How does delivery service change food accessibility: a modified 2-step floating catchment area method

Supplementary Materials

Section A: Data Visualization and Filtering

CASE STUDY: CITY OF SEATTLE

Collecting demand (population demographic) and supply (food establishments) data

The study area is Seattle, Washington, and includes 135 census tracts with a total population of 779,200 reported in 2023. The sociodemographic data of the residents in the study area is collected from the American Community Survey (ACS) (US Census Bureau, n.d.). Additional characteristics such as low-income, low food access, and household SNAP participation rates are acquired from USDA Food Access Research Atlas and merged to ACS data based on census tract unique identifiers. According to the 2014-2018 ACS 5-year estimates, around 75% of Seattle's population consisted of individuals aged between 18 and 64. Additionally, 23.1% of the population are young adults aged 25 to 34. Nearly two-thirds of Seattle residents aged 25 years and older held a Bachelor's degree or higher, according to data collected between 2017-2021 (US Census Bureau, n.d.). Research has shown that regions with younger, more highly educated residents are more likely to have customers who patronize online food delivery services (Keeble et al., 2020).

The 2019 data from the USDA Food Atlas and the Washington SNAP program indicated that, on average, each tract has 10% of the households participated in the SNAP program, while 50% of all tracts have a SNAP participation rate of less than 7%, which suggests that there are a small number of tracts relying heavily on the SNAP program. According to the Pareto principle, the wealth distribution typically ends up with 20% of the population using 80% of the resource. Hence, this study focuses especially on the tracts with participation rate greater than 16% (that is, the 20% of the population relying the most on SNAP benefit). Other than high SNAP participation rate, this study also adopts the same definition for low-income and low-access, following USDA Food Access Research Atlas's definition. There are 35 low-income tracts and 22 low-access tracts, with 9 tracts that falls into both categories. The spatial distribution of three types of census tracts is presented in Figure S1.

Data on food establishments are obtained from the King County Food Facilities Inspection data, which provides accurate latitude, longitude, category, and capacity information for food establishments. The food inspection data contains 10,000 food establishments such as grocery stores, restaurants, bakeries, etc. The food inspection data also includes food establishments such as school lunch program, bed and breakfast, and convenience stores and they are excluded in this study since they do not provide food to the public nor serve standard portion of meals. Among these establishments, about 85.5% of the food establishment are reported with a seating capacity of a range, e.g., between 0-12. This range of 0-12 means the food establishment can sit at most 12 customers. The seating capacity for the other 14.5% of food establishments is approximated using data from Safegraph and Google Place API. These two sources offer additional geometry information which delineates the occupied square footage of the establishment. For each type, there exist a recommended square footage per customer such that there is enough space to maneuver in case of fire. For example, restaurants should allocate 12-15 square feet per customer, whereas fast food establishments should assign 11-14 square feet per customer (Total Food Service, 2022). The supply capacity, cap_j, is calculated as the number of customers this establishment can hold (i.e., the seating capacity) times the number of hours this establishment is open for service. This study assumes different hours of operations for different categories: restaurants open 8 hours, grocery stores open 14 hours, and fast-foods open for 18 hours, after surveying the food establishment near University of Washington's U-District, a vibrant community of food retailing.

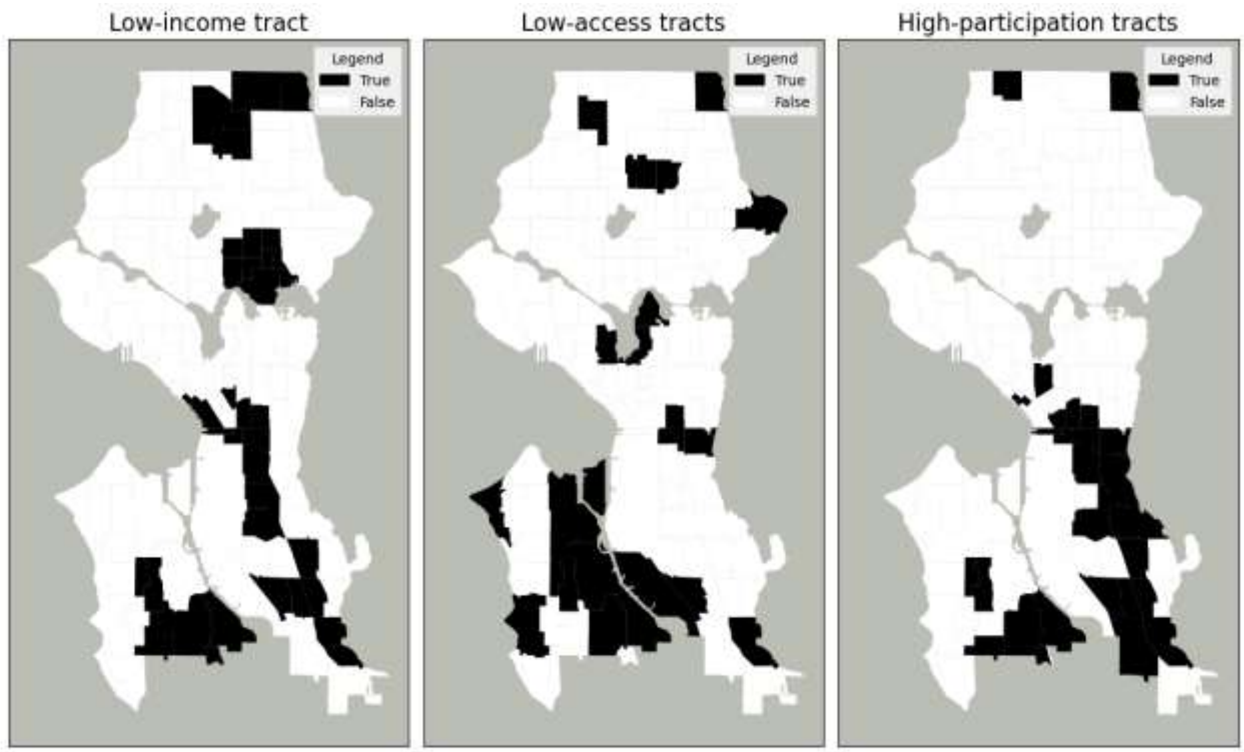

FIGURE S1: The distribution of low-income, low-access, and high SNAP participation tracts in Seattle.

After filtering, 4,607 food establishments in this case study are classified into three types: 3,654 full-service restaurants (referred to as restaurants), 389 quick service restaurants (referred to as fast-foods), and 564 groceries. Restaurants are defined as establishments offering table service, dining amenities, and waitstaff. On the other hand, fast-foods focus on a specific type of food, like burgers and pizza, and prioritize speed and convenience through counter or drive through ordering and payment. According to USDA, grocery stores are defined as food departments selling fresh fruits, vegetables, canned and frozen foods, fresh and prepared meats, fish, and poultry (Rhone, 2018). The spatial distribution of three types of food establishments is presented in Supplementary Material Figure S2, overlapped with the Seattle Census tracts. Figure S2 demonstrates that restaurants cluster in downtown Seattle, but fast-food and grocery establishments cluster less and are more evenly distributed across the study area.

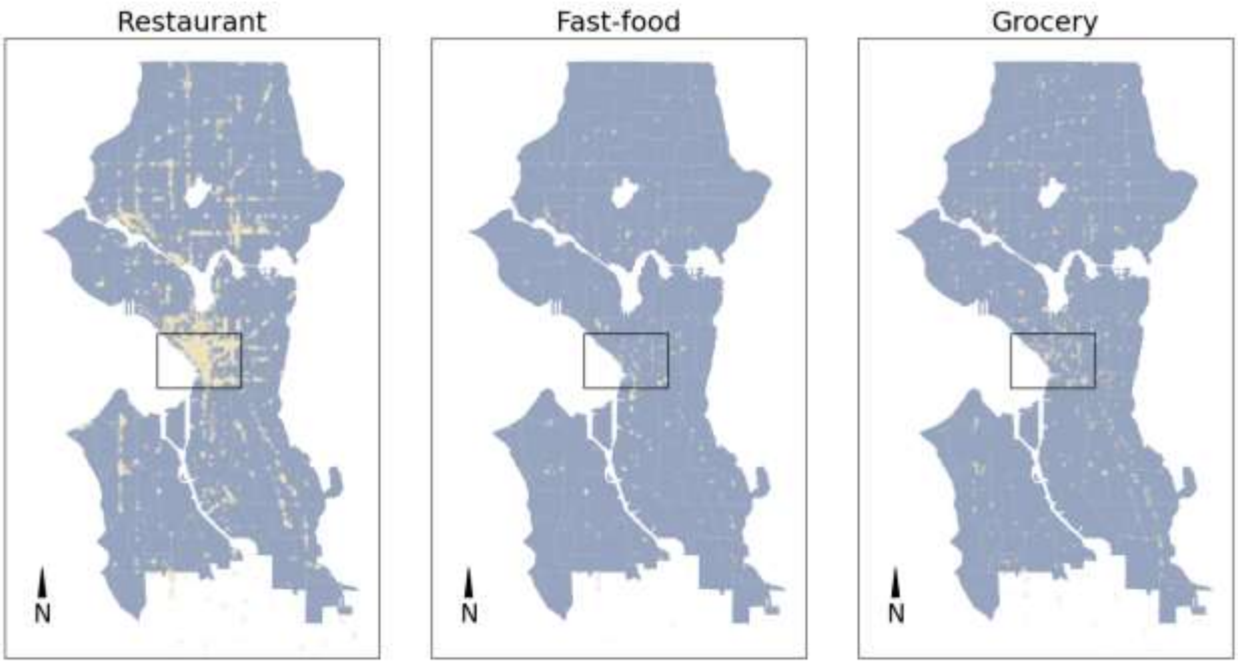

FIGURE S2: The distribution of food establishments by category in Seattle.

Section B

The methodology proposed in the manuscript ensures that the total supplies offered by the food establishment equals to the total supplies received by the population. And the conservation of supply is proved in this section. The following proof is prepared for the delivery accessibility; however, the proof can be adjusted to show that the preservation of supply holds for on-premise food accessibility by changing the function $r_1 < d_{ij} < r_2$ to $d_{ij} < r_2$. Further, assume all food establishments belong to category c.

Given:

$$R_j = \frac{cap_j}{\sum_{i \in \{N | r_1 < d_{ij} < r_2\}} P_i \times p(d_{ij})},$$

$$p(d_{ij}) = \frac{e^{-d_{ij}^2/\beta}}{\sum_q e^{-d_{iq}^2/\beta}}, where\ \ q = 1, \dots, j, \dots, M \wedge r_1 < d_{iq} < r_2,$$

$$A_i = \sum_{j \in \{M | r_1 < d_{ij} < r_2\}} R_j \times p(d_{ij}),$$

Prove:

$$\sum_i A_i P_i = \sum_j cap_j$$

Step 1: substitute R_j into A_i

$$A_i = \sum_{j \in \{M | r_1 < d_{ij} < r_2\}} \left(\frac{cap_j}{\sum_{i \in \{N | r_1 < d_{ij} < r_2\}} P_i \times p(d_{ij})} \right) p(d_{ij})$$

Step 2: multiply both sides of the equation in step 1 by P_i

$$A_i P_i = P_i \sum_{j \in \{M | r_1 < d_{ij} < r_2\}} \frac{cap_j p(d_{ij})}{\sum_{i \in \{N | r_1 < d_{ij} < r_2\}} P_i \times p(d_{ij})}$$

Step 3: sum over i on both sides for equation in step 2:

$$\sum_i A_i P_i = \sum_i P_i \sum_{j \in \{M | r_1 < d_{ij} < r_2\}} \frac{cap_j p(d_{ij})}{\sum_{i \in \{N | r_1 < d_{ij} < r_2\}} P_i \times p(d_{ij})}$$

Step 4: interchange the sign of summation on the right hand side of equation from step 3:

$$\sum_i A_i P_i = \sum_{j \in \{M | r_1 < d_{ij} < r_2\}} \frac{cap_j \sum_{i \in \{N | r_1 < d_{ij} < r_2\}} P_i \, p(d_{ij})}{\sum_{i \in \{N | r_1 < d_{ij} < r_2\}} P_i \times p(d_{ij})}$$

Let $\sum_{i \in \{N | r_1 < d_{ij} < r_2\}} P_i = \mathrm{D}_j$, which is the demand for food establishment j.

Step 5: substitute D_j

$$\sum_i A_i P_i = \sum_j \left(\frac{cap_j D_j}{D_j} \right) = \sum_j cap_j$$

Thus, the supply given from the food establishments, $\sum_j cap_j$, equals to the supply received by the population location, $\sum_i A_i P_i$.

Section C: Results on Supply-to-demand Ratio

All food establishments have supply-to-demand ratio (R_j) greater than one, meaning that they provide excess supply compared to demand, regardless of the category or whether through on-premise or delivery service. However, the distribution of R_j is highly skewed to the right, so the mean value is much smaller and less reliable than the median (see Table S1).

Table S1: Summary statistics for food establishments supply-to-demand ratio through on-premise service (top) and delivery (bottom).

On-premise	**Mean**	**Median**	**Standard deviation**
Restaurant	153.14	27.00	1,586.21
Fast-food	159.69	15.61	888.14
Grocery	115.23	38.68	906.48
Delivery	**Mean**	**Median**	**Standard deviation**
Restaurant	69.29	27.00	540.54
Fast-food	159.69	15.61	888.14
Grocery	191.77	38.68	1,277.37

Restaurants, fast-food, and grocery establishments have median of 27.00, 15.61, and 38.68, respectively. And the values are the same for delivery and on-premise services. This is due to approximating the seating capacity within a range (e.g., assuming an establishment can sit 6 individuals if the range is 0-12). Consequently, many food establishments have the same capacity since 23.9% of the food establishments overall have a seating capacity between 0 and 12 and 31.2% of the food establishments overall have a seating capacity between 13-50. Therefore, many establishments will appear to share the same capacity, resulting in very similar supply-to-demand ratios. The food establishments in Seattle are providing excessive supply; however, this does not suggest residents are not competing for food. The supply capacity is calculated by counting on the hours of operation, where customers might only patronize at specific time of the day, for example, lunch breaks or hours after work. Some of the service capacity could be underutilized due to variations in customer demand patterns throughout the day. On average, fast-foods provide the most supply to residents through on-premise service, and grocery stores provide the most supply through delivery. Grocery stores provide the most supply observed from mean and median values, which suggests fresh produce are the main channel in food supply.

For on-premise services, restaurant's standard deviation is the largest among four categories. The conjecture for large standard deviation is that the seating capacity for restaurants has a wide spread. Investigating the food inspection data reveals that there are five intervals for seating capacity: 0-12 people, 13-50 people, 51-150 people, 151-250 people, and above 250 people; and there are 1437, 1099, 904, 133, and 81 food establishments that fall into those intervals, respectively. About 53% of restaurants sit less than 50 people, but other restaurants serve 51 to more than 250 customers. Such a variation in capacity leads to large standard deviation in its supply-demand ratio. With delivery, grocery stores provide the most supply, but its standard deviation is the largest. The reason for observing the large standard deviation can be inferred from the spatial distribution of the grocery stores. According to Figure S1 in the case study section, grocery stores locate more evenly in the study area rather than clustered in downtown areas. Some grocery stores, therefore, serve less customers if they are not located in residential areas, resulting in high ratios. The number of residents who live within the catchment area varies more, thus affecting the supply-demand ratio calculation.

Reference:

Keeble M, Adams J, Sacks G, et al. (2020) Use of Online Food Delivery Services to Order Food Prepared Away-From-Home and Associated Sociodemographic Characteristics: A Cross-Sectional, Multi-Country Analysis. *International Journal of Environmental Research and Public Health* 17(14). 14. Multidisciplinary Digital Publishing Institute: 5190.

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