

Anticipated Changes in Food Acquisition Modality During Future Extreme Events

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STRUCTURED ABSTRACT

Objectives: Food acquisition cannot be deferred; yet extreme events constrain it through different mechanisms. This study examines how three restaurant-based channels – dining in, picking up, and delivery – are adopted when disruptive extreme events occur, and how the perceived severity of a prior event shapes anticipated future behavior.

Methods: The Community Adaptation and Resilience to Extremes survey collected responses from 5,089 U.S. adults between August 2024 and February 2025, oversampling metropolitan Phoenix and Seattle. The 4,661 who had experienced at least one event of interest yielded 7,468 respondent-event observations. A generalized heterogeneous data model was used to jointly estimate perceived severity and anticipated change in each channel usage, while accounting for effects of latent social interaction propensity, transit-oriented living preference, and personal resilience. Average treatment effects were computed to quantify impacts.

Findings: No channel is resilient across all three events. Relative to a power outage, extreme heat raises the probability of using more delivery and dine-in options in the future; extreme cold raises the prospect of using delivery services while reducing the probability that pick-up or dine-in modalities will be used more. Delivery is thus the favored adaptation under both thermal extremes. Power outage is the only event considered in which use of delivery services declines, presumably due to infrastructure failures. An extremely severe prior experience amplifies shifts toward dine-in and delivery. Delivery reliance is greatest among households with children and people with travel limitations, and lowest in rural areas.

Novelty: The study provides an individual-level, multi-hazard comparison of anticipated food-access adaptation linking prior-experience severity to expected future behavior.

Practical Applications: Emergency food planning should be event-differentiated. Strategies include subsidizing delivery and protecting couriers under heat and cold; and providing back-up power for food retail and payment systems and designating accessible pickup points for mobility-constrained households during power outages.

1. INTRODUCTION AND MOTIVATION

Access to food is a fundamental requirement of daily living and a critical component of household well-being. Many activities can be deferred when disruptive conditions arise, but accessing food remains a critical household need. Households must continue to obtain meals even when travel conditions deteriorate, utilities fail, and normal routines are interrupted. Food acquisition therefore offers an important lens through which to examine household resilience during extreme events.

Prepared food may be obtained by dining inside a restaurant, picking up an order, or having food delivered. The use of pickup and delivery has grown substantially, with the COVID-19 pandemic accelerating online ordering, curbside service, contactless payment, and app-based delivery (Kim et al. 2021). These options altered the relationship among food consumption, personal travel, and commercial delivery. A meal that once generated a household trip to a restaurant may now generate a pickup trip, a delivery trip, or no household travel at all. The choice among these modalities is also shaped by income, household composition, vehicle availability, work arrangement, and residential context (Haddad et al. 2023, 2025).

The pandemic demonstrated how quickly a major disruption can reshape restaurant operations. Establishments were forced to modify staffing, kitchen processes, ordering systems, payment practices, and customer-service models with little warning. Although many restaurants pivoted successfully toward pickup and delivery, others struggled financially or closed permanently (Kim et al. 2021; Wray et al. 2025). This experience exposed large differences in adaptive capacity across establishments and showed that alternative food acquisition channels must remain available during disruptive events.

Restaurants are essential community businesses. They provide access to prepared meals, support employment, contribute to local economic activity, and often serve as neighborhood gathering places. Many are small businesses with limited financial reserves and little ability to absorb prolonged interruptions. Anticipating how customers may shift among dine-in, pickup, and delivery modalities is therefore important for decisions regarding staffing, inventory, operating hours, payment systems, and delivery arrangements. Such insights are equally important for public agencies seeking to design and provide services that maintain food access and support local businesses during emergencies.

These shifts in food access modalities also have direct transportation implications. Dining in, pickup, and delivery generate different patterns of person travel, vehicle travel, destination activity, curb demand, and courier movement. Changes in modality can alter the number, timing, and spatial distribution of trips. Travel demand models are already challenged in representing activity-travel behavior under normal conditions due to an array of changing circumstances and technological forces; the ability of models to forecast activity-travel patterns during severe disruptions is even more limited (Miller, 2023). Extreme events may simultaneously affect destination availability, network conditions, perceived exposure risk, household responsibilities, and business operations. There is therefore a need for evidence on how people expect to modify food acquisition under different types of disruptive events to obtain more accurate insights on travel demand, delivery activity, and emergency service needs.

Different event types are unlikely to produce a uniform response. Extreme heat raises the burden and health risk associated with outdoor travel and waiting. It may increase demand for delivery, although this transfers exposure from consumers to restaurant employees and delivery workers. Air-conditioned restaurants may also serve as temporary cooling environments, creating competing pressures for dine-in activity. Extreme cold may similarly discourage out-of-home food acquisition while leaving electricity, online ordering, refrigeration, and delivery systems largely

intact. Under such conditions, having prepared food delivered to the home may become especially attractive.

Power outages create a different set of constraints. Households may lose refrigeration and cooking capability, increasing the need for prepared food – all while restaurants, communications systems, payment networks, and delivery platforms may be impaired by the same outage (Ma et al. 2026). Pickup may become a fallback when some establishments remain operational, although access may still depend on vehicle availability, travel conditions, and the geographic distribution of open businesses. A modality that functions as an adaptation under one event may therefore become unreliable under another.

Existing research offers useful but fragmented evidence. Studies of extreme heat show reductions in trip-making and outdoor activity, with greater constraints among lower-income individuals, older adults, service workers, and other vulnerable groups (Batur et al. 2024). Huo et al. (2026) further showed that the perceived severity of a prior heat event shapes anticipated mobility and activity adjustments. Research on meal acquisition demonstrates that dining out, takeout, and delivery are not interchangeable and that their use varies systematically across population groups and circumstances (Haddad et al. 2023, 2025).

A parallel literature on disaster planning documents disruptions to grocery and retail food access. Hurricane warnings may prompt advance stockpiling, although lower-spending households appear less able to increase purchases before an event (Wahdat and Lusk, 2024). Low-income and minority communities experienced greater losses in grocery accessibility during Hurricane Harvey (Esmalian et al. 2022), while retailers reported closures, reduced operating hours, food shortages, and prolonged supply-chain interruptions (Rosenheim et al. 2024). Winter Storm Uri similarly reduced access to active food stores and forced some low-income communities to travel farther (Wei and Mukherjee, 2025). Recent evidence also shows that food access disruptions may persist alongside power outages and that residents shift toward closer available destinations when normal options become less accessible (Ma et al. 2026).

Other studies show that delivery demand may rise during uncomfortable heat or cold, although the magnitude varies across weather conditions and food categories (Yao et al. 2023; Zhang et al. 2025; Xie et al. 2025). Increased reliance on delivery, however, does not imply that the delivery system itself is resilient. Couriers may face substantial heat exposure (Jiang et al. 2024), and restaurant or platform operations may fail when power and communications are disrupted (Ma et al. 2026). Consumer adaptation may therefore transfer risk to workers or create dependence on a service channel that is itself vulnerable.

This study aims to address three research gaps. First, prior studies generally examine one hazard at a time, limiting direct comparison of impacts across multiple events such as extreme heat, extreme cold, and power outages. Second, much of the evidence to date comes from aggregate mobility, transaction, retail, or platform data. Such sources reveal the footprint of behavioral change but provide limited insight into the individual characteristics, resources, attitudes, and prior experiences that shape adaptation. Third, most studies document realized behavior during past events, whereas emergency planning also requires information on how people expect to respond when a similar event occurs again in the future.

This study addresses these gaps by jointly examining anticipated changes in dining in, picking up prepared food, and having food delivered during extreme heat, extreme cold, and power outages. The analysis uses data from 4,661 adults collected through a specially designed survey, yielding 7,468 respondent-event observations. A generalized heterogeneous data model jointly represents the perceived severity of the most recent event and anticipated changes in the three food

acquisition modalities during a future event of the same type. The framework also incorporates latent dispositions related to social interaction propensity, transit-oriented living preference, and personal resilience, thus accounting for attitudinal factors that may shape food acquisition behavioral response to extreme events.

The analysis addresses three questions. How do anticipated shifts among dine-in, pickup, and delivery differ across event types? How does the perceived severity of prior experience shape expected behavior during a future event? Which population groups are most likely to face constrained access during times of disruption? The answers can improve transportation forecasts under disruptive conditions, guide emergency interventions for households that may be unable to travel or obtain delivered food when these events occur, and provide insightful information for businesses that seek to be prepared for the next disruptive event.

The remainder of this paper is organized as follows. Section 2 describes the survey, sample, outcomes, and attitudinal indicators. Section 3 presents the modeling framework. Section 4 discusses the estimation results and treatment effects. Section 5 concludes with implications for restaurant operations, transportation planning, and emergency food access.

2. DATA DESCRIPTION

This section describes the data used in the analysis. It first provides an overview of the survey design, data collection process, and sample characteristics. It then presents the endogenous outcomes and attitudinal indicators used to define the latent constructs.

2.1. Survey Overview and Sample Characteristics

The data for this study were collected through a specialized survey called the Community Adaptation and Resilience to Extremes (CARE) Survey, administered between August 2024 and February 2025. The survey targeted adults residing in the United States, with deliberate oversampling in Maricopa County (Greater Phoenix), Arizona, and the Puget Sound (Greater Seattle) region of Washington. The survey gathered information on respondents' experiences with extreme events, perceived impacts, coping strategies, access to household and community resources, attitudes and lifestyle preferences, and travel and activity patterns. The survey also collected detailed individual and household socioeconomic and demographic information. It was administered through a commercial online panel service and yielded 5,089 completed responses, including 1,047 respondents from Maricopa County and 1,000 from the Puget Sound region. Quotas for age, gender, and Census region were introduced during data collection to obtain a sample with rich variation in demographic and geographic composition.

Respondents were asked whether they had previously experienced several types of extreme events, including extreme heat, defined as temperatures substantially above normal for their area; extreme cold, defined as temperatures substantially below normal for their area; and a power outage. Although the survey covered other extreme event types (e.g., earthquake, flooding), this paper focuses exclusively on extreme heat, extreme cold, and power outage. A randomly selected subset of respondents who reported prior experience with an event received a follow-up module concerning the severity of its impact on daily life, anticipated effects of a similar future event, and expected changes in activity participation were the event to happen again. Of the 5,089 survey respondents, 4,661 reported experiencing at least one of these three event types. Because these follow-up questions were administered separately for each applicable event type, respondents who had experienced more than one event could contribute multiple observations. Completed follow-up responses for the extreme heat, extreme cold, and power outage modules were pooled into a

single respondent-event dataset. Because respondents could complete follow-up modules for more than one event type, the unit of analysis is the respondent-event combination, yielding a final estimation sample of 7,468 observations. Pooling the event-specific modules into a single respondent-event dataset enables estimation of a unified behavioral model in which event-type indicators and interaction terms capture both shared behavioral mechanisms and event-specific responses. For ease of presentation, distributions of characteristics in the pooled sample are considered equivalent to distributions in the respondent sample for all practical purposes.

Table 1 presents the socioeconomic and demographic characteristics of the original respondent-level sample (S1) and the pooled respondent-event estimation sample (S2). The two distributions are generally similar, indicating that construction of the pooled sample did not materially alter the composition of the original survey sample. In the estimation sample, 58.2 percent of observations are provided by female respondents. Adults 65 years or older constitute the largest age group, accounting for 31.1 percent of the sample, whereas adults 18-30 years account for 12.8 percent. The remaining age groups are distributed relatively evenly, with shares ranging from 16.1 to 22.9 percent.

About 45 percent of respondents are workers, 2.4 percent are students, and 2.9 percent are both workers and students; approximately one-half are neither working nor studying. Among workers, 72.1 percent work primarily indoors, 9.3 percent work primarily outdoors, and 18.6 percent work in a combination of indoor and outdoor settings. Work-from-home patterns also vary considerably. About one-half reported no work from home during the previous week, 13.7 percent worked from home one or two days, and 36.1 percent did so three or more days. Educational attainment is relatively high, with 38.2 percent reporting some college or technical-school education, 22.7 percent holding a bachelor's degree, and 12.4 percent holding a graduate degree. The sample is predominantly White at 78.7 percent – while 12.1 percent identify as Black, 3.0 percent as Asian or Pacific Islander, and the remainder as Native American or another race. Nearly one in five respondents reports a condition that limits travel outside the home, an especially salient characteristic for examining food access during extreme events.

Household income is concentrated in the lower and middle ranges with one-half living in households earning less than \$50,000 annually, and another 31.1 percent reporting incomes between \$50,000 and \$99,999. Household sizes are distributed relatively evenly, with 27.7 percent living alone, 34.6 percent in two-person households, and 37.7 percent in households of three or more persons. Most respondents live in stand-alone homes, and 56.6 percent are homeowners. Vehicle availability is generally high, although 12.0 percent live in zero-vehicle households, while 45.8 percent have one vehicle and 29.8 percent live in two-vehicle households. About 26.2 percent live with one or more children. Just over one-half, 53.7 percent, report having air conditioning at home, a resource likely to shape responses to extreme heat.

Residential context was characterized in two ways. First, ZIP codes were classified as urban, suburban, or rural using population and employment density thresholds. Based on this classification, 25.1 percent of respondents reside in urban areas (population density >2500 persons/sq mi; employment density >1000 jobs/sq mi), 66.9 percent in suburban areas (population density 500-2500 persons/sq mi; employment density 100-1000 jobs/sq mi), and 8.0 percent in rural areas (population density <500 persons/ sq mi; employment density <100 jobs/sq mi). Second, respondent ZIP codes were mapped to metropolitan statistical areas and linked to the NOAA 1991–2020 U.S. Climate Normals. Among the 100 largest metropolitan areas, the 20 with the highest normal annual mean temperature were designated hot-climate metropolitan areas. These include, among others, Phoenix, Miami, Houston, Las Vegas, Tucson, San Antonio, and

several Florida metropolitan areas. About 27.7 percent of the estimation sample resides in one of these hot-climate regions.

TABLE 1 Sample Socio-Demographic Characteristics: Respondent-Level Sample (S1; N=4,661) and Respondent-Event Estimation Sample (S2; N=7,468)

<i>Individual Demographics</i>			<i>Household Characteristics</i>		
Variable	S1 (%)	S2 (%)	Variable	S1 (%)	S2 (%)
Gender			Household annual income		
Female	57.6	58.2	Less than \$50,000	50.0	48.9
Male	42.4	41.8	\$50,000 to \$99,999	31.1	30.2
Age category			\$100,000 to \$149,999	11.0	10.5
18 to 30 years	13.0	12.8	\$150,000 to \$249,999	6.5	5.9
31 to 40 years	17.4	17.1	\$250,000 or more	1.4	4.5
41 to 50 years	16.2	16.1	Household size		
51 to 64 years	22.7	22.9	One	27.7	28.2
65 years or older	30.7	31.1	Two	34.6	34.6
Employment and student status			Three or more	37.7	37.2
A student (part-time or full-time)	2.5	2.4	Housing unit type		
A worker (part-time or full-time)	45.0	44.6	Stand-alone home	56.2	56.5
Both a worker and a student	2.9	2.9	Condo/apartment	27.3	27.1
Neither a worker nor a student	49.6	50.1	Other	16.5	16.4
Education attainment			Home ownership		
High school or less	26.6	26.7	Own	56.6	56.7
Some college or technical school	38.0	38.2	Rent	39.5	39.4
Bachelor's degree(s)	22.5	22.7	Other	3.9	3.9
Graduate degree(s)	12.9	12.4	Number of vehicles		
Race			Zero	12.2	12.0
Asian or Pacific Islander	3.1	3.0	One	45.5	45.8
Black	12.4	12.1	Two	29.8	29.6
Native American	1.2	1.1	Three or more	12.5	12.6
White	78.2	78.7	Number of children		
Other	5.1	5.1	Zero	73.2	73.8
Travel-limiting condition			One or more	26.8	26.2
Yes	19.4	19.5	Air conditioning at home		
No	80.6	80.5	Yes	49.2	53.7
WFH in the last week (^)			No	50.8	46.3
Zero day	48.7	50.2	Household location		
One or two days	14.2	13.7	Urban	25.1	24.5
Three or more days	37.1	36.1	Suburban	66.9	67.9
Work environment (^)			Rural	8.0	7.6
Indoors	71.6	72.1	Residence in hot metro area (*)		
Outdoors	9.3	9.3	Yes	27.7	27.8
Both indoors and outdoors	19.1	18.6	No	72.3	72.2

Notes: (^) = Only asked to workers; (*) Residence in one of the 20 U.S. metropolitan statistical areas (MSAs) with the highest normal annual mean temperatures, based on respondents' ZIP codes.

2.2. Endogenous Variables and Attitudinal Indicators

The analysis includes four endogenous outcomes that capture respondents' prior experience with extreme events and their anticipated food acquisition responses during a similar future event. The first outcome measures the perceived severity of the respondent's most recent experience with extreme heat, extreme cold, or a power outage. The remaining three outcomes represent anticipated

changes in dining inside a restaurant, picking up takeout, and having food delivered relative to the respondent's normal routine in the event that the disruption were to happen again.

Respondents who reported prior experience with an extreme event were asked: "Thinking about the last time you experienced [extreme heat/extreme cold/a power outage], how severe would you rate its impact on your daily life?" Responses were recorded on a five-point ordered scale ranging from (1) Not severe at all to (5) Extremely severe. The question was administered separately for each event type that a respondent had experienced, allowing perceived severity to vary across extreme heat, extreme cold, and power outages.

Respondents who experienced disruptions were then asked the follow-up question/module: "The next time there is an [extreme heat event/extreme cold event/power outage], how would your participation in the following activities change compared to your normal routine?" Although the survey included a broader set of activities, this study focuses on three restaurant-based food acquisition modalities: dining indoors at a restaurant, picking up takeout from a restaurant, and having food delivered from a restaurant. For each activity, respondents selected one of four responses: "I do not usually do this activity", "Less", "About the same", or "More". For model estimation, "I do not usually do this activity" was combined with "About the same", yielding a three-level ordered outcome coded as (1) less, (2) about the same, and (3) more. Each outcome therefore captures the direction of anticipated change during a future event relative to the respondent's usual behavior.

Figure 1 presents the distributions of perceived severity and anticipated changes in the three food acquisition modalities by event type. Extreme heat was perceived as the most severe, with 54.4 percent rating its impact as at least moderately severe, compared with 49.9 percent for extreme cold and 46.4 percent for power outages. Across all event-activity combinations, "about the same" is the most common response, accounting for 51.2 to 63.4 percent of observations. Thus, most respondents expect to maintain their usual food acquisition patterns, although sizable shares anticipate changing modalities during disruptive conditions.

The distributions nevertheless reveal distinct event-specific patterns. During extreme heat, delivery is the only modality with a clear net anticipated increase; 22.8 percent expect to use delivery more, compared with 13.8 percent who expect to use it less. Dining in and pickup show modest net declines, with nearly 22 percent anticipating reductions and 16-17 percent anticipating increases. These patterns suggest that some consumers may shift toward home-based food access when heat increases the discomfort or risk associated with travel.

Extreme cold produces the largest anticipated reductions in out-of-home food acquisition. About 36.6 percent expect to dine-in less and 34.1 percent expect to pick up food less, while only 12.2 and 14.3 percent, respectively, expect to increase these activities. Delivery is comparatively more stable and exhibits a small net increase, with 23.6 percent expecting greater use and 20.4 percent expecting less use. This pattern is consistent with delivery serving as a home-centered alternative when cold conditions discourage travel.

Power outages produce a different response. Dining in is expected to decline substantially, with 30.2 percent anticipating less participation and 17.3 percent anticipating more. Pickup is comparatively more robust, with 21.4 percent expecting to increase its use and 24.7 percent expecting to reduce it. Delivery similarly shows a net anticipated decrease under outages, with 23.5 percent expecting less use and 17.5 percent expecting more. This may reflect the simultaneous disruption of restaurant operations, communications systems, electronic payments, and delivery platforms, even as households lose the ability to prepare or refrigerate food at home.

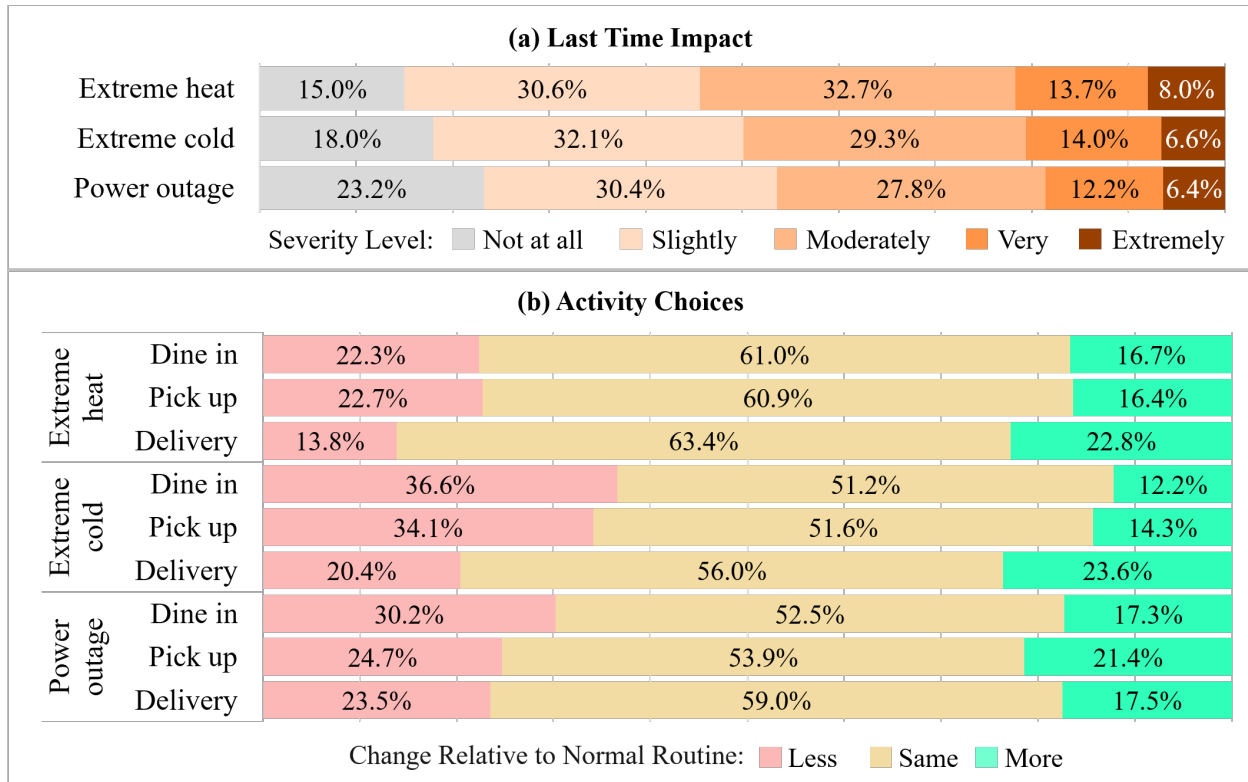


Figure 1. Last Time Impact and Anticipated Food Access Modality Changes by Event Type (N=7,468)

2.3. Stochastic Latent Constructs

The model incorporates three stochastic latent constructs that capture attitudinal dispositions expected to shape how individuals perceive and respond to extreme events: social interaction propensity, transit-oriented living preference, and personal resilience. The three attitudinal constructs were specified based on evidence from prior literature, empirically identified through exploratory factor analysis, and subsequently refined and validated through confirmatory factor analysis to ensure statistically significant indicator loadings and satisfactory measurement-model fit. These constructs are measured using the attitudinal indicators shown in Figure 2.

Social interaction propensity reflects an individual's inclination toward social engagement, group participation, and interaction in public settings. It is measured through agreement with statements concerning enjoyment of meeting people unexpectedly, participation in community activities, and feeling energized in large groups. In the estimation sample, 52.3 percent somewhat or strongly agree that they enjoy meeting people unexpectedly or making new acquaintances in public places. About 33.1 percent agree that they regularly participate in community activities that strengthen their sense of belonging, while 33.9 percent agree that they feel energized when part of a large group. Individuals scoring higher on this construct may place greater value on the social dimensions of restaurant dining and may respond differently when extreme events disrupt opportunities for interaction.

Transit-oriented living preference captures a preference for denser, mixed-use neighborhoods with nearby stores, restaurants, offices, and transit access. The construct is defined by agreement with statements about living close to transit, even at the cost of a smaller home, and having commercial uses mixed among residences. About 64.5 percent somewhat or strongly agree

that they prefer to live close to transit, while 35.3 percent agree that they favor neighborhoods where stores, restaurants, and offices are interspersed among homes. This construct is relevant because neighborhood form and proximity to destinations may influence the ease with which individuals can dine in, pick up food, or receive deliveries during disruptive conditions.

Personal resilience represents confidence in one's ability to cope with and recover from challenging situations. It is measured through respondents' self-assessed ability to bounce back quickly and their knowledge of safety measures during extreme events. About 71.9 percent somewhat or strongly agree that they can recover quickly from difficult circumstances, and 74.1 percent report being knowledgeable about the steps needed to protect themselves during extreme events. Higher levels of personal resilience may reduce perceived event severity and enable individuals to adapt more effectively (without necessarily requiring a substantial change of routine) when confronted with a disruption.

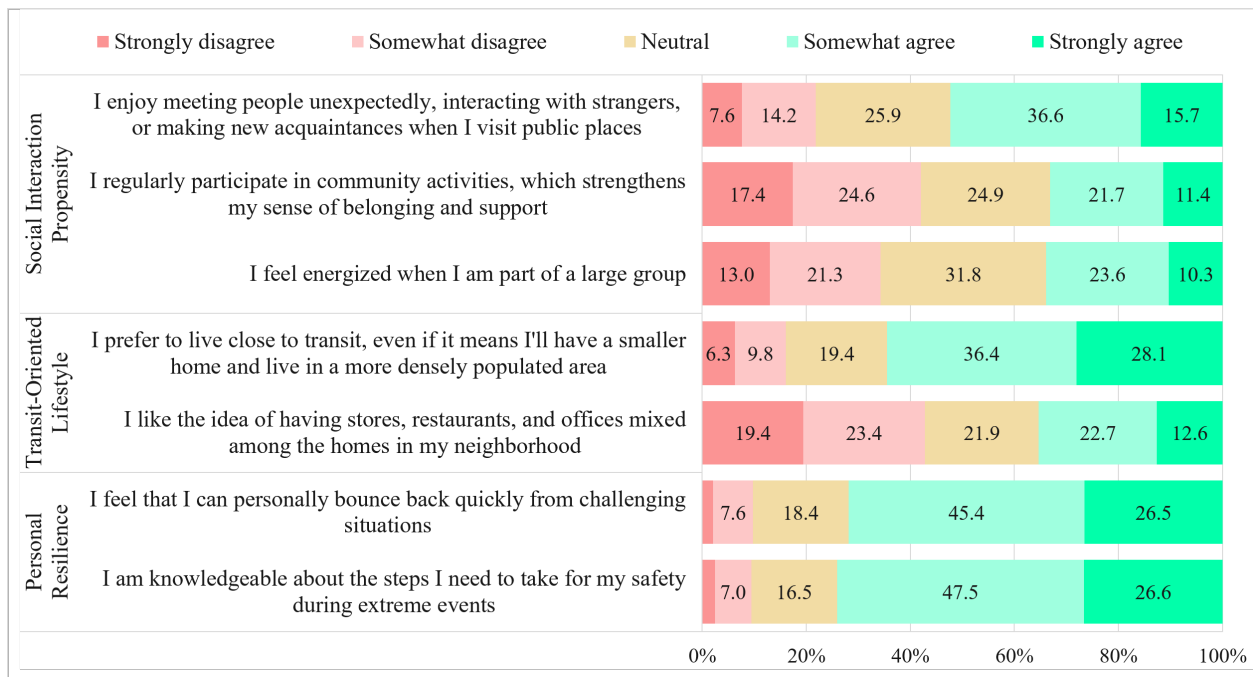


Figure 2. Agreement with Attitudinal Indicators Defining Latent Constructs (N=7,468)

3. MODELING FRAMEWORK

This study employs a generalized heterogeneous data model (GHDM) to jointly examine perceived event severity and anticipated changes in food acquisition behavior the next time an event occurs. The framework is well suited to the analysis because the four endogenous outcomes are ordered and potentially interdependent. These outcomes include the perceived severity of the respondent's most recent experience with an extreme event and anticipated changes in dining in, picking up food, and having food delivered during a future event of the same type. Estimating these outcomes jointly allows the analysis to recognize that individuals' responses across food acquisition modalities may be shaped by common observed and unobserved factors.

The conceptual structure of the model is shown in Figure 3. Individual-level attributes, including socioeconomic and demographic characteristics, household characteristics, and community resources, enter the model through two pathways. First, they may exert direct effects on perceived event severity and anticipated changes in the three food acquisition modalities.

Second, they may operate indirectly through three stochastic latent constructs: social interaction propensity, transit-oriented living preference, and personal resilience. These constructs capture underlying dispositions that are not directly observed but are measured through the attitudinal indicators described previously.

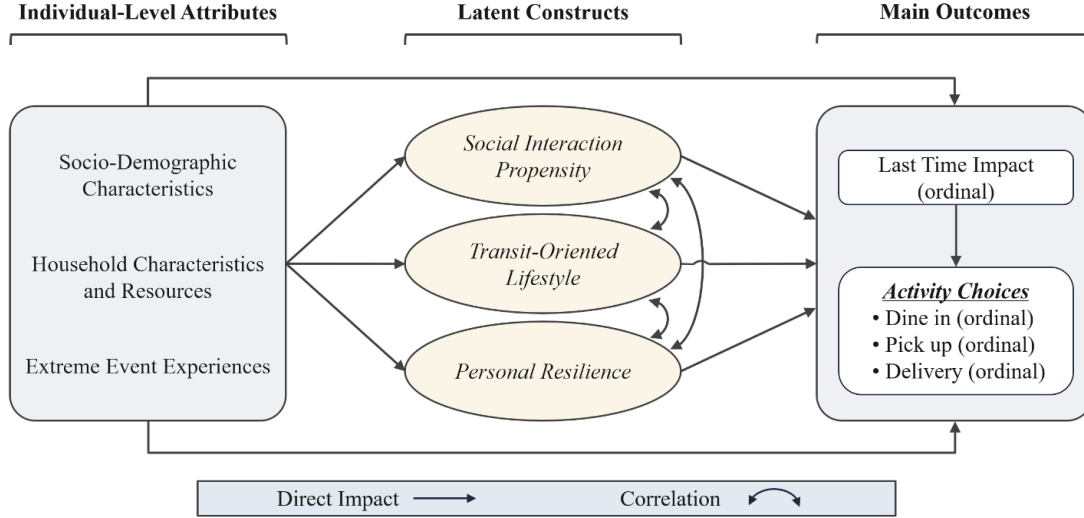


Figure 3. Model Framework

The latent constructs are represented through structural and measurement components. In the structural component, individual and household attributes explain variation in each latent construct. In the measurement component, the latent constructs are linked to their observed attitudinal indicators. This integrated treatment allows the model to account for the role of attitudes and lifestyle preferences without relying on simple deterministic factor scores. Because the constructs are stochastic, uncertainty in their measurement is carried through the full model.

A central advantage of the GHDM framework is its ability to represent dependence among the endogenous outcomes. The three latent constructs are allowed to be correlated, as indicated by the double-headed arrows in Figure 3. Because the same latent constructs enter multiple outcome equations, their correlations induce dependence across perceived event severity and the anticipated changes in dine-in, pickup, and delivery. This structure recognizes that the same underlying dispositions may simultaneously shape how severely a person perceives an extreme event and how that person expects to adjust food acquisition behavior. For example, a stronger social interaction propensity may affect both perceived disruption and the desire to continue dining in, while greater personal resilience may reduce perceived severity and the extent of anticipated behavioral adjustment.

The model also allows the perceived severity of the most recent event to influence anticipated changes in food acquisition during a future event of the same type. This endogenous linkage captures the central behavioral premise of the study that prior experience may shape future expectations and adaptation. Respondents who previously experienced greater disruption may or may not anticipate more substantial changes during a future event, depending on the specific event type and food acquisition modality.

All four endogenous variables are modeled as ordered outcomes. The perceived severity measure ranges from not severe at all to extremely severe, while each food acquisition outcome ranges from *less* to *about the same* to *more* relative to the respondent's normal routine. The GHDM

framework estimates these ordered responses simultaneously while accounting for direct effects, indirect effects through latent constructs, and dependence generated by shared unobserved dispositions.

The complete mathematical formulation of the GHDM is notation intensive and is omitted in the interest of brevity, particularly because the methodological development itself is not the primary contribution of this study. A detailed formulation of the modeling methodology is available in Bhat (2015) and Bhat and Mondal (2022). The emphasis here is on the ability to jointly represent multiple ordered outcomes, incorporate stochastic latent constructs, and account for correlated behavioral responses across event severity and anticipated changes in food acquisition modalities.

4. MODEL ESTIMATION RESULTS

This section presents the model estimation results in detail. The discussion begins with the latent construct component, which relates individual and household characteristics to the three lifestyle-oriented constructs – social interaction propensity, transit-oriented living preference, and personal resilience – and reports the corresponding factor loadings for the attitudinal indicators. The discussion then turns to the main outcome component, focusing on the effects of exogenous variables, the influence of the latent constructs, relationships among the endogenous outcomes, and the correlations implied by the joint model structure. Model fit and performance are then assessed, and the section concludes with average treatment effects that express the estimated effects as probability shifts.

4.1. Latent Construct Model Component

Table 2 presents the structural and measurement equation results for the three latent constructs. The upper portion of the table identifies the individual and household attributes associated with social interaction propensity, transit-oriented living preference, and personal resilience. The lower portion reports the factor loadings linking each construct to its observed attitudinal indicators.

Social interaction propensity is higher among adults 18-30 years of age, Black respondents, workers, and individuals living in households with three or more members. These patterns suggest that younger adults and individuals whose work or household circumstances provide more frequent opportunities for interpersonal engagement are more inclined toward social interaction and community participation, broadly consistent with prior research on social connectedness and participation (Kannan and Veazie, 2023; Hovbrandt et al. 2021). In contrast, females and respondents from households earning less than \$50,000 exhibit lower values of this construct. The income relationship may reflect differences in the time, financial resources, or opportunities available for participation in social and community activities (Kannan and Veazie, 2023).

Preferences for transit-oriented living are stronger among younger adults, workers and students, zero-vehicle households, urban residents, and renters. The largest coefficient in this equation is associated with living in a zero-vehicle household, underscoring the close relationship between limited automobile availability and preferences for neighborhoods with nearby destinations and transit service. Urban residence and renting are also positively associated with the construct, consistent with the greater prevalence of compact, mixed-use, and transit-accessible environments among these groups. Females exhibit a modestly lower preference for transit-oriented living than males. Overall, the results suggest that life-cycle stage, mobility resources, employment or student status, and residential context jointly shape preferences for proximity, density, and multimodal accessibility.

TABLE 2 Determinants of Latent Variables and Loadings on Indicators (N=7,468)

Explanatory Variables (base category)		Structural Equations Model Component					
		Social Interaction Propensity		Transit-Oriented Lifestyle		Personal Resilience	
		Coef.	t-stat	Coef.	t-stat	Coef.	t-stat
Individual Characteristics							
Age (*)	18 to 30 years	0.25	5.56	0.27	4.70	—	—
	65 years or older	—	—	—	—	0.13	3.25
Gender (male)	Female	-0.20	-6.51	-0.09	-2.39	-0.30	-8.11
Race and ethnicity (*)	Black	0.27	6.50	—	—	—	—
	Asian	—	—	—	—	-0.22	-2.14
Employment (*)	Worker	0.40	13.25	—	—	—	—
	Worker or student	—	—	0.58	13.97	—	—
Travel limitations (no)	Yes	—	—	—	—	-0.23	-5.30
Household Characteristics							
Household size (one or two)	Three or more	0.36	12.05	—	—	—	—
Vehicle ownership (one or more)	Zero	—	—	0.81	13.15	—	—
Household income (≥ \$50,000)	Less than \$50,000	-0.30	-9.77	—	—	-0.24	-6.70
Location (rural or suburban)	Urban	—	—	0.72	15.03	—	—
Housing tenure (own)	Rent	—	—	0.55	12.98	—	—
Correlations Between Latent Constructs							
Social interaction propensity		1.00	—	0.47	20.51	0.51	24.30
Transit-oriented lifestyle				1.00	—	0.43	16.23
Personal resilience						1.00	—
Attitudinal Indicators		Loadings of Latent Variables on Indicators (Measurement Equations Model Component)					
I enjoy meeting people unexpectedly, interacting with strangers, or making new acquaintances when visiting public places		0.93	34.47	—	—	—	—
I feel energized when I am part of a large group		0.76	38.34	—	—	—	—
I regularly participate in community activities, which strengthen my sense of belonging and support		0.64	32.15	—	—	—	—
I like the idea of having stores, restaurants, and offices mixed among the homes in my neighborhood		—	—	0.74	19.39	—	—
I prefer to live close to transit, even if it means I'll have a smaller home and live in a more densely populated area		—	—	0.40	23.01	—	—
I feel that I can personally bounce back quickly from challenging situations		—	—	—	—	0.56	22.17
I am knowledgeable about the steps I need to take for my safety during extreme events		—	—	—	—	0.75	20.02

Note: Coef. = coefficient; “—” = not applicable; (*) Base category is not identical across the model equations and corresponds to all omitted categories.

Personal resilience is positively associated with being 65 years of age or older, indicating greater self-reported confidence in recovering from difficult situations and knowledge of appropriate safety measures among older adults. Lower values are found among females, Asian respondents, individuals with a travel-limiting condition, and respondents from households earning less than \$50,000. The negative associations for lower-income individuals and those with travel limitations are especially salient because these groups may have fewer financial, physical, or logistical resources available (to adapt) when disruptive events occur. These findings are

broadly consistent with research emphasizing the role of resource constraints and differential vulnerability in shaping perceived coping capacity (Enarson et al. 2007; Fothergill and Peek, 2004).

The measurement equation results provide strong support for the specification of the three constructs. All factor loadings are positive and statistically significant. The significance and intuitive direction of these loadings indicate that the selected indicators capture the intended attitudinal dimensions. The three latent constructs are also positively and significantly correlated. Social interaction propensity is correlated with transit-oriented living preference at 0.47 and with personal resilience at 0.51, while transit-oriented living preference and personal resilience are correlated at 0.43. These correlations indicate that the constructs are related but empirically distinct. Individuals who are more socially engaged also tend to express stronger preferences for connected, transit-accessible environments and greater confidence in their ability to cope with disruption. Accounting for these correlations is important because the constructs jointly influence perceived event severity and anticipated changes in food acquisition behavior.

4.2. Estimation Results for Main Outcomes Model

This section provides a discussion of estimation results for the main outcomes model presented in Table 3. Throughout the discussion, all estimated effects should be understood as influences on the latent propensity underlying each ordered outcome, rather than as direct effects on the observed response category itself; accordingly, all substantive interpretations should be done through an underlying propensity lens, even if the wording does not explicitly say so.

4.2.1 Exogenous Variable Effects

The exogenous variable effects in Table 3 indicate that perceived event severity and anticipated food acquisition adjustments in the future vary systematically across lifecycle stages, employment circumstances, mobility resources, and household conditions. Most effects are not uniform across all four outcomes, suggesting that different characteristics shape perceptions of disruption severity and the ability to shift among dine-in, pickup, and delivery through distinct pathways.

Age exhibits the broadest pattern of influence. Adults 18-40 years of age perceive their most recent extreme event as more severe and are also more likely to anticipate increasing dine-in, pickup, and delivery. This pattern may reflect their generally higher levels of activity participation, employment and household obligations, and familiarity with app-based ordering and alternative food acquisition channels (Keeble et al. 2020). Adults 41-50 years of age also report greater prior-event severity, whereas adults 65 years or older report lower severity. The latter finding may reflect differences in daily activity patterns, schedule flexibility, or exposure (Sun et al. 2021), although the model does not directly identify the underlying mechanism at play.

Gender effects are more limited. Females are less likely than males to anticipate increasing dine-in and exhibit a marginally lower propensity to increase pickup. Non-Hispanic White respondents report lower perceived event severity than other racial and ethnic groups, pointing to possible differences in exposure, housing conditions, access to protective resources, or neighborhood infrastructure (Chakraborty, 2024; Manware et al. 2022). Employment circumstances affect both exposure and adaptation. Individuals who are neither workers nor students report lower prior-event severity, possibly because they have greater flexibility to modify schedules and avoid hazardous conditions. Outdoor workers, in contrast, report substantially greater severity, consistent with the direct and sustained exposure associated with working outside. In the event of a future disruption, workers and students are more likely to increase dine-in and

pickup, while workers and students considered separately also exhibit greater propensities to increase delivery. These patterns suggest that established out-of-home routines, time constraints, and the need to maintain daily obligations contribute to continued reliance on restaurant-based food acquisition during disruptions.

Travel-limiting conditions emerge as an especially important marker of vulnerability. Respondents with such conditions report greater prior-event severity and are more likely to anticipate increasing delivery. Delivery may therefore constitute an essential adaptation mechanism for individuals who cannot travel easily when conditions become hazardous. At the same time, this reliance creates additional vulnerability if delivery services are constrained by disruptive circumstances, unavailable, unaffordable, or geographically limited.

Household resources also shape both perceived impact and anticipated response. Respondents with household incomes below \$50,000 report greater prior-event severity, consistent with prior research showing that lower-income households often possess fewer housing, transportation, and financial resources with which to mitigate extreme event impacts (Hsu et al. 2021). Households earning more than \$100,000 are more likely to increase dine-in, potentially reflecting greater discretionary resources and a wider set of available food acquisition options. Households with children report both greater prior event severity and a greater propensity to increase delivery in a future event. Caregiving responsibilities may heighten the consequences of disruption while making it more difficult to leave home, consistent with research emphasizing the particular challenges faced by households with children during disasters (Choi et al. 2025).

Mobility and residential circumstances further differentiate anticipated responses. Households with two or more vehicles are more likely to increase dine-in, reflecting greater ability to reach restaurants. Renters are more likely to decrease pickup in future extreme events, possibly because renters are more resource constrained. Working from home at least one day per week is associated with a marginally greater propensity to increase delivery, consistent with more home-centered daily routines. Rural residents are less likely to adopt more delivery in a future event, likely reflecting more limited service coverage and longer delivery distances. Finally, access to air conditioning is associated with lower perceived event severity, underscoring the protective value of household resources during extreme heat. Overall, the results show that food acquisition adaptation is shaped not only by preference, but also by the financial, mobility, housing, and household resources available to the individual.

4.2.2 Endogenous Variable and Interaction Effects

The endogenous effects reveal that anticipated food acquisition responses are strongly dependent on both event type and prior event severity. Relative to the omitted power outage category, extreme heat is associated with greater perceived severity and stronger propensities to increase both dine-in and delivery. Extreme cold reduces the propensity to increase pickup while increasing the likelihood of greater delivery use. These findings reinforce the premise that extreme events do not simply reduce activity. Instead, they alter the relative attractiveness of food acquisition channels, with delivery becoming more appealing when outdoor exposure or travel conditions discourage household trips.

The severity of the most recent event also shapes anticipated future behavior. Relative to the omitted lower severity categories, a moderately severe prior event is associated with a greater propensity to increase dine-in. A very severe event is associated with increases in both dine-in and pickup propensities, while an extremely severe event is associated with increases in dine-in and delivery. Greater prior disruption therefore appears to prompt stronger anticipated future

adjustment, but the selected modality varies with the level and nature of the disruption. Dining in appears to be an appealing option for all higher severity levels, with delivery becoming an appealing option for the most severe circumstances.

TABLE 3 Multivariate Model of Main Outcomes (N=7,468)

Explanatory Variables (base category)		Main Outcome Variables							
		Last Time Impact <i>Ordinal (5-level)</i>		Dine in		Pick up		Delivery	
				<i>Ordinal (3-level): Less, Same, More</i>					
		Coef.	t-stat	Coef.	t-stat	Coef.	t-stat	Coef.	t-stat
Endogenous Variable Effects									
Extreme event (*)	Extreme heat	0.14	3.26	0.30	5.53	—	—	0.17	4.44
	Extreme cold	—	—	—	—	-0.28	-5.80	0.10	2.93
Last time impact (*)	Moderately severe	—	—	0.10	1.97	—	—	—	—
	Very severe	—	—	0.25	3.69	0.11	2.42	—	—
	Extremely severe	—	—	0.21	4.16	—	—	0.28	5.70
Interaction terms (*)	Extreme heat × Moderately severe	—	—	-0.17	-2.40	—	—	—	—
	Extreme heat × Very severe	—	—	-0.40	-4.28	—	—	0.20	3.21
	Extreme cold × Moderately severe	—	—	-0.24	-3.44	-0.10	-1.88	—	—
	Extreme cold × Very severe	—	—	-0.31	-3.28	-0.16	-1.92	—	—
Latent Constructs									
Social interaction propensity		0.13	5.96	0.04	2.56	—	—	—	—
Transit-oriented lifestyle		—	—	—	—	—	—	0.04	2.42
Transit-oriented lifestyle × Extreme cold		—	—	0.08	3.10	0.11	4.05	—	—
Personal resilience		-0.05	-2.01	—	—	0.08	4.02	0.09	4.08
Individual Characteristics									
Age (*)	18 to 40 years	0.18	4.87	0.14	4.37	0.19	5.87	0.16	5.00
	41 to 50 years	0.10	2.37	—	—	—	—	—	—
	65 years or older	-0.20	-5.34	—	—	—	—	—	—
Gender (male)	Female	—	—	-0.08	-2.63	-0.05	-1.67	—	—
	Non-Hispanic White	-0.08	-2.55	—	—	—	—	—	—
Employment (*)	Worker	—	—	—	—	—	—	0.10	2.59
	Student	—	—	—	—	—	—	0.17	2.03
	Worker or student	—	—	0.10	2.78	0.10	2.96	—	—
	Neither worker nor student	-0.12	-3.61	—	—	—	—	—	—
Work environment (*)	Outdoor	0.27	4.09	—	—	—	—	—	—
Travel limitations (none)	Has limitations	0.25	6.24	—	—	—	—	0.10	2.79
Household Characteristics									
Household income (*)	Less than \$50,000	0.14	5.23	—	—	—	—	—	—
	More than \$100,000	—	—	0.19	4.50	—	—	—	—
Housing tenure (own)	Rent	—	—	—	—	-0.14	-4.75	—	—
Presence of child (none)	One or more	0.18	5.53	—	—	—	—	0.17	5.51
Vehicle ownership (<2)	Two or more	—	—	0.14	4.16	—	—	—	—
WFH last week (no)	Yes, at least one day	—	—	—	—	—	—	0.06	1.67
Location (urban or suburban)	Rural	—	—	—	—	—	—	-0.14	-2.54
Has AC at home (no)	Yes	-0.10	-3.33	—	—	—	—	—	—
Interaction Terms (*)									
Extreme heat × Travel-limitations		0.20	2.99	—	—	—	—	—	—
Extreme heat × Income ≥ \$100,000		—	—	-0.20	-2.63	—	—	—	—
Extreme heat × Home rent		—	—	0.08	1.67	—	—	—	—
Extreme heat × No vehicles		—	—	—	—	—	—	0.12	1.70
Extreme heat × Hot metro resident		0.30	6.54	—	—	—	—	—	—

Extreme cold × Less than high school	0.17	3.81	—	—	—	—	—	—
Extreme cold × Work indoor	-0.15	-2.96	—	—	—	—	—	—
Extreme cold × 2+ vehicles	—	—	-0.20	-3.75	—	—	—	—
Power outage × Neither student nor worker	—	—	0.15	2.95	—	—	—	—
Power outage × 2+ vehicles	—	—	—	—	0.14	3.48	—	—
Thresholds								
1 2	-0.82	-17.10	-0.29	-6.03	-0.66	-16.84	-0.60	-15.71
2 3	0.12	2.41	1.32	26.36	0.93	23.49	1.11	28.33
3 4	1.01	20.61						
4 5	1.70	32.90						
Implied Correlations Between Outcomes								
Dine in	0.13	—	1	—	0.05	—	0.08	—
Pick up	-0.04	—	0.05	—	1	—	0.25	—
Delivery	0.09	—	0.08	—	0.25	—	1	—
Data Fit Measures	GHDM				Independent Model			
Predictive log-likelihood at convergence	-31647.10				-32005.97			
Predictive log-likelihood at constants	-32915.00				-32914.98			
Number of parameters	126				112			
Adjusted likelihood ratio index	0.036				0.025			
Bayesian information criterion	32208.92				32505.40			
Non-nested likelihood ratio test	-27.56							

Note: Coef. = coefficient; “—” = not applicable; (*) Base category is not identical across the model equations and corresponds to all omitted categories.

The event severity interactions show that these relationships are nonlinear. Although extreme heat has a positive main effect on dine-in, this tendency is attenuated when the prior heat event was moderately or very severe (as opposed to extremely severe). Extreme cold similarly reduces the tendency to increase dine-in when the prior event was moderately or very severe. These results suggest that restaurants may serve as attractive indoor destinations under less severe conditions, but the journey becomes increasingly undesirable or unsafe as exposure intensifies. Extreme cold also further suppresses pickup among those who previously experienced moderately or very severe cold. In contrast, very severe heat strengthens the propensity to increase delivery, indicating a shift toward home-based food acquisition when travel becomes especially burdensome.

Several interactions identify population groups for whom event impacts are compounded. The positive association between a travel-limiting condition and perceived severity is amplified during extreme heat. Residents of hot climate metropolitan areas also report substantially greater heat severity. Thus, residence in a warmer climate does not eliminate vulnerability and may instead reflect repeated exposure to more intense or persistent heat, consistent with concerns surrounding urban heat exposure (Habeeb et al. 2015). Extreme cold is perceived as more severe among respondents with less than a high-school education, while indoor workers report lower cold severity, presumably because they are better shielded from direct exposure.

Event conditions also modify the role of household resources. During extreme heat, households earning more than \$100,000 are less likely to increase dine-in, possibly because they can substitute toward delivery and maintain adequate thermal comfort at home. Renters exhibit a marginally greater inclination to dine in during heat, which may reflect a desire for greater use of cooled commercial spaces. Zero-vehicle households show a marginally greater propensity to increase delivery under heat, underscoring the importance of delivery when both exposure and mobility constraints are present.

During extreme cold, households with two or more vehicles are less likely to increase dine-in despite their greater general propensity to do so. Vehicle availability alone may not offset hazardous driving conditions or longer travel distances in auto-oriented areas. During power outages, individuals who are neither workers nor students are more likely to increase dine-in, potentially because they lack access to powered workplaces or campuses while food preparation at home is constrained. Multi-vehicle households are also more likely to increase pickup during outages, using their mobility resources to reach operating establishments when cooking or refrigeration is unavailable. This pattern is consistent with evidence that households shift toward accessible food destinations when outages disrupt normal food access (Ma et al. 2026). Overall, the interaction effects show that event type, prior experience, and household resources jointly determine the food acquisition channels that are more or less likely to be adopted in the future.

4.2.3 Latent Construct Effects

The latent constructs provide additional insight into the attitudinal mechanisms underlying perceived impact and adaptation. Social interaction propensity is positively associated with both prior event severity and anticipated increase in propensity to dine-in when confronted with a future extreme event. Individuals who place greater value on public interaction may experience greater disruption when extreme events interfere with social and community routines, while also exhibiting a stronger desire to preserve the social experience of restaurant dining. This interpretation is broadly consistent with prior research emphasizing the role of social connectedness, workplace interaction, and community participation in shaping daily activity engagement (Kannan and Veazie, 2023; Hovbrandt et al. 2021).

Transit-oriented living preference is positively associated with anticipated increase in delivery use. It also interacts with extreme cold to increase both dine-in and pickup. Individuals who prefer mixed-use, transit-accessible environments may reside closer to restaurants and other food-service establishments, allowing them to maintain some out-of-home food acquisition even when cold conditions make longer trips unattractive. The results suggest that proximity and neighborhood accessibility expand the range of feasible adaptation options during disruptive events.

Personal resilience is associated with lower perceived event severity but greater propensities to increase pickup and delivery in the future. This is substantively important. Resilient individuals do not necessarily preserve their normal routines; rather, they may experience less disruption because they are more willing or able to shift among available food acquisition channels. Resilience may therefore be expressed through behavioral flexibility and knowledge of alternatives rather than trying to maintain status quo. This interpretation is consistent with disaster research emphasizing that coping capacity depends on access to resources, preparedness knowledge, and the ability to mobilize alternative strategies when normal arrangements fail (Enarson et al. 2007; Fothergill and Peek, 2004). By incorporating these stochastic latent constructs, the model captures dimensions of adaptation that would not be explained by observed socioeconomic and household characteristics alone.

4.2.4 Implied Correlations and Goodness-of-Fit

The joint model estimation effort is found to be appropriate in this context by virtue of the superior statistical goodness-of-fit. The statistics provided at the bottom of Table 3 show that the joint model provides a better fit than the independent ordered probit specification. Despite including additional parameters, it yields a higher predictive log-likelihood, a larger adjusted likelihood ratio

index (0.036 versus 0.025), and a substantially lower Bayesian Information Criterion (32,208.92 versus 32,505.40), supporting the joint modeling of outcomes and their shared latent influences.

The case for joint model estimation is further strengthened by the implied correlations among the outcome variables, which indicate that common unobserved factors shape perceived event severity and anticipated adjustments across food acquisition modalities. The correlations in the first column suggest that unobserved influences associated with perceiving greater event impacts are also associated with a higher propensity to increase dine-in and delivery, but a slightly lower propensity to increase pick up. One possible interpretation is that pickup is the least attractive fallback for those most affected, as it requires an out-of-home trip without the on-site comfort of a restaurant or the travel avoidance of delivery – although this mechanism is not directly measured. The modest but positive correlations between dine-in, pick-up, and delivery further suggests a broader underlying propensity to continue relying on restaurant-prepared food during disruptions, even if the preferred acquisition channel differs.

4.2.5 Average Treatment Effects (ATEs)

The coefficients in Table 3 identify the direction and statistical significance of effects on the latent propensity underlying each ordered outcome, but they do not directly convey the magnitude of the resulting probability shifts. Average treatment effects (ATEs) are therefore computed to translate the model estimates into changes in the predicted probabilities of anticipating less or more use of each food acquisition modality. For each observation, the variable of interest is first assigned to the designated base condition – for example, power outage – while all other observed characteristics are retained at their original values, and the corresponding outcome probabilities are predicted. The observations are then reassigned to the treatment condition – extreme heat or cold – with all applicable interaction terms updated, and the probabilities are recomputed. The observation-specific difference between the treatment and base probabilities is then averaged over the full sample. The same procedure is applied to changes in prior-event severity, using “not severe at all/slightly severe” as the base. The percent average treatment effect (PATE) expresses the ATE relative to the average predicted probability under the base condition. Because the data are observational and the outcomes represent stated anticipated behavior, these estimates should be interpreted as model-based counterfactual probability shifts rather than causal treatment effects per se. Additional details on the calculation of ATEs are provided by Bhat (2015).

The event-type effects reveal sharply different patterns across modalities. Relative to a power outage, extreme heat reduces the probability of anticipating less dine-in by 5.7 percentage points and less delivery by 5.5 percentage points. At the upper end of the distribution, heat raises the probability of anticipating more dine-in by 4.0 percentage points and more delivery by 6.1 percentage points, corresponding to relative increases of 27.0 and 32.5 percent, respectively. Food pickup modality changes very little. These results suggest that heat may simultaneously increase the attractiveness of air-conditioned restaurants and encourage greater reliance on delivery when households seek to limit travel and exposure.

Extreme cold produces a more pronounced retreat from out-of-home food acquisition. Relative to a power outage, cold raises the probability of anticipating less dine-in and pick up by 5.7 and 9.0 percentage points, respectively. It also reduces the probability of anticipating more dine-in and pickup by 3.2 and 5.9 percentage points, equivalent to relative declines of 21.8 and 31.1 percent. Delivery moves in the opposite direction: the probability of anticipating less delivery falls by 2.8 percentage points, while the probability of anticipating more delivery rises by the same

amount, representing a 14.8 percent increase relative to the base. Thus, extreme cold appears to shift food acquisition away from restaurant visits and pickup and toward home delivery.

Prior-event severity also produces meaningful, but nonlinear, probability shifts. A moderately severe prior experience yields only modest changes, reducing the probabilities of anticipating more dine-in and pickup. A very severe experience is associated with small increases in the probabilities of anticipating more pickup and delivery. The largest changes occur among respondents whose most recent event was extremely severe. Relative to those reporting little or no prior severity, the probability of anticipating more dine-in and more delivery rise by 5.5 and 8.7 percentage points, respectively. These changes correspond to relative increases of 35.5 and 41.6 percent, respectively, while the probabilities of anticipating less use of each of these two modalities decline by 6.7 percentage points. No corresponding change is observed for pickup modality.

Overall, the treatment effects reinforce the event-specific nature of food acquisition adaptation. Delivery emerges as the most consistently favored response under extreme heat and cold, whereas dine-in and pickup are more sensitive to the conditions governing travel and destination access. The severity effects further suggest that especially disruptive prior experiences lead individuals to anticipate more substantial reallocation across food acquisition channels, particularly toward delivery. These probability shifts provide a more tangible representation of the behavioral implications of disruptive events and their severity.

TABLE 4 Average Treatment Effects for Food Modalities by Event Type and Last Time Impact

Variable	Base	Treatment	Same → Less			Same → More		
			Dine in	Pick up	Delivery	Dine in	Pick up	Delivery
ATEs (change in predicted probability)								
Event	Power outage	Extreme heat	-0.057	0.006	-0.055	0.040	-0.006	0.061
		Extreme cold	0.057	0.090	-0.028	-0.032	-0.059	0.028
Last time impact	Not/slightly severe	Moderately severe	0.014	0.012	0.000	-0.008	-0.007	0.000
		Very severe	-0.003	-0.017	-0.017	0.003	0.018	0.023
		Extremely severe	-0.067	0.000	-0.067	0.055	0.000	0.087
Percent ATEs (% change relative to base)								
Event	Power outage	Extreme heat	-18.89	2.35	-24.96	27.03	-3.04	32.52
		Extreme cold	18.94	36.25	-12.84	-21.80	-31.10	14.80
Last time impact	Not/slightly severe	Moderately severe	4.92	4.46	0.00	-5.16	-4.05	0.00
		Very severe	-0.89	-6.30	-8.39	2.06	10.29	11.15
		Extremely severe	-23.01	0.00	-34.00	35.53	0.00	41.61

5. DISCUSSION AND CONCLUSIONS

This study examined how individuals anticipate changing their use of three restaurant-based food acquisition modalities – dining in, picking up food, and having food delivered – during future extreme heat events, extreme cold events, and power outages. Data from 4,661 adults responding to a special extreme events response survey yielded 7,468 respondent-event observations. A generalized heterogeneous data model jointly represented the perceived severity of the respondent’s most recent event and anticipated changes in the three food acquisition modalities in the event of a future disruption, while incorporating latent constructs reflecting social interaction propensity, transit-oriented living preference, and personal resilience.

The central finding is that extreme events do not uniformly reduce food acquisition; rather, they alter the relative feasibility and attractiveness of dine-in, pickup, and delivery modalities. The descriptive patterns in the data show that maintaining the usual routine is the most common

response across all event-modality combinations. Nevertheless, the direction of anticipated change during the next event differs sharply across modalities. Under extreme heat, 22.8 percent expect to increase delivery, compared with 13.8 percent who expect to reduce it. Delivery also exhibits a net anticipated increase during extreme cold, with 23.6 percent expecting greater use and 20.4 percent expecting less. In contrast, more respondents expect to reduce dine-in and pickup than increase them during both heat and cold events in the future. Delivery therefore appears to be the favored adaptive channel when exposure risk, discomfort, or hazardous travel makes out-of-home travel onerous.

This finding makes continuity of delivery service an important component of community resilience. Delivery depends on operating restaurants, available workers and vehicles, functioning communications and payment systems, and navigable transportation networks. Communities and food-service businesses should therefore incorporate delivery capacity into extreme-event preparedness. Potential measures include backup power for participating restaurants, redundant communications, advance agreements with delivery providers, and identification of establishments capable of maintaining limited operations. Delivery subsidies or emergency meal vouchers may be particularly valuable for lower-income households, zero-vehicle households, older adults, and individuals with travel-limiting conditions.

Maintaining delivery should not, however, transfer the burden of adaptation entirely to couriers. Extreme heat and cold may protect consumers who remain at home while exposing delivery personnel to hazardous conditions. Worker protections could include temperature-based operating protocols, reduced delivery radii, limits on consecutive assignments, access to cooling or warming locations, protective equipment, and hazard compensation. Platforms and establishments should also permit workers to decline unsafe trips without penalty and suspend service when conditions exceed established safety thresholds.

Power outages expose the limitations of delivery-dependent food access. Outages are the only event for which more respondents expect to reduce delivery than increase it: 23.5 percent anticipate less delivery, compared with 17.5 percent anticipating more. An outage may simultaneously disrupt restaurant kitchens, refrigeration, telecommunications, internet access, electronic payment, and platform operations. Pickup performs comparatively better and may serve as a fallback when some establishments remain open. Communities should therefore identify food establishments with backup generation, establish offline or alternative payment capabilities, maintain publicly accessible information on operating locations, and designate neighborhood pickup or meal-distribution points. Paratransit, volunteer driver programs, mobile food distribution, and partnerships with community organizations may be necessary for residents who cannot reach these locations independently.

The findings also demonstrate that the role of dine-in depends on event conditions. Air-conditioned restaurants may provide both food and temporary thermal relief during extreme heat, and the model results indicate a greater inclination toward dine-in under heat than under a power outage. However, this tendency weakens as perceived event severity increases, presumably because the journey itself becomes unsafe and unpleasant. Restaurants may therefore complement formal cooling centers only when they are open, nearby, affordable, and safely accessible. Extreme cold produces a broader retreat from dine-in and pickup, reinforcing the importance of maintaining home-delivery capacity during severe cold conditions.

Vulnerability is shaped not only by exposure, but also by the resources available for adaptation. Lower-income households, outdoor workers, households with children, and individuals with travel-limiting conditions report greater prior-event severity. Zero-vehicle

households may rely more heavily on delivery during heat, while rural residents may have less access to delivery services. These results point to a potential mismatch: those with the greatest need to avoid travel may depend most heavily on a modality that is costly, geographically limited, or vulnerable to operational failure. Emergency food planning should therefore combine delivery support with transportation assistance, decentralized distribution points, pre-positioned supplies, and targeted outreach to populations with constrained mobility or limited financial resources.

The personal resilience construct offers an additional policy insight. It reflects both knowledge of appropriate safety measures and confidence in the ability to recover from disruption. Communities can strengthen this form of resilience through clear and repeated communication about available food outlets, cooling and warming centers, transportation services, emergency delivery programs, and assistance eligibility. Multilingual resource guides, neighborhood-level maps, alert systems, preparedness workshops, and opportunities to preregister for food or mobility assistance can reduce uncertainty when an event occurs. Community organizations, faith-based groups, schools, and neighborhood associations can also help build social networks through which residents learn about resources and receive assistance. Personal resilience should not replace structural support – but awareness, preparedness, and social connection can help households use available resources more effectively.

Several limitations warrant acknowledgment. The study measures anticipated future behaviors rather than realized behavior. Event categories do not capture duration, geographic extent, timing, or compound disruptions. The outcomes indicate only directional change and do not measure baseline frequency, actual service availability, or food adequacy. Future research should connect stated responses with mobility, transaction, business-operation, and delivery-platform data observed during actual events.

Overall, food-access resilience calls for multiple, event-specific channels. Transportation plays a critical role in food-access resilience as delivery modality is likely to become increasingly important during extreme heat and cold, but it must remain operational without compromising worker safety. Pickup requires mobility and accessible operating establishments, while dine-in may provide food and refuge only under conditions that permit safe travel. Communities can enhance resilience by implementing programs that address the needs of particularly vulnerable groups and raising awareness about available resources.

AI STATEMENT

Artificial intelligence tools – ChatGPT and Claude – were used to support the preparation of this manuscript, assisting with formatting content and refining language. All AI-assisted output was critically reviewed, revised, and validated by the authors. The study design, analysis, interpretation of results, and conclusions reflect the authors’ academic and professional judgment. AI tools improved efficiency and communication but did not substitute for engineering judgment, technical review, or responsibility for the final content. The authors are solely responsible for all content, including any errors or omissions.

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AUTHOR CONTRIBUTIONS

The authors confirm contribution to the paper as follows: study conception and design: J. Huo, I. Batur, C.R. Bhat, and R.M. Pendyala; data collection: I. Batur, J. R. Dimas Valle, S. Roy, C. Chen and R.M. Pendyala; analysis and interpretation of results: J. Huo, I. Batur, D. Robbennolt, J. R. Dimas Valle, S. Roy, C. Chen, C.R. Bhat, and R.M. Pendyala; draft manuscript preparation: J. Huo, I. Batur, D. Robbennolt, J. R. Dimas Valle, C.R. Bhat, and R.M. Pendyala. All authors reviewed the results and approved the final version of the manuscript.

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