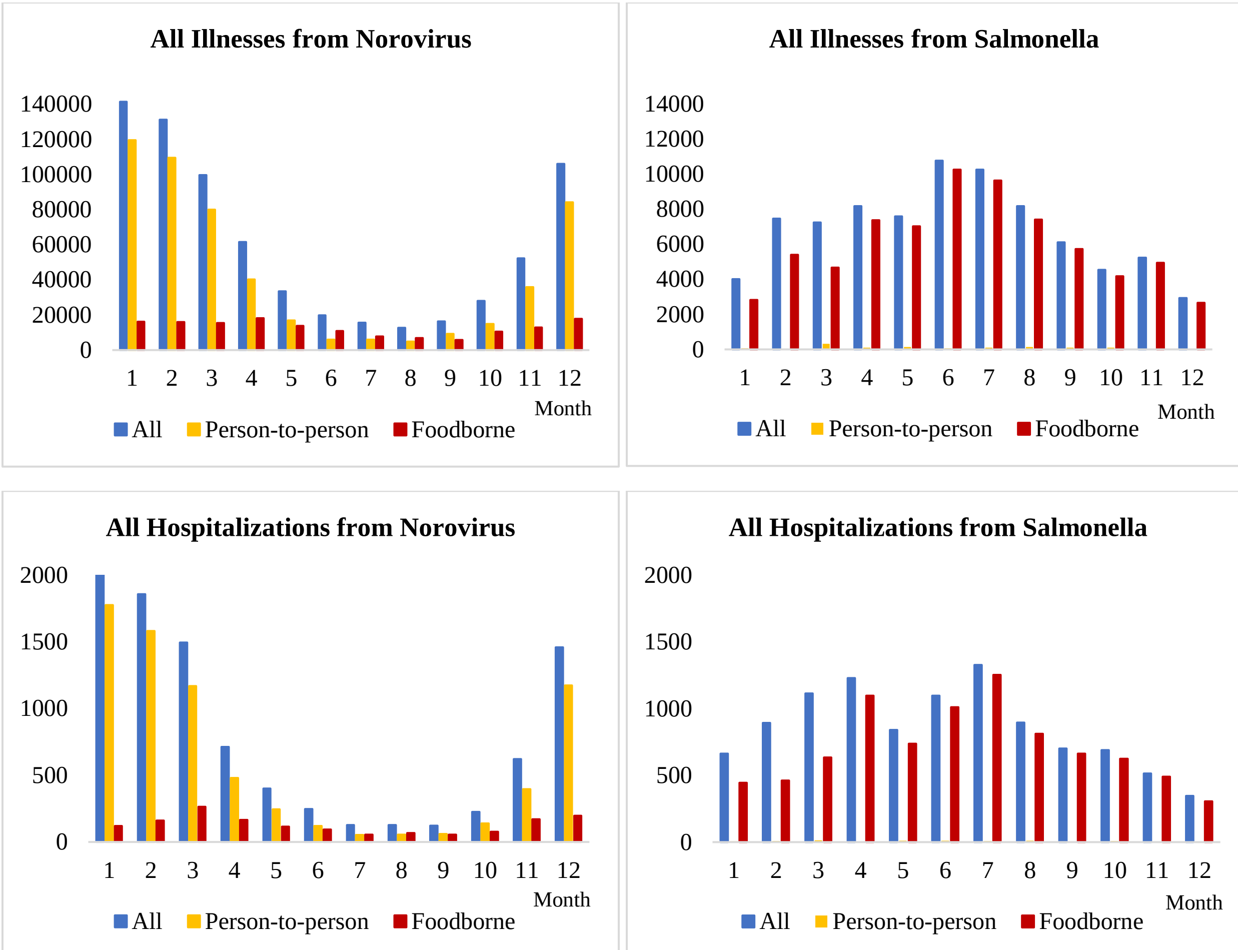

Figure 2. Seasonality of all gastroenteritis illnesses from norovirus vs. from salmonella reported in NORS (from 2009 to 2016)

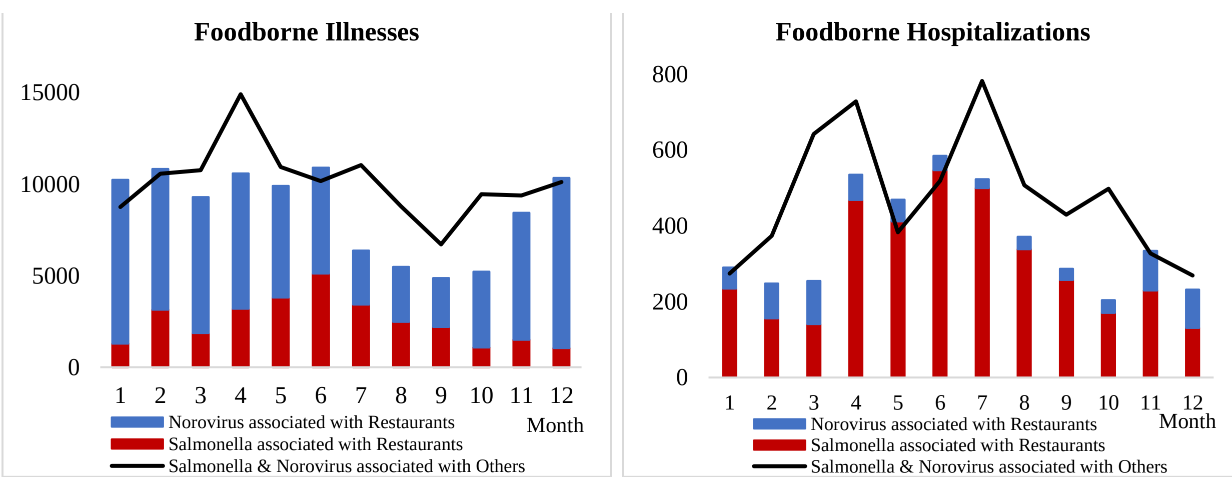

Figure 3. Seasonality of foodborne illnesses from salmonella and norovirus originating at restaurants vs. at others reported in NORS (from 2009 to 2016)

Table 1. Monthly gastroenteritis outbreaks from 2009 to 2016

Month	All Illnesses		All Hospitalizations		Foodborne Illnesses		Foodborne Hospitalizations	
1	**144,746**	**18.6%**	**2,377**	**14.9%**	8,291	8.2%	227	5.4%
2	**142,161**	**18.3%**	**2,255**	**14.2%**	9,383	9.3%	158	3.8%
3	**111,197**	**14.3%**	**1,999**	**12.6%**	9,491	9.4%	315	7.5%
4	63,893	8.2%	1,258	7.9%	**9,878**	**9.7%**	378	9.0%
5	35,376	4.5%	985	6.2%	**9,547**	**9.4%**	**385**	**9.2%**
6	24,588	3.2%	1,229	7.7%	**9,722**	**9.6%**	**640**	**15.2%**
7	23,515	3.0%	1,059	6.6%	7,187	7.1%	**451**	**10.7%**
8	17,610	2.3%	803	5.0%	6,425	6.3%	**402**	**9.6%**
9	22,592	2.9%	760	4.8%	6,013	5.9%	359	8.5%
10	30,552	3.9%	708	4.4%	6,925	6.8%	369	8.8%
11	53,247	6.8%	930	5.8%	8,206	8.1%	302	7.2%
12	**108,615**	**14.0%**	**1,563**	**9.8%**	**10,289**	**10.2%**	216	5.1%
Total	778,092	100.0%	15,926	100.0%	101,357	100.0%	4,202	100.0%

Table 2. OLS regression: monthly gastroenteritis outbreaks from 2009 to 2016

	All Illnesses			All Hospitalizations		
Etiology	**All**	**Norovirus**	**Salmonella**	**All**	**Norovirus**	**Salmonella**
Temperature	**-0.0320*** (0.0015)**	**-0.0365*** (0.0016)**	**0.0130*** (0.0019)**	**-0.0090*** (0.0012)**	**-0.0222*** (0.0018)**	**0.0035* (0.0019)**
Temperature Anomaly	0.0269*** (0.0073)	0.0214*** (0.0077)	-0.0027 (0.0102)	-0.0017 (0.0066)	0.0071 (0.0083)	-0.0059 (0.0110)
Precipitation	-0.0036 (0.0173)	0.0242 (0.0190)	-0.0146 (0.0281)	0.0536*** (0.0149)	0.0573*** (0.0209)	0.0129 (0.0255)
Precipitation Anomaly	-0.0148 (0.0236)	-0.0407 (0.0269)	-0.0007 (0.0356)	-0.0566*** (0.0208)	-0.0585** (0.0292)	-0.0066 (0.0320)
Constant	5.9207*** (0.0808)	5.9897*** (0.0879)	1.5516 (0.1183)	1.6073*** (0.0739)	1.9607*** (0.0990)	0.6532*** (0.1155)
R^2	0.1386	0.1847	0.0381	0.0243	0.1104	0.0063
Observation	3,802	2,680	1,112	2,490	1,259	751

Table 3. OLS regression: monthly foodborne illnesses from 2009 to 2016

	Foodborne Illnesses Restaurants			**Foodborne Illnesses All**		
Etiology	**All**	**Norovirus**	**Salmonella**	**All**	**Norovirus**	**Salmonella**
Temperature	**-0.0048*** (0.0016)**	**-0.0093*** (0.0020)**	**0.0067** (0.0030)**	**-0.0019 (0.0014)**	**-0.0096*** (0.0018)**	**0.0106*** (0.0024)**
Temperature Anomaly	-0.0018 (0.0076)	0.0007 (0.0089)	-0.0027 (0.0160)	-0.0034 (0.0072)	-0.0055 (0.0080)	0.0026 (0.0124)
Precipitation	-0.0476** (0.0203)	-0.0359 (0.0244)	-0.0261 (0.0406)	-0.0417** (0.0183)	-0.0292 (0.0216)	-0.0312 (0.0323)
Precipitation Anomaly	0.0552** (0.0272)	0.0191 (0.0329)	0.0927* (0.0531)	0.0329 (0.0252)	0.0199 (0.0294)	0.0301 (0.0408)
Constant	2.9807*** (0.0937)	3.2241*** (0.1176)	1.9149*** (0.2182)	3.2889*** (0.0810)	3.6530*** (0.0947)	1.8809*** (0.1570)
R^2	0.0131	0.0346	0.0228	0.0043	0.0332	0.0232
Observation	1,629	835	365	2,496	1,189	782

Table 4. OLS regression: monthly foodborne-illness-related hospitalizations from 2009 to 2016

	Foodborne Hospitalizations Restaurants			**Foodborne Hospitalizations All**		
Etiology	**All**	**Norovirus**	**Salmonella**	**All**	**Norovirus**	**Salmonella**
Temperature	**0.0069*** (0.0019)**	**-0.0019 (0.0020)**	**-0.0001 (0.0031)**	**0.0080*** (0.0014)**	**-0.0029 (0.0018)**	**0.0031 (0.0023)**
Temperature Anomaly	0.0115 (0.0101)	0.0083 (0.0109)	0.0093 (0.0199)	0.0007 (0.0073)	0.0102 (0.0087)	0.0103 (0.0136)
Precipitation	0.0031 (0.0265)	0.0123 (0.0276)	0.0223 (0.0420)	0.0020 (0.0195)	0.0065 (0.0239)	0.0088 (0.0294)
Precipitation Anomaly	0.0173 (0.0350)	-0.0212 (0.0354)	0.0299 (0.0540)	-0.0010 (0.0265)	-0.0079 (0.0312)	-0.0030 (0.0369)
Constant	0.2744** (0.1074)	0.2976*** (0.0950)	0.8351*** (0.2125)	0.3947*** (0.0844)	0.4247*** (0.0995)	0.7293*** (0.1527)
R^2	0.0330	0.0094	0.0108	0.0280	0.0117	0.0055
Observation	551	158	248	1,172	274	560

Table 5. OLS regression: monthly foodborne illnesses from 2009 to 2016

	Foodborne Illnesses Restaurants / All			**Foodborne Hospitalizations Restaurants / All**		
Etiology	**All**	**Norovirus**	**Salmonella**	**All**	**Norovirus**	**Salmonella**
Temperature	**-0.0039*** (0.0012)**	**0.0023 (0.0014)**	**-0.0040*** (0.0015)**	**-0.0040*** (0.0012)**	**0.0013 (0.0010)**	**-0.0034*** (0.0012)**
Temperature Anomaly	0.0035 (0.0057)	0.0023 (0.0067)	0.0025 (0.0079)	0.0119** (0.0055)	0.0024 (0.0043)	0.0032 (0.0077)
Precipitation	0.0352** (0.0151)	0.0453*** (0.0154)	0.0094 (0.0217)	0.0117 (0.0171)	-0.0179* (0.0095)	0.0021 (0.0165)
Precipitation Anomaly	-0.0450** (0.0222)	-0.0329 (0.0228)	0.0030 (0.0267)	-0.0123 (0.0229)	0.0251 (0.0158)	-0.0039 (0.0171)
Constant	-0.5296*** (0.0735)	-0.6345*** (0.0810)	0.0329 (0.0863)	-0.0746 (0.0595)	-0.0739* (0.0441)	0.0808 (0.0587)
R^2	0.0072	0.0153	0.0191	0.0193	0.0142	0.0175
Observation	1,629	835	354	551	158	241

Table 6. Bayesian linear regression: monthly foodborne illnesses from 2009 to 2016

		Foodborne Illnesses Restaurants / All		
	Etiology	**All**	**Norovirus**	**Salmonella**
Temperature	Mean	**-0.0040**	**0.0021**	**-0.0040**
	Std.	(0.0012)	(0.0015)	(0.0015)
	MCSE	0.0001	0.0001	0.0001
	Median	**-0.0040**	**0.0020**	**-0.0040**
	95% Interval	**-0.0064/-0.0016**	**-0.0007/0.0052**	**-0.0070/-0.0010**
Temperature Anomaly	Mean	0.0035	0.0025	0.0019
	Std.	(0.0062)	(0.0065)	(0.0080)
	MCSE	0.0003	0.0002	0.0004
	Median	-0.0035	0.0024	0.0018
	95% Interval	-0.0086/0.0159	-0.0105/0.0152	-0.0127/0.0188
Precipitation	Mean	0.0343	0.0451	0.0100
	Std.	(0.0161)	(0.0179)	(0.0217)
	MCSE	0.0007	0.0014	0.0009
	Median	0.0343	0.0445	0.0101
	95% Interval	0.0036/0.0660	0.0099/0.0802	-0.0276/0.0470
Precipitation Anomaly	Mean	-0.0452	-0.0339	0.0014
	Std.	(0.0227)	(0.0255)	(0.0259)
	MCSE	0.0011	0.0014	0.0012
	Median	-0.0450	-0.0343	0.0008
	95% Interval	-0.0898/-0.0004	-0.0816/0.0157	-0.0490/0.0529
Constant	Mean	-0.5219	-0.6243	0.0307
	Std.	(0.0734)	(0.0804)	(0.0998)
	MCSE	0.0036	0.0041	0.0031
	Median	-0.5203	-0.6234	0.0299
	95% Interval	-0.6641/-0.3798	-0.7803/-0.4616	-0.1635/0.2315
$Sigma^2$	Mean	0.7622	0.5028	0.2197
	Std.	(0.0271)	(0.0247)	(0.0171)
	MCSE	0.0006	0.0005	0.0004
	Median	0.7615	0.5016	0.2191
	95% Interval	0.7097/0.8172	0.4568/0.5543	0.1879/0.2548
Observation		1,629	835	354

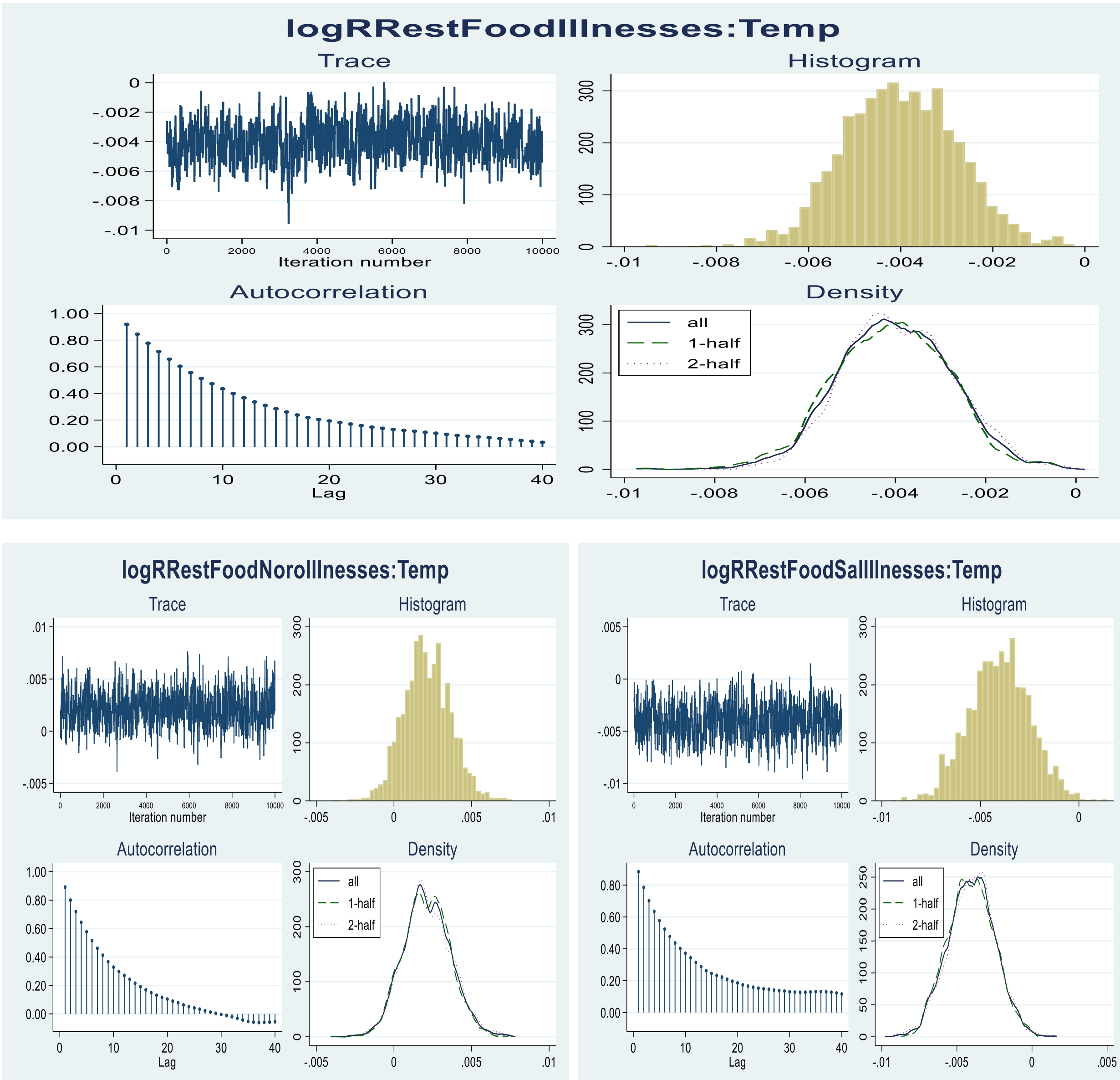

Figure 4. Diagnostics for foodborne illnesses associated with restaurants over all foodborne illnesses

Table 7. Bayesian linear regression: monthly foodborne-illness-related hospitalizations from 2009 to 2016

		Foodborne Hospitalizations Restaurants / All		
	Etiology	**All**	**Norovirus**	**Salmonella**
Temperature	Mean	**-0.0041**	**0.0013**	**-0.0031**
	Std.	(0.0013)	(0.0013)	(0.0016)
	MCSE	0.0001	0.0001	0.0001
	Median	**-0.0041**	**0.0013**	**-0.0032**
	95% Interval	**-0.0067/-0.0015**	**-0.0014/0.0039**	**-0.0062/-0.0000**
Temperature Anomaly	Mean	0.0122	0.0026	0.0030
	Std.	(0.0068)	(0.0054)	(0.0095)
	MCSE	0.0003	0.0002	0.0005
	Median	0.0121	0.0027	0.0027
	95% Interval	-0.0010/0.0253	-0.0083/0.0130	-0.0153/0.0224
Precipitation	Mean	0.0119	-0.0193	0.0021
	Std.	(0.0160)	(0.0153)	(0.0190)
	MCSE	0.0008	0.0014	0.0009
	Median	0.0121	-0.0195	0.0020
	95% Interval	-0.0188/0.0447	-0.0482/0.0110	-0.0340/0.0399
Precipitation Anomaly	Mean	-0.0133	0.0268	-0.0045
	Std.	(0.0226)	(0.0200)	(0.0262)
	MCSE	0.0012	0.0013	0.0012
	Median	-0.0133	0.0264	-0.0040
	95% Interval	-0.0588/0.0316	-0.0111/0.0650	-0.0573/0.0462
Constant	Mean	-0.0692	-0.0716	0.0666
	Std.	(0.0726)	(0.0596)	(0.1046)
	MCSE	0.0045	0.0042	0.0054
	Median	-0.0740	-0.0734	0.0671
	95% Interval	-0.2099/0.0770	-0.1866/0.0440	-0.1473/0.2641
$Sigma^2$	Mean	0.2559	0.0654	0.1625
	Std.	(0.0152)	(0.0077)	(0.0147)
	MCSE	0.0003	0.0002	0.0003
	Median	0.2551	0.0647	0.1615
	95% Interval	0.2271/0.2876	0.0525/0.0817	0.1360/0.1946
Observation		551	158	241

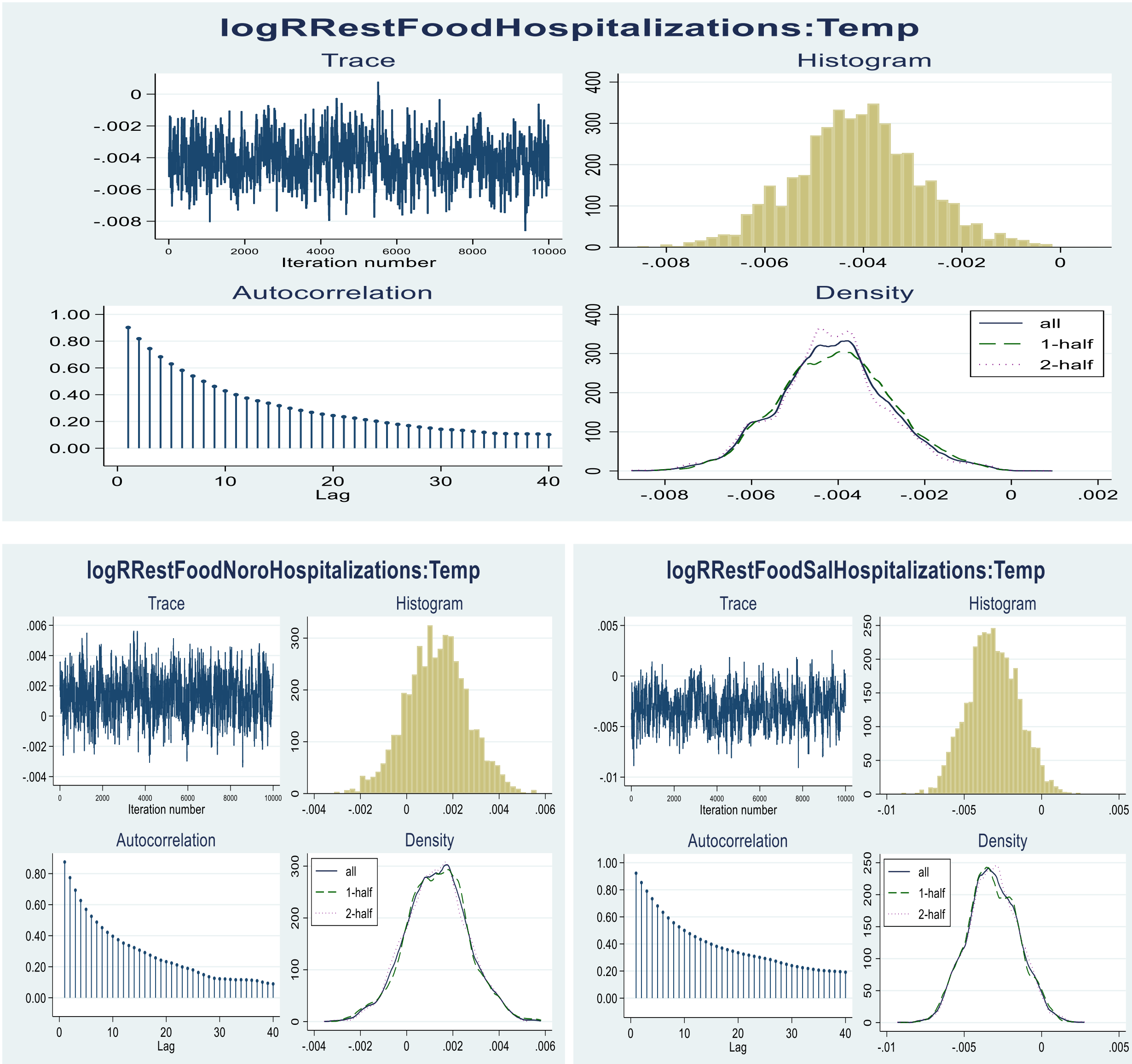

Figure 5. Diagnostics for foodborne-illness-related hospitalizations associated with restaurants over all foodborne-illness-related hospitalizations

Table 8. Food sources of restaurant-associated foodborne illnesses

	Illnesses				Hospitalizations			
	All restaurants		Other foodborne		All restaurants		Other foodborne	
Beef	4,024	2.3%	**7,605**	**3.3%**	239	3.5%	**603**	**6.2%**
Chicken	2,873	1.7%	**7,129**	**3.1%**	164	2.4%	**556**	**5.7%**
Eggs	**4,198**	**2.4%**	1,867	0.8%	**259**	**3.8%**	130	1.3%
Fish	**2,787**	**1.6%**	2,085	0.9%	151	2.2%	204	2.1%
Fruits	2,991	1.7%	**6,264**	**2.7%**	170	2.5%	**777**	**8.0%**
Mollusks	**2,125**	**1.2%**	1,754	0.8%	**131**	**1.9%**	73	0.7%
Pork	2,508	1.5%	**4,674**	**2.0%**	211	3.1%	288	3.0%
Seeded Vegetables	4,403	2.6%	**5,490**	**2.4%**	438	6.5%	**708**	**7.3%**
Sprouts	834	0.5%	940	0.4%	**132**	**2.0%**	62	0.6%
Turkey	1,374	0.8%	**5,025**	**2.2%**	133	2.0%	166	1.7%
Vegetable Row Crops	**3,990**	**2.3%**	2,924	1.3%	325	4.8%	345	3.5%
Unknown	76,731	44.7%	97,196	42.0%	2,494	36.9%	2,393	24.5%
Total	171,666	100.0%	231,444	100.0%	6,766	100.0%	9,751	100.0%

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