

Food Access after Disasters: A Multi-dimensional View of Restoration after Hurricane Harvey

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Problem, research strategy, and findings: Access after disasters to resources such as food poses planning problems that affect millions of people each year. Understanding how disasters disrupt and alter food access during the initial steps of the recovery process provides new evidence to inform both food system and disaster planning. This research takes a supply-side focus and explores the results from a survey of food retailers after Hurricane Harvey in three Texas counties. The survey collected information on how the disaster affected a store's property, people, and products and the length of time a store was closed, had reduced hours, and stopped selling fresh food items. We find that a focus only on store closures and property damage would underestimate the number of days residents have limited fresh food access by nearly two weeks. Further, stores in lower-income communities with chronic low-access to supermarkets (food deserts) were closed longer than other stores, potentially compounding pre-existing inequalities. We conclude that to plan for a more equitable food supply post-disaster, planners should embrace more dimensions of access, encourage retailer mitigation, and assess the types of retailers and their distribution within their communities.

Takeaway for practice: Practicing planners aspire to ensure equitable access to resources (e.g. food, education, and health care). In the context of food access, planners should consider: (a) that common proximity-based measures of accessibility (e.g. food deserts) may underestimate inequality and that the inclusion of multiple dimensions of access may provide a more accurate picture; (b) that efforts to encourage business resilience can complement food systems planning; and (c) that targeted engagement with local food retailers, food suppliers, and food aid agencies is important for both day-to-day community needs and for disaster planning.

Keywords: Food access; disasters; critical infrastructure; equity; food desert

Disasters like hurricanes and other extreme environmental events can disrupt all aspects of food systems, from production to storage to distribution and acquisition (Brown et al., 2015; Clay et al., 2021; De Haen & Hemrich, 2007; Schmidhuber & Tubiello, 2007; Vermuelen et al., 2012). These disruptions exacerbate chronic food access issues that affect millions in the United States each year (Coleman-Jensen et al., 2019), generating acute and expanded food insecurity. Most households depend on food retailers for food access (Okrent et al., 2018), but disasters can force these critical distributors to temporarily close due to property damage, infrastructure disruptions, or employee shortages (Zhang et al., 2009). These closures coincide with an increased demand for food, particularly perishable items, amplifying food insecurity across a community at a time of heightened need. Understanding the key factors that lead to longer interruptions in food retail businesses will help identify areas to focus hazard mitigation planning efforts.

Although food access and disaster planning are recurring themes in planning literature (Fang & Ewing, 2020), research on their intersection is limited (Smith et al., 2018). Most studies focus on the extent and length of retail closures after disasters (Brinkley et al., 2019), while overlooking other factors highlighted in the food systems literature, such as inventories and hours of operation, that also affect food access (Caspi et al., 2012; Nozhati et al., 2019). Addressing additional dimensions of access can enhance planning strategies, both pre- and post-disaster.

Drawing from a survey of food retailers (Rosenheim, Peacock et al., 2021), we analyze supply-side disruptions and restorations of food access after Hurricane Harvey in 2017. Specifically, this study identifies: 1) the types of operational disruptions experienced by food retailers; 2) factors leading to longer disruptions; and 3) the restoration timeline to pre-disaster food access levels. Our findings reveal that the restoration of food access is influenced by a complex interplay of property damage, critical infrastructure, and other

factors such as supply chains. We found that while the majority of stores closed, they were

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able to reopen within four days; return to normal operating hours three days later; but would not have fresh dairy or bread for nearly two weeks after the storm. These disruptions were more pronounced in low-income and low access communities.

This paper begins with a review of the relevant literature on food access, vulnerability of food retail to interruption, and planning for post-disaster food access. We then discuss the survey methodology and findings from survey responses. We present our multivariate analysis, which assesses factors associated with the restoration of operations. Given the potential increased severity of coastal hazards and inland flooding due to climate change (Landsea & Knutson, 2022), and how the recent pandemic highlighted vulnerabilities of the supply chain and labor markets (Hobbs, 2020), we offer suggestions for incorporating food access into disaster planning. Specifically, we find that restoration of food retail operations is longer when accounting for a wider array of factors affecting food access, i.e., operating hours and availability of fresh foods. These different facets of food retail operations have implications for food access, and must be considered in disaster planning to support food security during post-disaster periods. This study highlights the importance of carefully considering the vulnerabilities of food retail operations in disaster planning and mitigation, particularly for disaster preparation and the design of food assistance efforts.

Background

Conceptualizing Food Access

Over two decades ago, Pothukuchi and Kaufman (1999) emphasized how municipal institutions and planning shape urban food systems and access (Pothukuchi & Kaufman, 2000; Pothukuchi, 2004). Since then, planning and cognate fields have been more attentive to disparities in food access (Larson et al., 2009; Walker et al., 2010) and the ways local food environments shape health outcomes (e.g., Fraser et al., 2010; Charreire et al., 2010). In particular, literature has attempted to identify factors shaping inequality in access by focusing

on food deserts, defined as communities with low-income populations that have limited access to larger grocery stores (Walker et al., 2010). The U.S. Department of Agriculture (USDA) estimated that nearly one-quarter of Americans lived in census tracts identified as food deserts (Ver Ploeg et al., 2009) and that 10.5% of American households faced chronic food insecurity (Coleman-Jensen et al., 2021). In light of these realities, ensuring equitable access to resources like food is an aspirational goal of the planning process (American Planning Association, 2021; Mui et al., 2021).

Food desert research generally defines access based on proximity to food retailers, particularly supermarkets (Ver Ploeg et al., 2009; Beaulac et al., 2009). Critiques, however, note the limits of proximity-based conceptualizations of food access (De Master & Daniels, 2019; Shannon, 2014), highlighting the importance of other factors like affordability and variety of foods available at retailers (e.g., Farley et al., 2009). These studies emphasized that the presence of supermarkets does not guarantee equitable food access—lower income neighborhoods often face higher prices and limited selection (Block & Kouba, 2006), and may actually find variety and affordability at smaller retailers (Short et al., 2007), which are often excluded from food desert analyses. Dollars redeemed through the Supplemental Nutrition Assistance Program (SNAP) highlight the diversity of stores used to access food. While 79% (\$125 billion) of SNAP dollars were redeemed at large super stores or supermarkets, SNAP transactions were also common at drug/dollar stores (\$6.7 billion), farmers markets (\$33.6 million), and convenience stores (\$6.3 billion) (USDA, 2021). This paper contributes to this research that seeks to understand other facets of food access and a broader set of food sources. Nonetheless, we are still limited by a supply side approach to measuring food access, and thus do not address the numerous individual-level factors, such as limited mobility, which can also constrain food access (Clifton, 2004; LeDoux & Vojnovic, 2013).

Given the multitude of factors that influence food access (Charreire et al., 2010), Caspi et al. (2012) drew upon literature on access to medical care (Penchansky & Thomas, 1981) and proposed five facets of food access: accessibility (i.e. proximity to operating stores), accommodation (i.e. store hours and responsiveness to customer needs), availability (i.e. adequacy of healthy food supplies), affordability (i.e. pricing), and acceptability (i.e. food quality). Drawing on these conceptualizations of food access, this paper offers a broader understanding of the role of food retailers in shaping food access, particularly after disasters. For the purposes of this study, we adopted the Caspi et al. (2012) framework to examine the three metrics of food retailer operations that affect supply-side food access following a disaster: retailers open for business (accessibility), hours of operation (accommodation), and the adequacy of fresh food supplies (availability).

Vulnerability of Food Retailers to Interruption

Post-disaster food access depends, to a great extent, on the uninterrupted functioning of local food retailers. When assessing business interruptions, hazard researchers (e.g., Barbisch & Koenig, 2006; Jacques et al., 2014) identified three major requirements for organizational operations: staff, structure, and stuff. For food retailers, these translate to 1) people to run the store, 2) property and infrastructure to house and conduct operations; and 3) products or foodstuffs to sell. Different food retailers—e.g., large grocers, convenience stores, and combination stores—will have different arrangements of these capital resources, thereby shaping their vulnerabilities to different types of disruptions (Zhang et al., 2009).

The impacts of disasters on staff, particularly employees, can affect their ability to travel and work, in turn limiting retail operations (Aghababaei et al., 2021; Xiao & Van Zandt, 2012; Zhang et al., 2009). Employees may be unable to reach work due to transportation disruptions, damage to their homes and vehicles, deaths/injury to household members, displacement/evacuation, or additional household responsibilities (Alesch et al.,

2001; Watson et al., 2020). Following disasters, labor shortages may be difficult to address temporarily or quickly (Stevenson et al., 2012; Zhang et al., 2009). Large chains may benefit from a larger workforce and employee transfers across locations (Zhang et al., 2009). However, they also have more specialized positions that may be difficult to temporarily fill, thereby limiting operations.

Damage to property or equipment (storage, refrigerator/freezer units, etc.) and supporting infrastructure (transportation, communication, water, electricity, etc.) may also disrupt operations (Tierney & Nigg, 1995; Orhan, 2014). Perishable products, such as dairy, meat, and frozen foods, have greater dependence on equipment and infrastructure, potentially increasing vulnerabilities. In these cases, electricity disruption can increase restoration times and limit mitigation strategies such as stockpiling (Sheffi & Rice, 2005). Product supply chains are similarly dependent on electricity, water, and a refrigerated cold chain of rail cars, shipping containers, trucks and distribution centers (Freidberg, 2009). Suppliers and retailers are connected by roads and transportation infrastructure, which can be disrupted by damage and debris. These critical components in food retail operations—people, property, and products—create a nodal network spanning time and space such that damage across the network may reduce food access inside and outside disaster areas (Casellas Connors et al., 2023; Zhang et al., 2009).

Like the concept of disaster recovery in general (Bates & Peacock, 1989; Quarantelli, 1999; Topping & Schwab 2014; Platt, Brown, & Hughes 2016), full business recovery of food retailers is a multidimensional concept. These dimensions include reopening, regaining function, undertaking repairs, returning to pre-event levels of sales, employees, or profits, and subjective assessments, to name a few (Stevenson et al., 2017; Marshall & Schrank 2014; Watson et al., 2023). Therefore, we employ the more conservative term restoration based on short-term impacts to people, property, and products, to reflect that we are capturing initial steps in the more long-term and multi-dimensional recovery process. The business

interruption literature helps to inform when and why businesses are likely to re-open (i.e. accessibility), but is less robust on factors affecting the quality of their operations upon re-opening (i.e. availability and accommodation) (Watson et al., 2023). This highlights an important need to integrate this literature with advances in food systems concepts.

Planning for Food Access after Disasters

The goal to ensure equitable access to food resources motivates many urban planners.

Disasters create an extreme case, where even short-term disruptions to food access may have far reaching impacts, as most households have fewer than three days of food supplies (Al-Rousan et al., 2014). Disasters can be particularly disruptive for socially vulnerable populations, which have greater food insecurity than others (e.g., Baker & Cormier, 2013; Cummins & Macintyre, 2006, Van Zandt, 2019). Short-term household food insecurity can increase after disasters, but such events can also exacerbate or even trigger chronic food insecurity (Clay et al., 2017; Clay & Ross, 2020; Fitzpatrick 2020). Changes in household food security can result from changes in access to food sources, including food retailers, which may experience extended or permanent closures (Rose et al. 2011). Such closures also affect the functioning of existing food assistance programs, particularly SNAP, which require participants to use benefits for eligible items at food retail locations.

After a disaster, the Disaster SNAP (D-SNAP) program provides funding for eligible households to purchase food at SNAP retailers after an area receives a Presidential major disaster declaration with Federal Emergency Management Agency (FEMA) Individual Assistance (USDA, 2014). Typically, eligible households have seven days to apply for D-SNAP. State governments coordinate efforts with county and local officials to determine the start date based on when SNAP food retailers reopen and how to stagger application periods across a region (USDA, 2014). Meanwhile, other mechanisms to address chronic food insecurity, such as food pantries and school meal programs, may be unavailable or

inaccessible after disasters (Kinsey et al., 2019; Casellas Connors et al., 2023). Given the reliance of federal programs on food retailers and the potential disruptions to other programs, post-disaster food retail access could have major implications for food security and disaster recovery.

While food access research has grown in recent years, this work has rarely intersected with research on and practice of disaster planning (Smith et al., 2018; Brinkmann & Bauer, 2016). The American Planning Association's Planning Advisory Service (PAS) offered one of the first systematic guides for community planning for post-disaster recovery (Schwab, 2014). A goal was to stimulate pre-disaster recovery plans, allowing for more careful development, deliberation, and community participation in the process (Schwab 2014). While not yet widespread, recovery planning has grown in areas where it is emphasized at the state level (e.g., Florida & North Carolina) and in areas at higher disaster risk (e.g., Louisiana) (Horney et al., 2016a). However, systematic evaluations of these plans find that they focus primarily on housing, land use planning, and building codes, or address issues of how and where to rebuild (Archer et al., 2022; Berke et al., 2015; Horney et al., 2016b). Though these plans may consider public health, well-being, and economic/business recovery (Archer et al., 2022; Boyd 2014), they often ignore issues of food systems and food access. Some cities have developed plans to enhance food systems resilience (Zeuli & Nijhuis, 2017; Biehl et al., 2018), but such initiatives are rare. In non-disaster times, local governments can play an important role in removing barriers to food access through land use policies and economic development incentives (Allen, 1999; Block et al., 2012; Pothukuchi & Kaufman, 1999). Building off this research, this paper makes recommendations for disaster recovery planning and post-disaster monitoring to address food access issues, with the hope of improving equitable access to resources.

Methods

Given the critical role of food retailers in shaping food supplies and access, this study focuses on food retailers affected by Hurricane Harvey, a Category 4 Hurricane that made landfall in Texas on August 25, 2017 (NOAA, 2018). Hurricane Harvey was the largest rainfall event on record in the United States (NOAA, 2018), depositing rain along the Texas Coast for seven days. Some areas received over 70cm of rain, resulting in floods that displaced hundreds of thousands of households, power failures, road closures, water system failures, and boil water orders. With an estimated \$125 billion of damage, it was the second costliest disaster in U.S. history (NOAA, 2022).

Study Area

Our study area includes the three counties of Harris, Jefferson, and Orange counties in southeast Texas (Figure 1). These counties experienced the highest precipitation and most extensive flooding; at one point, an estimated one-third of Harris County was inundated with flood waters (FEMA, 2019). In the Orange and Jefferson County cities of Beaumont, Port Arthur, and Orange, 72% of residents reported being affected by Hurricane Harvey, either through home damage, vehicle damage, or income/job loss (Hamel et al., 2018).

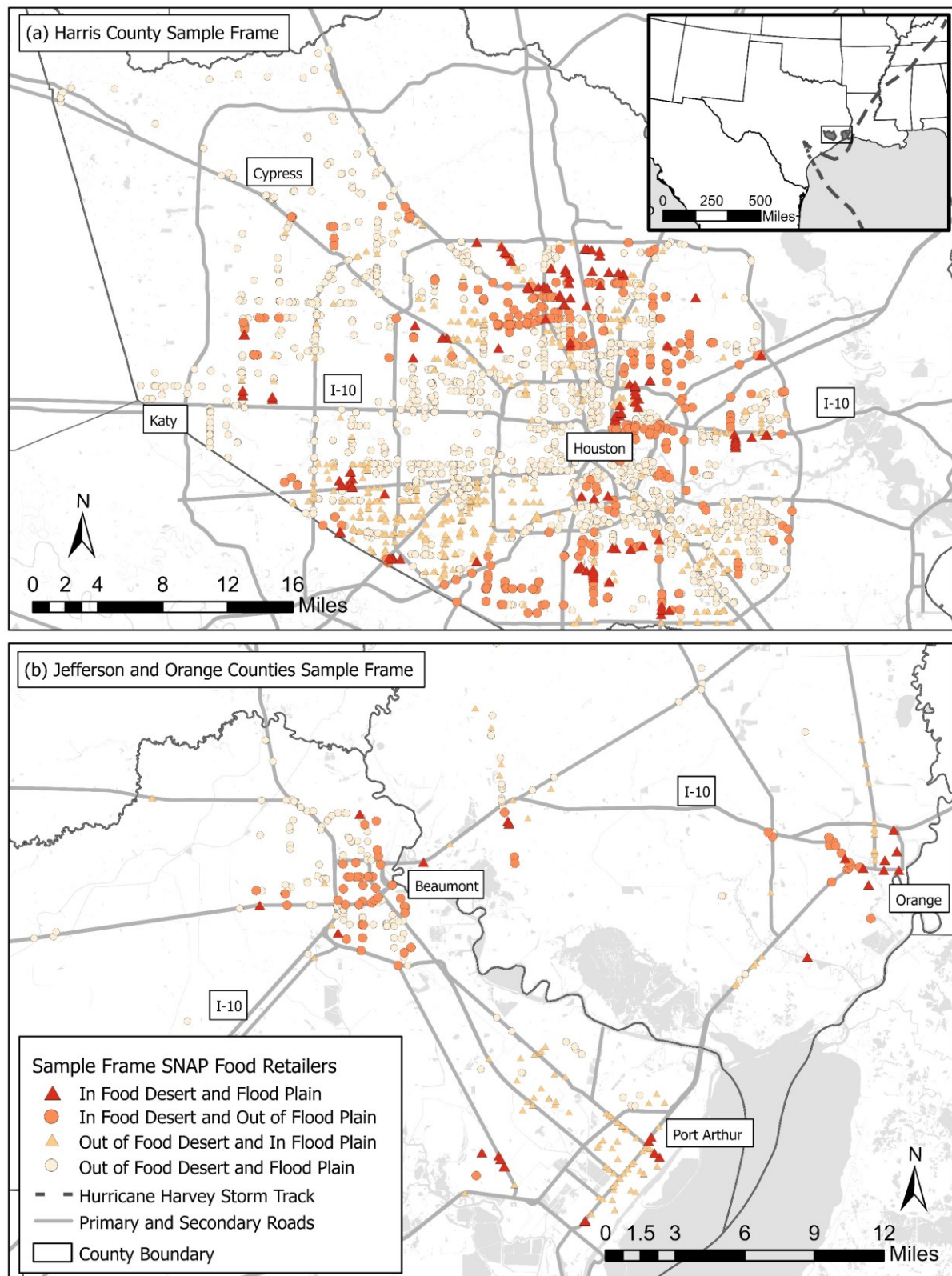


Figure 1. Sample frame of SNAP food retailers by location in food deserts and/or floodplain for a) Harris County and b) Jefferson and Orange counties, Texas, 2017.

Note: Map shows 2,755 stores in the sample frame, random sample is not displayed to protect the privacy of survey respondents.

Sources: FEMA, 2017; NOAA, 2019; U.S. Census Bureau, 2020; USDA, 2017a.

These three counties encompass a diverse population, spanning a gradient of rural to urban development. In 2016 (the year prior to Hurricane Harvey) Harris County, which includes the city of Houston—the 4th largest U.S. city at the time—was home to an estimated 4,589,928 people (U.S. Census Bureau, 2016a). The median household income was \$56,377, with 20.3% of families with children at or below the poverty level, and an estimated 13.2% of the population received SNAP benefits (U.S. Census Bureau, 2016b). Jefferson and Orange Counties are comparatively smaller and more rural, with pre-Harvey populations of 254,679 and 84,964 respectively (U.S. Census Bureau, 2016a). Jefferson County had a significantly lower median household income (\$45,390) and higher percentage (28.4%) of families with children living below poverty when compared to Orange County (\$53,480 and 13.5% respectively), but both counties had similar SNAP participation rates (13.2% and 13.8% respectively) (U.S. Census Bureau, 2016b). Across the three counties, nearly 800,000 people (16.5%) lived in USDA-defined food deserts before Hurricane Harvey, and there were significant differences based on race: non-Hispanic Black and Hispanic populations were more likely to live in food deserts (1.7 and 1.4) compared to White non-Hispanic populations who were less likely to live in food deserts (0.46) (USDA, 2017a, U.S. Census Bureau, 2016c).

Sample Frame and Survey Methodology

We considered a number of factors when sampling food retailers. We began with a comprehensive list of SNAP-eligible food retailers in Harris, Jefferson, and Orange counties, compiled and maintained by USDA (USDA, 2017b; Figure 1). Given the widespread acceptance of SNAP benefits (USDA 2017b & 2021), the sample frame included a variety of food retail establishments, which we assumed provided a close approximation of all available food retailers. The database of SNAP stores includes store name and store location, but lacks details such as store size, type or number of employees. We classified stores into broad

categories based on store names which were manually cross-referenced against existing lists of national and regional brands. Nearly 10.9% of stores were classified as “*Dollar*” stores and 6.7% of the sample were “*Large Supermarket*” chains that appeared on the Progressive Grocer’s *Super 50* listing based on their parent company’s annual sales (Progressive Grocer, 2017). An additional 8.0% were national chain pharmacies (CVS, Walgreens, etc.), termed “*Combination stores*”, that carry health care products and some food items. *Convenience* stores (7-Eleven, Shell, Super K, Circle K, etc.) and *medium groceries* (Big-Lots, Sellers, etc.) were 12.9% and 2.9% of the sample, respectively. The remaining establishments (58%) are termed “*Non-chain*” retailers and generally included relatively small, often locally owned, and sometimes specialized (ethnic, bakery, fish/seafood, etc.) food retailers.

A primary consideration was to draw a representative sample of food retailers in the counties, while allowing for sufficient observations to compare retailers in and outside of food deserts and flood plains. Most retailers were in Harris County (87.4%) and relatively few were in food deserts (19.3%). Additionally, a third (29.2%) of food retailers were in either the 500-year or 100-year flood plain. While flood plains have been found to not accurately reflect actual flooding in our study area (Smiley, 2020), the use of floodplains provided both a proxy for stores with a higher probability of flooding and a means to compare stores in and out of the flood plain with observed flooding. To ensure representativeness and facilitate comparisons, a non-proportionate stratified random sample was made. Specifically, food retail establishments were classified into four strata based on store location 1) in or outside floodplains (FEMA, 2017) and 2) in or outside food deserts (USDA, 2017a).

The resulting random sample consisted of 468 stores. Survey teams administered in-person surveys with owners or managers of sampled stores five to eight months after Hurricane Harvey. Survey responses were based on respondent’s memory, which previous studies have found to be stable when asking about physical, non-emotional, losses and

damage (Norris & Kaniasty, 1992; Wu, 2020). The overall contact rate was 69% with an ultimate response rate of 47%, yielding a final sample of 206.¹

Measuring Food Access and Retail Disruption

The survey instrument was designed to capture information on three supply-side food access dimensions from the Caspi et al. (2012) framework—accessibility, availability, and accommodation. For accessibility, the instrument collected data on number of days the store was closed. For accommodation, we gathered data on the number of days with reductions in operating hours. Availability was captured by asking which fresh food groups were stocked before the hurricane and the number of days until each of these food group items were again available post-hurricane. Additional suites of questions addressed disruptions to critical infrastructure, staffing and supply chains, along with damaged to property and product lines. Damage to buildings, equipment, and inventory damage used a 5-point Likert scale.

Electricity and water utility loss combined yes/no questions with numeric responses for the number of days before the utility was restored. Limited road access and employee issues were complex issues based on a cumulative count from multiple yes/no questions. For stores with disruptions, respondents selected primary reasons for closure, reduced hours, or reduced fresh food availability from a list. Respondents also had opportunities to provide other reasons perceived to be important for food access disruptions. Details on these questions are provided in discussions below and for more technical details, a public archive with survey instruments, sample design, and detailed methodology has been made available online (Rosenheim, Lane et al., 2021; Rosenheim, Peacock et al., 2021).

Analytical approaches and findings

We offer two sets of analyses to capture the impacts of Hurricane Harvey on food retailers and dimensions of food access. We begin with descriptive analyses of the survey responses, which includes primary reasons that respondents perceived as causing disruptions. The

second set of analyses seeks a more objective understanding of factors influencing the restoration of food access by estimating three regression models predicting: 1) accessibility (number of days closed); 2) accommodation (number of days with reduced hours after reopening); and 3) availability (the number of days without fresh food – dairy and bread – after reopening). We selected these measures to represent different facets of food retail operations, which each affect different elements of food access. Together, these analyses offer insights into determinants of initial steps in a broader recovery process.

Food Retailers Experienced Severe Disruptions

Table 1 presents weighted descriptive statistics on selected variables. Following Harvey, 92% of stores had some form of reduced access: 61% closed, 35% reduced hours, and 65% stopped selling fresh food. For our study area, the estimated average closure time was 3.9 ($\pm$ 2.3) days, with a median of one day. The range of closure length extended from 0 to a maximum of four months. By contrast, among just those stores that reported closures, the average increased to 6.4 days. Six of these retailers were closed for more than 57 days. The average number of days with reduced hours after reopening was 2.4 ($\pm$ 1.8) days, but among just those stores that reported reduced operational hours (35%), the average was 7 days. For fresh food availability, we focused on dairy and bread because almost all retailers (91%) sold these items, while only 35% sold fresh fruit, 27% sold fresh vegetables, and 23% sold fresh meat. A focus on dairy and bread ensures that our analysis includes the largest number of stores. On average, food retailers had limited fresh dairy or bread for 6.3 ($\pm$ 1.2) days; however, the majority (65%) of stores had limited availability for ten days.

Despite the widespread disruptions to food access and retail products (i.e., fresh food and supply chain disruptions), the majority of stores reported no impacts to their property. While Hurricane Harvey was a destructive wind event in southern Texas, where it made landfall around Port Aransas, it was a rain/flooding event in the study area. Hence Table 1

reflects the lack of destructive winds where most retailers experienced no building damage (75.8%), no machine or equipment damage (87%), and no damage to their fresh food inventories² (83%). Flooding, however, greatly affected infrastructure in the region, contributing to transportation issues³, which subsequently affect supply chains (noted above) and commuting (labor availability). The vast majority of the sample mentioned road issues (89%), employee/staffing issues (82%), and supply chain issues (70%). In addition, 25% of establishments experienced electricity outages. The average power disruption among all stores was less than a day (see Table 1), but disruptions averaged 2.6 days for those that reported power losses. Water loss was reported by only 4.5% of stores; however, 29% of stores in Jefferson County were without water because the city of Beaumont's water pumps failed for several days (Beaumont Enterprise, 2017).

Table 1. Definitions and descriptive statistics of selected variables.

Variable Label: Description	Count	Min	Median	Max	Population mean
Dimensions of Food Access					
Accessibility: Days closed	199	0	1.00	120	3.87 ± 2.26
Accommodation: Days reduced hours after reopening	164	0	0.00	161	2.44 ± 1.82
Availability: Days w/o dairy/bread after reopening	158	0	5.00	56	6.27 ± 1.17
Property: Building Damage					
None: No damage; no flood water contact	205	0	1	1	$75.8\% \pm 7.5$
Minor: Water touches floor, no drywall damage	205	0	0	1	$15.5\% \pm 4.5$
Moderate: Water level ≤ 2 ft with drywall damage	205	0	0	1	$6.1\% \pm 1.1$
Severe: Water level 2-8 ft; substantial damage	205	0	0	1	$1.7\% \pm 1.7$
Complete: Significant structural damage present	205	0	0	1	$0.6\% \pm 0.7$
Property: Machinery Damage					
None: No damage to refrigerators, freezers, etc.	206	0	1	1	$87.0\% \pm 2.3$
Minor: Easily operational once dried	206	0	0	1	$2.6\% \pm 1.3$
Moderate: Partially operational at 60% capacity	206	0	0	1	$6.1\% \pm 2.2$
Severe: Partially operational at 30% capacity	206	0	0	1	$0.4\% \pm 0.5$
Complete: Full replacement is required	206	0	0	1	$3.5\% \pm 1.8$
Infrastructure: Limited Road Access					
None: Not mentioned on survey	206	0	0	1	$10.9\% \pm 6.0$
Minor: Road issues mentioned 1-3 times	206	0	0	1	$28.5\% \pm 4.7$
Moderate: Road issues mentioned 4-8 times	206	0	1	1	$60.6\% \pm 3.7$
Infrastructure: Utility Loss					
Electric Power: Total days to full repair	182	0	0.00	60	0.64 ± 0.35
Electric Power: Days open but not back to normal	182	0	0.00	6	0.12 ± 0.06
Water: Total days to full repair	191	0	0.00	21	0.33 ± 0.46
Water: Days open but not back to normal	191	0	0.00	14	0.21 ± 0.28
People: Employee issues					
None: Not mentioned on survey	206	0	0	1	$17.9\% \pm 1.2$
Minor: Employee issues mentioned 1-2 times	206	0	0	1	$25.7\% \pm 4.0$
Moderate: Employee issues mentioned 3-7 times	206	0	1	1	$56.3\% \pm 4.4$
Product: Fresh Food Inventory Damage					
None: No damage	205	0	1	1	$82.7\% \pm 5.5$
Minor: Reusable/usable easily once dried	205	0	0	1	$5.0\% \pm 2.0$
Moderate: About 60% reusable	205	0	0	1	$4.8\% \pm 2.8$
Severe: About 30% reusable	205	0	0	1	$2.4\% \pm 0.9$
Complete: Non-reusable	205	0	0	1	$4.6\% \pm 3.3$
Product: Supply Chain					
Supply not available or suppliers not operating	171	0	1	1	$70.4\% \pm 10.3$
Store Type					
Non-chain: Not a national or regional store name	206	0	1	1	$55.0\% \pm 2.2$
Convenience Store: 7-Eleven, Shell, Timewise, etc.	206	0	0	1	$8.5\% \pm 2.2$
Medium Grocery Store: Big Lots, Sellers Brothers, etc.	206	0	0	1	$3.1\% \pm 1.7$
Dollar Store: Dollar General, Dollar Tree, Family Dollar	206	0	0	1	$12.8\% \pm 2.4$
Top 50 grocer: Walmart, Kroger, HEB, Market Basket, etc.	206	0	0	1	$11.1\% \pm 3.0$
Combination Store: CVS, Walgreens, etc.	206	0	0	1	$9.5\% \pm 4.4$
Store Location					
USDA Food Desert: Low income census tract with limited supermarkets access	206	0	0	1	$19.3\% \pm 22.4$
Flood Plain: 500-year or 100-year FEMA flood plain	206	0	0	1	$29.2\% \pm 31.9$

Note: Many of the variables are binary and the population mean represents the estimate for all food retailers in the study area. The margins of error are based on 90% confidence intervals.

Source: Survey responses to various questions in Rosenheim, Lane et al. (2021).

Provenance: FARM_3dv3_Table1_DescVars_2023-12-12.do .../FARM_2fv7_CleanModelData_2023-12-12.dta 12 Dec 2023

Table 2. Food retailer perceptions of primary reasons for disruptions.

Primary Reason	Store closed (Accessibility)	Store reduced hours (Accommodation)	Store stopped or reduced fresh food sales (Availability)
Property			
Damage to building	14.4%	2.4%	0.7%
Damage to inventory	7.2%	0.0%	1.4%
Damage to equipment	4.8%	1.2%	1.4%
Critical Infrastructure			
Road Closures	59.2%	15.5%	22.9%
No electricity service	12.0%	0.0%	1.4%
No water service	1.6%	0.0%	0.0%
No telephone service	0.0%	0.0%	0.0%
No Internet service	0.0%	0.0%	0.0%
People			
Employees unavailable	27.2%	50.0%	2.1%
Few or no customers	0.8%	7.1%	7.6%
Product			
Supply not available	0.8%	3.6%	72.2%
Suppliers not operating	0.0%	2.4%	54.2%
Food safety	0.8%	0.0%	1.4%
Other			
Other reason: Please describe below	24.0%	56.0%	26.4%
Curfew	0.0%	27.4%	0.0%
Employee safety	8.0%	15.5%	0.0%
Ran out of product	0.0%	0.0%	8.3%
Financial - short of money	0.0%	0.0%	0.7%
Transferred products	0.0%	0.0%	1.4%
Average Number of Reasons	1.61	1.81	2.02
Food Retailers (N)	125	84	144

Source: Survey responses to questions 13.a-iii, 13.b-ii, 15.b, 16.b in Rosenheim, Lane et al. (2021).

Provenance: FARM_3ev2_Table2_Reasons_2023-12-12.do .../FARM_2iv7_CleanModelData_2023-12-12.dta 12 Dec 2023

Table 2 summarizes the frequency of primary reasons for service disruptions selected from a list of 14 potential responses or provided as “other” responses. Respondents were able to select multiple reasons for each of the three types of disruptions in our study (closures, reduced hours, and reduced fresh food inventory). Respondents attributed store closures (accessibility disruptions) to road closures (59%), employees unavailable (27%), electricity loss (12%), and building damage (14%). With respect to decreased store hours (accommodation), respondents identified employees unavailable (50%), curfews (27%), road closures (16%), and employee safety (16%) as primary causes. Curfews were frequently mentioned as a reason not on our numbered list, especially in Orange County and Port Arthur where curfews required stores to close in the evening. Finally, respondents attributed

disruptions to fresh food availability to not being able to restock due to supply not being available (72%) or fresh food suppliers not operating (54%), and road closures (23%).

Modelling Restoration: Factors That Shape Food Access

To assess the effects of Harvey-related damages and other factors on the restoration of each component of access, we developed three regression models. The dependent variables for the three models were the different dimensions of access: days closed (accessibility), days with reduced hours after reopening (accommodation) and days without dairy/bread after reopening (availability). These models employed a set of 15 independent variables in five categories: 1) property damage, 2) infrastructure disruptions, 3) people and product disruptions, 4) store type, and 5) store location. Table 3 provides a detailed summary of these variables, their coding, descriptive statistics, and anticipated effects.

Table 3. Descriptive statistics for dependent and independent variables used in food access restoration models with expected effects and coding/recoding specifications. a

Variable Label (Hypothesized Effect)	Coding	Accessibility	N = 135	Accommodation	N = 111	Availability	N = 121
		Mean	SD	Mean	SD	Mean	SD
Accessibility	Days Closed	1.84	2.61				
Accommodation	Days reduced hours after reopening			2.27	4.37		
Availability	Days w/o dairy/bread after reopening					6.65	8.67
Building Damage (+)	1=Moderate or Severe \n 0=None or Minor	7.9%	0.27	5.5%	0.23	8.1%	0.27
Machine Damage (+)	1= Severe or Complete \n 0=None, Minor or Moderate	1.7%	0.13	0.7%	0.08	0.8%	0.09
Limited Road Access (+)	1=Moderate \n 0=none, minor	61.8%	0.49	60.1%	0.49	61.5%	0.49
Electricity Loss (+)	Total days to full repair	0.62	1.95	0.36	1.31	0.62	1.98
Electricity Loss after reopen (+)	Days open but not back to normal	0.14	0.54	0.12	0.53	0.16	0.59
Water Loss (+)	Total days to full repair	0.35	2.00	0.38	2.21	0.31	1.90
Water Loss after reopen (+)	Days open but not back to normal	0.25	1.57	0.29	1.76	0.22	1.48
Employees Issues (+)	1=Moderate \n 0=None or Minor	60.0%	0.49	57.9%	0.50	59.2%	0.49
Fresh Food Damage (+)	1=Severe or Complete \n 0=None or Minor	6.4%	0.25	3.3%	0.18	5.3%	0.23
Supply Issues (+)	1=Yes 0=No	73.6%	0.44	72.1%	0.45	71.2%	0.45
Dollar Store	1=Yes 0=No	14.6%	0.35	14.7%	0.36	15.1%	0.36
Top 50 Grocer	1=Yes 0=No	11.0%	0.31	12.7%	0.33	11.3%	0.32
Combination Store	1=Yes 0=No	11.3%	0.32	8.8%	0.29	12.5%	0.33
USDA Food Desert	1=Yes 0=No	19.3%	0.40	19.3%	0.40	19.3%	0.40
FEMA Flood Plain (+)	1=100-year or 500-year \n 0=Outside Floodplain	29.2%	0.46	29.2%	0.46	29.2%	0.46

Notes: a. To enhance interpretability, we have reported the means for dummy coded variables as percentages; however, their standard deviations are based on their proportions

Provenance: FARM_3fv3_Table3_ModelObs_2023-12-12.do ./FARM_2fv7_CleanModelData_2023-12-12.dta 12 Dec 2023

For the regression analyses, we excluded six cases that experienced extended closure times, mentioned in the previous section. The closures for these stores were far above the

mean and ranged from 57 to 120 days. While all these businesses experienced some combination of complete damage – two had complete building damage, five had complete equipment damage, and all six had complete inventory damage – high levels of damage were not exclusive to these businesses. Thus, additional factors delaying repairs and equipment replacement, such as insurance issues, financial constraints, or procurement difficulties, likely played a role in prolonging their closures. Notably, four of these six food retailers were in food deserts. By the time these exceptional cases reopened, general issues related to utilities and transportation were non-issues, making these 6 retailers distinct from the general sample in our study.

Given our study's focus on understanding the *initial* restoration of food access after a disaster, it is justified to exclude these six cases from the subsequent models.⁴ As a result of excluding these six observations, the sample for the regression analysis had a significantly lower mean number of days closed (1.8 vs. 3.9), but similar number of days with reduced store hours (2.3 vs. 2.4) and days with limited fresh food (6.6 vs. 6.3). To enhance interpretability and mitigate low observation counts for individual coefficients, we converted several measures into dummy variables. In this coding, a “0” indicates minimal or no disruption, and a “1” indicates damage or disruption. Our models also account for electricity and water loss before and after reopening. To appropriately assess the statistical significance of each variable, we used one-tail and two-tail tests. We applied one-tailed tests for variables with a directional hypothesis, such as damage and disruptions that would only extend restoration times. For variables where the literature is non-specific—like different store types or stores in food deserts—we opted for a more conservative two-tailed test.

Table 4 shows the significant models, with the *accessibility* model producing the highest R^2 (60%), followed by *availability* (30%) and *accommodation* (24%). The models differ in the effects and significance of the independent variables across the five categories.

First, we discuss physical damage to property and products. Building damage (moderate or

severe) marginally but significantly lengthened the number of days before reopening and resuming normal hours, but it did not significantly affect dairy/bread availability. Equipment damage (severe or complete) increased days until reopening by over six days. Fresh food inventory damage (severe or complete) had a pronounced effect, leading to an additional 2.5 days of closure and more than eight days with limited dairy or bread. These findings show that when compared to other forms of damage, building damage played the smallest role.

Infrastructure disruptions had mixed effects on store operations. As expected, limited road access and utility loss reduced food access. Limited road access increased store closures and days without dairy/bread by more than one day. Each additional day without electricity resulted in stores being closed an additional 0.4 days and operating at reduced hours for 1.2 days. The size of coefficients on electricity and water loss may be important. For example, if a store only has electricity loss, the model would suggest that a day without electricity would only close the store for around half a day. Similarly, a day without water would not cause store closure, but would cause reduced hours. While there are many confounding factors, our models suggest that stores may not be as dependent on utilities as expected.

Table 4. Multivariate regression models predicting restoration days for levels of access after Hurricane Harvey, 2017.

	Days closed (accessibility)	Days reduced hours after reopening (accommodation)	Days without dairy or bread after reopening (availability)
Property Damage			
Building Damage Moderate or Severe	0.78*	1.67**	-0.43
	(-0.14 1.70)	(0.44 2.90)	(-2.52 1.66)
Machine Damage Severe or Complete	6.34***	-1.29	1.33
	(4.32 8.36)	(-7.34 4.76)	(-10.37 13.03)
Critical Infrastructure			
Limited Road Access	1.42***	-0.29	1.16*
	(0.77 2.07)	(-1.72 1.14)	(-0.08 2.41)
Electricity Loss (days)	0.41***		
	(0.20 0.61)		
Electricity loss after reopen (days)		1.16**	-0.02
		(0.10 2.21)	(-2.82 2.78)
Water Loss (days)	-0.08		
	(-0.21 0.05)		
Water loss after reopen (days)		0.22**	0.07
		(0.05 0.39)	(-0.23 0.37)
People			
Employee issues	-0.05	0.97	-0.20
	(-0.48 0.38)	(-0.86 2.80)	(-1.13 0.74)
Product			
Fresh Food Damage Severe or Complete	2.45**	0.90	8.33**
	(0.13 4.77)	(-0.71 2.51)	(0.91 15.74)
Supply Issues	-0.43	0.75	7.95***
	(-1.04 0.19)	(-1.03 2.52)	(6.43 9.48)
Store Type			
Dollar Store	0.27	1.59**	0.24
	(-0.95 1.48)	(0.44 2.74)	(-1.60 2.07)
Large Supermarket	0.03	4.06***	3.85
	(-0.96 1.02)	(2.43 5.68)	(-4.56 12.26)
Combination Store	1.27*	2.74***	-0.03
	(0.11 2.43)	(1.34 4.13)	(-2.52 2.47)
Store Location			
USDA Food Desert	0.77**	2.87	-1.55***
	(0.21 1.32)	(-0.10 5.85)	(-2.17 -0.93)
Flood Plain	0.01	1.26	-0.14
	(-0.49 0.51)	(-1.01 3.52)	(-1.36 1.08)
Constant	0.42	-0.89	-0.17
	(-0.18 1.02)	(-2.30 0.53)	(-1.06 0.72)
R2	0.5983	0.2406	0.2984
N	135	111	121
Weighted Observations	2755.0	2755.0	2755.0

Notes: All significance tests reported with 1-tailed unless noted
a Two-tailed test (store type and USDA food desert).

* p<0.1, ** p<0.05, *** p<0.01. Ninety percent confidence intervals in parentheses.

90% confidence intervals in parentheses

Provenance: FARM_4av9_FoodAccessModelOLS_2023-12-12.do ../FARM_2fv7_CleanModelData_2023-12-12.dta 12 Dec 2023

In addition to the factors like physical damage and infrastructure, our research reveals the significant roles played by other factors such as supply, store types, and store location. For example, within our case study, disruptions to the supply chain resulted in nearly eight additional days without fresh dairy or bread. When examining different types of stores, we found that combination stores remained closed around one day longer than medium-sized grocers, convenience stores, and other non-chain stores combined. Also, both large supermarkets and combination stores operated at reduced hours for significantly longer durations—4.1 days and 2.7 days respectively—compared to their smaller counterparts. This outcome may be expected, considering that most of these large stores usually operate 24-hours and have large numbers of employees. Stores located in food deserts had food access disruptions that were significantly different from other stores net other factors. These stores, which serve low-income and low access communities, experienced an additional 0.8 days of closure, but had fresh dairy and bread available 1.6 days sooner.

The models highlight several surprising findings. We had expected employee issues to have a significant effect across all models, based on informant responses in Table 2. While employee issues were not significant in the full models (presented in Table 4), when we removed factors like road access and store type from the models, employee issues did become significant. This suggests that staffing issues are often interlinked with road accessibility and store size, warranting further study. Our models suggest that stores located in food deserts experienced differential closure delays and fresh food availability. Further scrutiny of our data found that non-chain stores in food deserts were significantly less likely to report supply issues. This intriguing finding points to the need for future research on how smaller, non-chain stores in low-income and low access communities manage their fresh food supplies. Finally, our models found that location in a flood plain was not a significant predictor for disruptions to food access. Furthermore, we did not find that stores in the floodplain were more likely to have any negative impacts when compared to stores outside

the floodplain. We did find a relationship to flood risk; 29% of stores in the floodplain reported that floodwaters touched the building, compared to 15% of stores outside the floodplain.

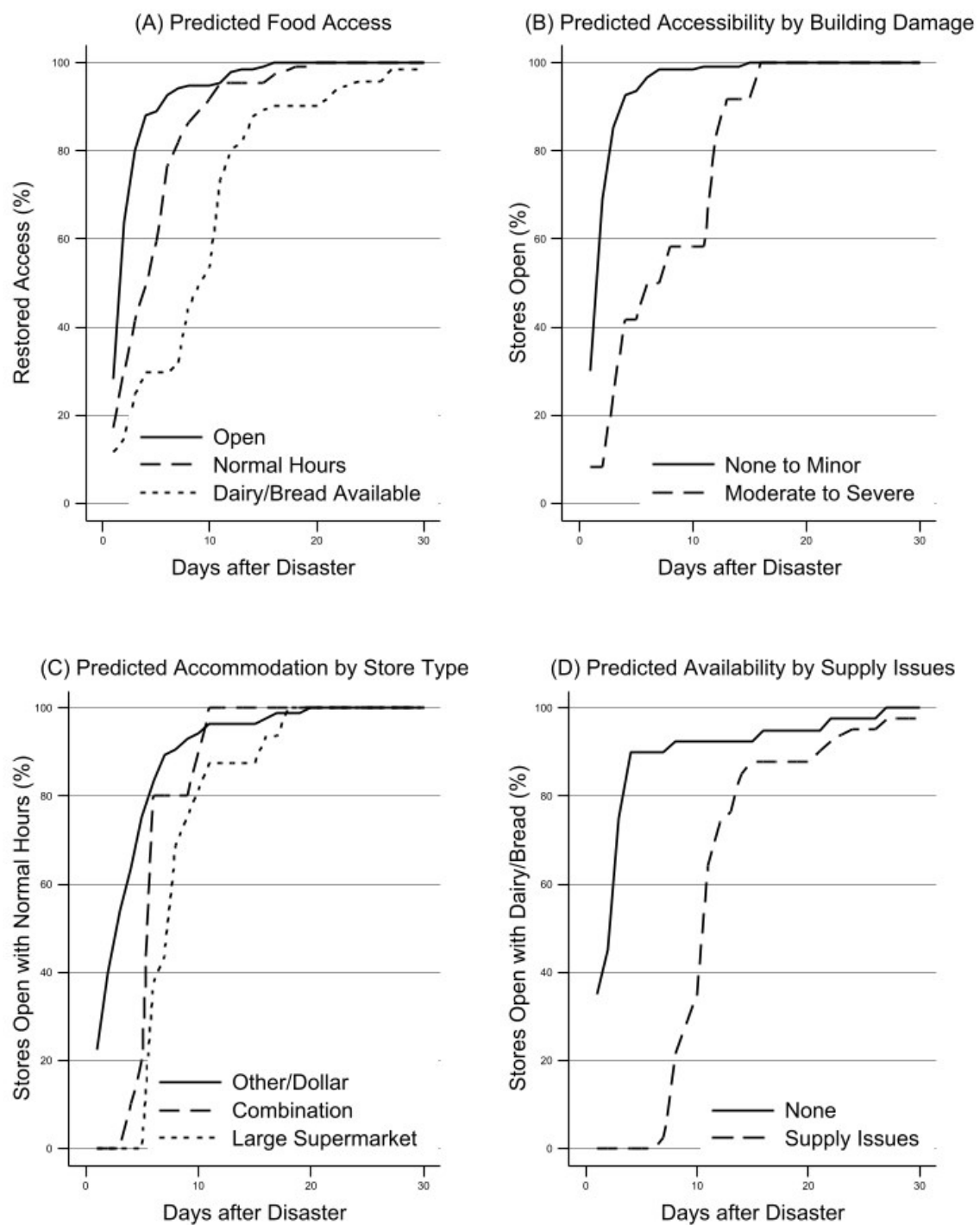
Length of Time to Restore Food Access Dimensions

We next applied our models from Table 4 to predict the number of days to restore food access. For a store level example, consider a hypothetical case for a large supermarket with increasing degrees of impacts from the disaster. As the impacts increase from building and equipment damage, to including three days of critical infrastructure disruption, and then to including supply issues, the days to restore food access increase from 12 to 16 to 23 days. Figure 2 presents predictions for our study area. Graph A compares restoration across our three dimensions of food access: accessibility, accommodation, and availability. On day one, the models predict that only 27% of stores will be open, 14% will be operating at regular store hours, and 12% will have fresh dairy and bread available. By the third day, 80% of stores are expected to reopen; by the seventh day, 80% should return to normal hours; and by the twelfth day, 80% should have fresh food available. Graph B underscores the importance of building damage for predicting when stores will reopen. Stores that experienced moderate or severe building damage take approximately four times as long to reopen as those without damage. Graph C compares restoration of accommodation by store types. Immediately post-disaster, no combination stores or large supermarkets are predicted to operate with normal hours. This situation persists for three days for combination stores and four days for large supermarkets. However, the situation improves rapidly; by the ninth day, 80% of large supermarkets and combination stores are projected to operate at normal hours. Graph D illustrates that supply issues are a significant bottle neck. Within the first four days, almost 80% of stores without supply chain issues are expected to have dairy and bread. Conversely, by the sixth day, stores with supply issues are projected to still lack these items. Supply

issues seem to resolve by the fourteenth day, with 80% of all stores expected to be fully stocked.

Overall, the results from the models suggest variations in the patterns of factors affecting the different dimensions of food access. Damage to the store's building, equipment, and fresh-food inventories, along with disruptions to electricity and road access, significantly increased the number of days before stores were able to reopen. After reopening, the number of days stores operated at reduced hours was influenced by building damage and utility disruptions. Large grocery chains and national combination stores were especially prone to extended periods of reduced hours. The delay in restoring fresh bread and dairy was mainly driven by supply chain issues and transportation infrastructure. Importantly, stores in food deserts faced additional delays, exacerbating accessibility issues for already vulnerable populations.

Our findings provide direction for future research to explore variables we missed or overly simplified. For example, limited road access, employee, and supply issues all deserve more attention and refined measurement than our research allows. Capturing how these issues change over time and their spatial extent could improve and refine future research. As hinted by our discussion of stores with extended periods of closure, our research did not include variables related to insurance issues or financial constraints, which may have played a role in limited food access. Despite these limitations, our findings fill several gaps in our understanding of how food retailers' function and restore food access after a disaster. A focus only on physical damage and accessibility would clearly underestimate the time a community would need to plan to have limited food access.



Provenance: FARM_5bv9_Figure2_2023-12-12.do FARM_4av9_FoodAccessModelOLS_2023-12-12/FARM_4av9_FoodAccessModelOLS_2023-12-12.dta 1.

Figure 2. Comparison of predicted restoration of food access after Hurricane Harvey by key factors.

Discussion and Takeaways for Planning

Consider Multiple Dimensions of Food Access in Disaster Planning

The results of this study illustrate the importance of using multiple measures to understand the effects of disasters on food access. A singular focus on whether or not businesses open neglects the implications of decreased business hours and limited inventory, which take longer to restore (Figure 2, panel A). During this process of restoring “normal” retail operations, households and individuals, especially those already experiencing food insecurity, may require additional resources. These delays also have implications for the use of existing food assistance resources, particularly D-SNAP, which provides timed benefits to purchase food once stores are open. Planners should consider the timing of D-SNAP and the potential gaps while vendors restore various facets of their operations. For instance, subsidizing supplies of fresh foods may be particularly important given prolonged supply chain disruptions. Our results also show that restoration takes longer in food deserts, making coordination with existing food assistance programs, such as food pantries, crucial for addressing food insecurity. Planners should take care to bring local retailers, food suppliers, public health agencies, and food aid agencies into the food system and disaster planning process. The inclusion of these partners will ensure that communication, logistics, and transportation infrastructure will support food access before and after a disaster. Furthermore, as municipal governments develop strategies to enhance food access and improve access in food deserts, attention should be given to the resilience of food systems. As the USDA invests billions of dollars in the new *Food System Transformation* program (USDA, 2023), we recommend that national planning organizations advocate for disaster planning and restoration of food access as high priority funding areas.

Encourage Business Continuity Planning as Food Access Planning

Damage to buildings—especially equipment and inventories—was significant in lengthening

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days to reopening and resuming normal hours of operation. Hence, reducing these disaster impacts can be critical to ensure continuity of business operations and food access. Research has shown disaster planning and mitigation efforts can significantly reduce damage to buildings and equipment (e.g., Xiao & Peacock, 2014), highlighting the importance of investing time and resources in disaster planning (Boyd, 2014; Masterson et al., 2014; Schwab, 2014). Planners can encourage food retailers to engage in disaster planning and mitigation through both financial and non-financial strategies. Planners can collaborate with business organizations in the community, such as chambers of commerce, to begin a discourse on disaster planning or offer continuity planning trainings aimed specifically at food retailers. Planners could also consider offering mitigation incentives programs through tax abatements or credits and licensing fee reductions for food retailers as part of their broader food access initiatives within food systems planning.

Integrate Food Access into Disaster Planning to Reduce Inequalities

This paper touches on a broader phenomenon in the disaster literature where disasters amplify existing inequalities (Peacock et al., 2014). Communities and households that are underserved, ignored, or underfunded see greater disaster damages, fewer resources, and slower recoveries, widening pre-disaster inequalities (Fothergill et al., 1999; Hendricks & Van Zandt, 2021; Peacock et al., 1997). In the case of food systems, retailers took longer to re-open after a disaster if they were located in a food desert; by definition, food deserts have fewer food retailers than non-food deserts, therefore any closures and particularly longer closures for the retailers in areas with low income populations can potentially exacerbate existing, chronic food access issues. While our findings focus on supply-side factors, planners must consider how to serve those that may not be able to access adequate food supplies from retailers. In combination with such considerations, our findings help to estimate potential food needs and the capacity of existing food sources to reduce post-disaster

inequalities in food access. For example, to understand post-disaster food access, scenario models should combine multiple factors such as predictions of how long parts of a community will have limited food access, and estimates of food insecurity and of food assistance resources. This information is crucial to understand where access may be limited, the capacity of existing assistance mechanisms, and where additional resources may be targeted. As such, this highlights the need to continue integrating a multi-dimensional access approach into disaster planning, to improve the restoration of food access after disasters.

Conclusions

This research has expanded our understanding of food systems by bridging concepts from food access, food retail vulnerability, and disaster recovery planning. Our exploration of three dimensions of food access in a post-disaster context – accessibility, accommodation, and availability – has broadened our general understanding of access to resources. We identified factors that significantly limit how food retailers operate after disasters for each dimension and how these factors vary across different types of stores and for stores located in low-income and low access communities (food deserts). This study illustrates how natural hazards can reveal vulnerabilities and exacerbate chronic problems related to equitable access to resources. As planners continue to prepare for climate change and an increasing number of natural hazards, the equitable access to resources like food must be included and appropriately centered in the planning process.

Notes

1. Our response rate is consistent with most in-person business surveys and higher than most post-disaster business surveys (Watson et al. 2023). The weighted sample closely approximated the sample frame, suggesting no response bias. Though survivor bias can be a concern (Deitch & Corey, 2011), only nine of the 468 stores were found to be out of business.
2. Fresh food inventory damage was significantly correlated (0.483) with electricity disruptions. Several stores surveyed mentioned selling out of food pre- hurricane, therefore they avoided inventory damage. Future surveys could assess stores' pre-disaster risk of product damage.
3. Our model used a binary measure for road access, which means that we do not capture the duration of closures. Local reports indicate significant road closures for seven days post-storm (Beaumont Enterprise 2017; Najmabadi 2017). Future surveys could include quantify the number of days with limited road access.
4. Diagnostic analysis on models including these six cases increased the skewness of the dependent variables and subsequent residuals, violating assumptions (Wooldridge, 2009). Using logged days as dependent variables addressed this, though some coefficients related to electricity disruption and road access remained non-significant. These findings suggested an important qualitative dissimilarity between extended closure businesses and the remainder of the sample when modelling shorter term restoration issues and hence justified their exclusion. This clearly is a line for future research.

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Data Availability Statement

The data and replication workflow that support the findings of this study are openly available in DesignSafe-CI <http://doi.org/10.17603/ds2-36xg-pt90>, project number 2769.

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