FOOD ENVIRONMENT AND GASTRIC CANCER RISK

By

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ABSTRACT

Background: Gastric cancer is the fifth most common cancer worldwide, with a disproportionate burden among populations living in poverty. Dietary patterns have been linked to gastric cancer risk and are often influenced by socioeconomic position. However, it is unclear whether the food environment in which people live, including proximity to healthy foods and socioeconomic factors that impede access to healthy foods, may contribute to socioeconomic disparities in gastric cancer incidence. **Purpose:** To examine associations between county level Food Environment Index (FEI) and gastric cancer incidence rates and assess whether associations vary by socioeconomic status and rurality. We also evaluated whether adding a measure of fast food outlets per capita to the FEI strengthens associations. **Methods:** Analyses for this ecologic study are based on 3,120 out of a total of 3,143 U.S. counties, for which FEI information was available and estimated age-adjusted gastric cancer incidence rates from 2016-2020. The FEI was defined based on indicators of socioeconomic status, unhealthy and healthy dietary options using county-level data from the U.S. Department of Agriculture (2011-2015). The FEI score was categorized into tertiles for analysis, with higher scores representing better quality. In secondary analysis, we evaluated the FEI incorporating an additional measure of the number of fast food restaurants per capita. Multivariable multinomial logistic regression models were used to estimate odds ratios for associations of our exposure of county-level FEI and our outcome of county-level gastric cancer incidence rates, stratified by county rurality and socioeconomic status (SES). **Results:** The FEI was inversely associated with gastric cancer incidence after accounting for gastric cancer risk factors (OR (95% CI) for high vs. low FEI = 0.43 (0.3, 0.7) at high vs. low incidence). Findings were similar in models assessing the FEI incorporating fast food per capita (OR (95% CI) for high vs. low FEI2 = 0.43 (0.3, 0.7) at high vs. low incidence. We did not observe any significant variation in associations across rurality (p_{int}=0.97) nor socioeconomic status (p_{int}=0.11). **Discussion:** Higher quality food environment, both with and without incorporating fast food outlets per capita, were associated with lower gastric cancer incidence rates in this ecological study. Further research is warranted to elucidate the role of FEI components on gastric cancer risk, and to develop targeted policy recommendations to reduce cancer risk through improved healthy food access.

This thesis is dedicated to my Mom, Dad, and late great friend Curtis Sutherland who passed away from cancer.

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PREFACE

The purpose of this thesis is to not only fulfill my degree requirements, but to also develop my skills as a researcher. I first began disease research through a summer fellowship during undergraduate. From there I really honed into epidemiology. At first, I was my Master's program was going to be in Biostatistics, but as coursework came along I felt more inclined into having my degree be in Epidemiology. This thesis is also for seeking to do better as previously mentioned in the dedication page. I am not a perfect student with flaws, but I always aspire to do better and self-improve with humbleness and a desire to learn.

There were many challenges in doing this thesis. The work of data collection and analysis has taken over a year, but in the grand scheme of things all the time it took was worth it. I was very inexperienced with R-Studio, but with the help of my professors and online help forms I have evolved my programming skills far beyond what I even thought was possible. Coding was something I hated at first, but now I appreciate it as a very convenient tool to solve many problems. The results of this thesis as well as finalizing a study design were also challenging, but these challenges really enhanced my own critical thinking skills allowing me to really understand the exact interpretations with thorough thought process.

I am thankful for my committee, professors from my coursework, and even department staff that helped me along my graduate school journey. No matter how miniscule each act of service may seem, it has snowballed into the greater butterfly effect of this thesis being completed.

Let this thesis be a testament of not dwelling on what we could have done, but rather what we still can do. Just like how every little action Curtis performed had a purpose, let us as researchers bring purpose to the numbers and data we collect. Though we are not perfect like science, striving to do and be better will push research even further. Like how research has progressed and grown so exponentially for the last 20 years, such past findings seem mundane compared to what we know now, and the trend will continue to be so. Even though sometimes the numbers will always hold a darker meaning, darkness brings more attention to light, in which there will be triumph from tragedy. Thank you for being my friend Curtis Sutherland.

I wish you a pleasant reading experience. Brandon Hall, Michigan State University, June 9th, 2025.

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CHAPTER 1: INTRODUCTION

Gastric cancer is the fifth most common cancer worldwide[1], with a disproportionate burden among populations living in poverty.[2] A United Kingdom Cohort found that unhealthy lifestyle has been linked to increased gastric cancer risk (HR = 1.48, 95% CI, (1.30, 1.68)).[3] Moreover, there are stark racial and ethnic gastric cancer disparities, with a nearly two-fold greater risk among Black and Hispanic populations compared to Non-Hispanic Whites in the United States.[4] Structural inequities, including household crowding, are commonly experienced by low-income, rural, and/or racial and ethnic minority populations, and are also associated with *Helicobacter pylori (H. plylori*) infection, a leading risk factor for gastric cancer.[5] Dietary factors, including high-salt foods and salt-preserved foods have been linked to an increased risk of gastric cancer. In one paper, pooled odds ratios showed a significantly positive association between high salt intake and gastric cancer compared with low salt intake (OR = 1.55, 95% CI (1.45, 1.64); $p < 0.001$).[6] In another study, intake of healthy Japanese foods, particularly soy, were associated with lower risk of other cancers such as stomach, colon, and rectal cancer.[7] Ultra-processed foods have been associated with increased risks of gastrointestinal cancers (colon, rectal, non–cardia gastric, pancreas, and hepatocellular carcinoma cancers).[8] Between 2013-2016, 36.6% of U.S. adults reported consuming fast food on a given day.[9] Fast food consumption has been associated with increased intake of calories, fat, and sodium, a previously mentioned risk factor for gastric cancer.[10]

Given that dietary choices are influenced by socioeconomic position, the food environment may contribute to socioeconomic disparities in gastric cancer incidence. Indeed, the food environment impacts access to healthy foods and varies substantially across neighborhoods in the United States. After adjustment for covariates, food destination density, regardless of the type, was positively associated with diet quality (β 0.06, 95 % CI 0.01-0.12, $p = 0.04$).[11] Furthermore, from 1985 to 2006, when obesity prevalence significantly increased among U.S. adults, those living in socioeconomically disadvantaged neighborhoods had less variety in away-from-home eating options, including fast food and non-fast food restaurants, compared to those living in advantaged neighborhoods.[12] Components of the food environment are tied to the physical, economic, political and socio-cultural contexts of a person's food system based on availability, accessibility, and desirability.[13] The Food Environment Index (FEI) is a validated composite measure incorporating access and availability of multiple food outlets as well factors that may influence one's decision making in food access (i.e. cost barriers). For example, in other cancers, an ecological study evaluation, an unhealthy FEI has been associated with a higher risk in colorectal cancer in a prior study.[14] Furthermore, other cancers have been tied to socioeconomic status, as residents of the most deprived neighborhoods defined by the census tract had a 31% higher risk of colorectal cancer diagnosis than the most affluent quartile, adjusting for risk factors.[15] However, it is unclear whether the food environment in which people live, including proximity to healthy foods and socioeconomic factors that impede access to healthy foods, may contribute to socioeconomic disparities in gastric cancer incidence.

Thus, the purpose of this study was to examine U.S. county-level associations between food environment quality and gastric cancer incidence, and to assess variability according to socioeconomic status and rurality. We also evaluated whether adding a measure of fast food outlets per capita to the FEI strengthens associations.

CHAPTER 2: METHODS

Study Design

We conducted an ecological study examining the association between the county-level food environment index (FEI) and age-adjusted gastric cancer incidence rates. Because of the long latency period for gastric cancer, we assessed associations between our exposure (FEI) and confounding factors measured between 2011-2015 with age-adjusted gastric cancer incidence rates from 2016-2020, inferring a 5-year latency period between exposures and gastric cancer diagnosis. Age-adjusted gastric cancer incidence rates were ascertained for the most recent 5-year period (2016 to 2020) from the Surveillance, Epidemiology, and End Results (SEER) database.[16] Because gastric cancer is a somewhat rare disease, incidence rates were only reported for 911 of the 3,143 total U.S. counties with 2,232 having suppressed incidence rates.

Food Environment

We used the Food Environment Index (FEI),[17] a previously created composite measure based on standardized latent variables representing indicators of socioeconomic status, unhealthy dietary options, and healthy dietary options in a county via the US. Department of Agriculture (USDA) dataset.[18] Of the 3,143 total US counties, 23 of them had FEI missing, with all of them having also suppressed gastric cancer incidence rates. Therefore, our analytic sample size was 3,120 US counties.

Figure 1 provides the conceptual model for creating FEI and lists the various components that contribute to the creation of the latent variables. The socioeconomic status latent variable included the following indicators: 2013 unemployment rate (% county unemployed), 2012-2014 household food insecurity (% county with low access by all people at all times to enough food for an active, healthy life), 2012-2014 household very low food security (% of county with lower criteria as mentioned before), and 2015 SNAP-households with low store access (SNAP enrolled household counts per county being more than one mile for urban and more ten miles for rural from a supermarket, supercenter or large grocery store). The unhealthy dietary options latent variable was grouped by the following indicators: 2012 SNAP-authorized stores/1,000 population (SNAP-authorized stores counts per person per county), 2011 number of convenience stores/1,000 population (convenient store counts per person per county), and 2015 percentage of households with no car & low access to grocery store (% of county with no vehicle and being more than one mile for urban and more ten miles for rural from a supermarket, supercenter or large grocery store). The healthy dietary options latent variable was grouped by the following indicators: 2013 number of farmer's markets/1,000 population (famer's market counts per person per county), 2011 number of grocery stores/1,000 population (grocery store counts per person per county), and 2011 number of full-service restaurants/1,000 population (full-service restaurants counts per person per county). In creating the composite FEI, the healthy dietary options latent variable score was multiplied by a negative one factor inversing the scale. Indicators were transformed to a N(0,1) scale to transform the mean of each variable to equal 0, and the standard deviation to equal +/- 1. This scaling was used due to differences in units of measurements of the indicators, like percentage being used in 2013 Unemployment Rate and capita per 1,000 being used for 2013 farmer's market/1,000 population. The composite FEI was then calculated as a sum of the latent variable scores for socioeconomic status, unhealthy dietary options, and healthy dietary options, multiplied by a factor of -1 to invert the scale. Thus, a FEI score of 0 represents the baseline mean of the composite, with negative values indicating a lower quality food environment, and positive values indicating a higher quality food environment.

Given that fast food outlets typically serve foods high in sodium,[19] we created a secondary measure of the food environment index (FEI2) using the exact methods described above with the addition of a N(0,1) scaled measure of the number of fast food restaurants/1000 population (2011) added to the unhealthy dietary options' latent variable. Fast food outlet density was ascertained via the 2016 food environment data set from the USDA.[13]

All components of the FEI was related to food availability, for example, farmer's markets, full-service restaurants and grocery stores may positively influence consumption of more vegetables and fruits.[20] Fast food and convenience stores served as indicators of unhealthy food envionment.[20] SNAP households, SNAP stores, unemployment, no car access and food insecurity were also considered in creating the FEI as they influence represent food affordability.[20] FEI and FEI2 were categorized in tertiles, with low as the reference.

Covariates

Data on confounding factors, including prevalence of gastric cancer risk factors, were ascertained from multiple publicly available county-level datasets. Sociodemographic data, including race/ethnicity (% Non-Hispanic White, Black, Asian, Pacific Islander or Hawaiian, American Indian or Alaska Native), age in years, and sex (% male/female) were obtained from

U.S. Census data averaged between 2011-2015.[21] Obesity (% of adults reporting BMI >= 30 kg/m^2) and physical inactivity (% of adults that report no leisure-time physical activity) were obtained from the USDA[13]. County-level estimates of excessive alcohol consumption (% adults reporting binge or heavy drinking) and smoking prevalence (% of adults that reported currently smoking) were ascertained from the 2015 County Health Rankings data.[22] The percentage of adults in the county that were unemployed in 2013 was ascertained via the U.S. Bureau of Labor Statistics.[23] County-level poverty rates, defined as the percentage of a tract's population that has an income at or below the federal poverty level for their family size, were ascertained from the USDA[13]. Counties were classified as rural or urban based on the 2013 data from the Office of Management and Budget (i.e., National Center of Health Services (NCHS) codes one through four reflecting urban and codes five and six indicating rural counties.[24]

Statistical Analysis

To assess potential for selection bias in conducting a complete case analysis, we used a two-sample t-test to examine in characteristics of counties (i.e., race, sex, smoking, alcohol consumption) with data reported on gastric cancer incidence rates (n=911) compared to those counties with data suppressed due to small numbers and having FEI available (n=2,209). As seen in **Table I**, counties with and without information on gastric cancer incidence rates differed significantly according to most sociodemographic and health-related factors. Comparisons were made using all available information for each sociodemographic characteristic in the two groups, Number of missing ranged between none to a maximum of 863 for "Excessive drinking" in the 2,209 counties with suppressed gastric cancer incidence rates. There were no missing values for FEI and FEI2.

Table I: Differences in the county-level characteristics for 2,209 incidence suppressed counties vs 911 counties with incidence values 2.9 or greater using ANOVA tests.

Category	Incidence Counties Mean (SD) (n=available)	No-Incidence Counties Mean (SD) (n=available)	p-value
Rurality	3.58 (1.4) (n=911)	5.14 (1.3) (n=1894)	**<0.05**
Race	(n=910)	(n=1894)	
Non-Hispanic White (%)	82.58 (15.0)	87.34 (15.7)	**<0.05**
Non-Hispanic Black (%)	11.54 (13.7)	7.75 (14.2)	**<0.05**
Asian (%)	2.25 (3.3)	0.83 (1.3)	**<0.05**
Hispanic (%)	9.81 (13.3)	8.12 (13.3)	**<0.05**
Pacific Islander (%)	0.16 (0.7)	0.08 (0.1)	**<0.05**
American Indian/Native Alaskan (%)	1.31 (4.0)	2.28 (7.5)	**<0.05**
Obesity (%)	30.09 (4.3) (n=911)	30.94 (4.3) (n=2204)	**<0.05**
Excessive Drinking (%)	15.99 (4.5) (n=853)	16.82 (5.5) (n=1362)	**<0.05**
Smoking (%)	20.48 (5.1) (n=902)	21.63 (6.7) (n=1791)	**<0.05**
Physical Inactivity (%)	25.64 (5.1) (n=911)	27.56 (5.3) (n=2204)	**<0.05**
Gender	(n=911)	(n=2209)	
Male (%)	49.31 (1.3)	50.36 (2.7)	**<0.05**
Female (%)	50.69 (1.3)	49.64 (2.7)	**<0.05**
Food Environment Index	0.00 (0.5) (n=911)	0.00 (0.5) (n=2209)	0.97
Food Environment Index II	0.00 (0.5) (n=911)	0.02 (0.4) (n=2209)	0.27

Since gastric incidence rates are reported as number of cases/100,000 population, we assessed their distribution using density plots, q-q plots, and the Shapiro test. Given the non-normal distribution of the age-adjusted gastric cancer incidence rates per 100,000, for all of our analyses, we categorized them as "low" (less than 2.9 per 100,000– all with suppressed incidence rates- 2.9 was the minimum rate reported for the 911 counties), "medium" (between 2.9-6.6 cases/100,000 based on the 2/3 tertile value of incidence rates for counties where incidence was available), and "high" (>6.6 cases/100,000). **Table II** provides a comparison of population size and distribution of the proportion of counties by tertile FEI and FEI2 index, for the three groups of our outcome variable.

Table II: Differences in the county size and proportion in FEI, FEI2 and rurality across all 3,120 US counties based on gastric cancer incidence status. Proportions were calculated by the number of counties in each category divided by the total number of counties in each incidence county.

	Very Low/Missing Gastric Cancer Risk Counties < 2.9 cases	**Medium Gastric Cancer Risk 2.9-6.6 cases**	**High Gastric Cancer Risk Counties > 6.6 cases**
# of Counties (% Total)	n = 2,209 (71%)	n = 609 (19%)	n = 302 (10%)
Mean County Size (SD)	52,656 +/- 289,729	205,553 +/- 257,130	280,696 +/- 577,489
Food Environment Index:			
Low	p̂ = 0.35 +/- 0.01	p̂ = 0.30 +/- 0.02	p̂ = 0.49 +/- 0.03
Medium	p̂ = 0.33 +/- 0.01	p̂ = 0.30 +/- 0.02	p̂ = 0.22 +/- 0.02
High	p̂ = 0.32 +/- 0.01	p̂ = 0.40 +/- 0.02	p̂ = 0.29 +/- 0.03
Food Environment Index 2:			
Low	p̂ = 0.33 +/- 0.01	p̂ = 0.29 +/- 0.02	p̂ = 0.47 +/- 0.03
Medium	p̂ = 0.30 +/- 0.01	p̂ = 0.33 +/- 0.02	p̂ = 0.22 +/- 0.02
High	p̂ = 0.37 +/- 0.01	p̂ = 0.38 +/- 0.02	p̂ = 0.31 +/- 0.03
Rurality:			
Rural	p̂ = 0.67 +/- 0.01	p̂ = 0.28 +/- 0.02	p̂ = 0.40 +/- 0.03
Urban	p̂ = 0.33 +/- 0.01	p̂ = 0.72 +/- 0.02	p̂ = 0.60 +/- 0.03
Poverty Rate:			
High Poverty	p̂ = 0.41 +/- 0.01	p̂ = 0.24 +/- 0.02	p̂ = 0.51 +/- 0.03
Low Poverty	p̂ = 0.59 +/- 0.01	p̂ = 0.76 +/- 0.02	p̂ = 0.49 +/- 0.03

Findings from this analysis suggest that counties with censored gastric cancer incidence rates had smaller population sizes and were more likely to be rural. Given the potential for selection bias in excluding these censored counties, we included US counties with censored gastric cancer rates in the main analysis and only excluded 23 counties with missing data necessary to compute FEI and FEI2, for the total analytic sample size of 3,120 counties. In comparing the multinomial regression models with binomial regression models, FEI and FEI2 tertile values from the 911 county binomial regression were slightly different than the tertile value used for ordinal regression's 3,120 county dataset.

Publicly available datasets for measures of FEI, covariates and gastric cancer incidence rates were merged based on county FIPS code. We described county-level characteristics across FEI tertiles and examined differences using ANOVA tests. We calculated odds ratios (ORs) and 95% confidence intervals (CIs) for the associations between FEI and FEI2 with age-adjusted gastric cancer incidence rate categories (low, medium, high) using age-adjusted and multivariable multinomial regression models. Selection of covariates for inclusion in the multivariable model was based on prior knowledge of gastric cancer risk factors and assessment of a Directed Acyclic Graph [25] (**Figure 5).** We evaluated an age-adjusted model using age-adjusted gastric cancer incidence rates. The final multivariable model additionally adjusted for county-level rurality, poverty, and race/ethnicity (Black, Hispanic, Asian).[26] We also conducted stratified logistic regression models by county-level rurality (rural vs. urban) and socioeconomic status (low vs high poverty rate, based on a 2/3 quantile value of 17.1%, where high poverty rate was above or equal to the threshold, and low poverty rate was below the threshold). In multivariable stratified models, rurality was removed from the rural-urban stratified models, and poverty was removed from the SES stratified models. We assessed interaction by socioeconomic status and rurality using the Likelihood Ratio test. All analyses were conducted in R-studio using R-Packages. We also compared the multinomial regression models, which included counties with suppressed gastric cancer rates considered to be low incidence, with binomial regression models, based on the 911 counties for which gastric cancer rates were available.

CHAPTER 3: RESULTS

As shown in **Table III**, county-level characteristics varied across FEI tertiles. The prevalence of obesity, smoking, and physical inactivity decreased with increasing FEI quality. The prevalence of excessive alcohol consumption was higher in counties with higher vs. lower FEI quality (18.3% vs. 13.7%, $p<0.05$). Counties with higher vs. lower quality FEI had a higher proportion of Non-Hispanic Whites, and Asian and lower average poverty rates.

Table III: Means and standard deviations of county-level characteristics across tertiles of the Food Environment Index (FEI).

	Low FEI mean (SD) (n=1040)	Medium FEI mean (SD) (n=1040)	High FEI mean (SD) (n=1040)	p-value
Obesity (%)	33.3 (3.6)	30.7 (3.4)	28.0 (4.2)	**<0.05**
Excessive Drinking (%)	13.7 (5.0)	16.5 (4.8)	18.3 (4.7)	**<0.05**
Smoking (%)	24.8 (6.2)	21.2 (5.4)	17.9 (5.1)	**<0.05**
Physically Inactive (%)	30.5 (4.1)	26.7 (4.4)	23.7 (5.0)	**<0.05**
Female (%)	50.1 (2.8)	50.0 (2.3)	49.8 (2.1)	**<0.05**
Non-Hispanic White (%)	78.4 (20.4)	87.5 (12.0)	91.4 (9.3)	**<0.05**
Non-Hispanic Black (%)	16.6 (19.4)	7.1 (9.9)	3.3 (6.0)	**<0.05**
Asian (%)	0.7 (0.6)	1.3 (1.6)	1.9 (3.4)	**<0.05**
Hispanic (%)	8.5 (15.8)	10.2 (13.8)	7.2 (9.5)	**<0.05**
Pacific Islander (%)	0.1 (0.1)	0.1 (0.2)	0.1 (0.7)	**<0.05**
American Indian (%)	2.5 (9.2)	2.0 (6.1)	1.5 (2.8)	**<0.05**
Poverty Rate (%)	21.5 (6.4)	15.3 (4.7)	12.0 (3.9)	**<0.05**
NCHS Rurality Code	5.0 (1.3)	4.4 (1.6)	4.6 (1.6)	**<0.05**

As seen in **Table IV,** high quality FEI was inversely associated with gastric cancer incidence rates in multivariable models, (OR (95% CI) for medium vs. low incidence = 0.59 (0.4, 0.8) and high vs. low incidence = 0.43 (0.3, 0.7). Counties with a medium FEI quality had higher odds of medium vs. low gastric cancer incidence rates, multivariable OR (95% CI) = 1.30 (1.0, 1.7). Findings were generally similar in models assessing the FEI incorporating fast food per capita, (multivariable OR (95% CI) for high vs. low FEI2 = 0.43 (0.3, 0.7) and positive associations for counties with medium FEI incorporating fast food and gastric cancer incidence were not observed.

Table IV: Age-adjusted and multivariable odds ratios and 95% confidence intervals for associations of Food Environment Index (FEI) and gastric cancer incidence rates (n=3,120 U.S. counties).

	Age-Adjusted Incidence OR (95% CI)			Multivariable-adjusted OR (95% CI)		
	Age-Adjusted Gastric Cancer Incidence			Age-Adjusted Gastric Cancer Incidence		
	Low (ref)	Medium	High	Low (ref)	Medium	High
Food Environment Index (FEI)						
Low (ref)						
Medium		2.45 (1.9, 3.1)	0.82 (0.6, 1.1)		1.30 (1.0, 1.7)	0.67 (0.5, 1.0)
High		1.40 (1.1, 1.8)	0.55 (0.4, 0.7)		0.59 (0.4, 0.8)	0.43 (0.3, 0.7)
Food Environment Index (FEI) + Fast Food						
Low (ref)						
Medium		1.69 (1.4, 2.1)	0.75 (0.6, 1.0)		0.83 (0.6, 1.1)	0.62 (0.4, 0.9)
High		0.85 (0.7, 1.1)	0.46 (0.3, 0.6)		0.36 (0.3, 0.5)	0.43 (0.3, 0.7)

For comparison, the results from logistic regression models of FEI and gastric cancer including only counties without suppressed gastric cancer incidence rate data (n=911) as seen in **Table V** contrarily showed higher quality FEI was positively associated with gastric cancer incidence in the age-adjusted model (OR (95% CI) for high vs. low = 1.82 (1.3, 2.6)). However, results were attenuated after accounting for gastric cancer risk factors (OR (95% CI) for high vs. low =0.69 (0.4, 1.1)). Findings were similar in models assessing the FEI incorporating fast food per capita (multivariable OR (95% CI) for high vs. low = 0.63 (0.4, 1.0)).

Table V: Age-adjusted and multivariable odds ratios and 95% confidence intervals for associations of Food Environment Index (FEI) and gastric cancer incidence rates (n=911 U.S. counties).

	Age-Adjusted Incidence OR (95% CI)	Multivariable-adjusted OR (95% CI)
Food Environment Index (FEI)		
Low	ref	ref
Medium	2.05 (1.4, 2.9)	1.09 (0.7, 1.7)
High	1.82 (1.3, 2.6)	0.69 (0.4, 1.1)
Food Environment Index (FEI) + Fast Food		
Low	ref	ref
Medium	2.19 (1.5, 3.1)	1.15 (0.8, 1.7)
High	1.78 (1.3, 2.5)	0.63 (0.4, 1.0)

Results of the multinomial regression models stratified by rurality and socioeconomic status are shown in **Table VI**. In multivariable models, we did not observe any significant variation in associations of FEI and gastric cancer incidence across rurality (p_{int}=0.97) or socioeconomic status (p_{int}=0.11). For the FEI incorporating fast food per capita, there was a non-significant variation in associations by socioeconomic status (p_{int}=0.21) and a non-significant variation by rurality (p_{int}=0.86). Inverse associations between FEI incorporating fast food and high vs. low gastric cancer incidence rates were stronger in rural (OR (95% CI) = 0.34, 0.2, 0.6) vs. urban (OR (95% CI) = 0.41, 0.2, 0.8) counties. In SES-stratified models, the inverse association between FEI quality and high vs. low gastric cancer incidence rates were stronger in low SES counties (OR (95% CI) = 0.37 (0.1, 1.0)) compared to higher SES counties (OR (95% CI) = 0.46 (0.3, 0.8)). Whereas inverse associations between FEI incorporating fast food and high vs. low gastric cancer incidence rates were more pronounced in counties with high SES (OR, (95% CI) = 0.46 (0.3, 0.8)) vs. low SES (OR, (95% CI) = 0.57 (0.2, 1.4)).

Table VI: Age-adjusted and multivariable odds ratios and 95% confidence intervals for associations of Food Environment Index (FEI) and gastric cancer incidence rates (n = 3,120 U.S. counties) stratified by rurality with interaction p-values.

		Rural (n=1768)		Urban (n=1037)	
		Age-Adjusted Incidence OR (95% CI)	Multivariable-adjusted OR (95% CI)	Age-Adjusted Incidence OR (95% CI)	Multivariable-adjusted OR (95% CI)
Food Environment Index (FEI)					
Low		ref	ref	ref	Ref
Medium	**(Med vs Low Inc)**	1.60 (1.1, 2.3)	1.21 (0.8, 1.9)	2.11 (1.5, 3.0)	1.31 (0.9, 1.9)
	(High vs Low Inc)	0.50 (0.3, 0.8)	0.62 (0.4, 1.0)	0.85 (0.6, 1.3)	0.73 (0.4, 1.2)
High	**(Med vs Low Inc)**	0.93 (0.6, 1.4)	0.54 (0.3, 0.9)	1.32 (0.9, 1.9)	0.56 (0.4, 0.9)
	(High vs Low Inc)	0.29 (0.2, 0.5)	0.38 (0.2, 0.7)	0.67 (0.4, 1.0)	0.44 (0.2, 0.8)
		P_{int}=0.97			
Food Environment Index (FEI) + Fast Food					
Low		ref	ref	ref	ref
Medium	**(Med vs Low Inc)**	1.17 (0.8, 1.7)	0.79 (0.5, 1.2)	1.34 (1.0, 1.9)	0.78 (0.5, 1.1)
	(High vs Low Inc)	0.45 (0.3, 0.7)	0.55 (0.3, 0.9)	0.75 (0.5, 1.1)	0.67 (0.4, 1.1)
High	**(Med vs Low Inc)**	0.73 (0.5, 1.1)	0.37 (0.2, 0.6)	0.73 (0.5, 1.0)	0.30 (0.2, 0.5)
	(High vs Low Inc)	0.26 (0.2, 0.4)	0.34 (0.2, 0.6)	0.56 (0.4, 0.9)	0.41 (0.2, 0.8)
		P_{int}=0.86			

Table VI (cont'd):

Age-adjusted and multivariable odds ratios and 95% confidence intervals for associations of Food Environment Index (FEI) and gastric cancer incidence rates (n = 3120 U.S. counties) stratified by socioeconomic status with interaction p-values as well.

		Low SES (n=1221)		High SES (n=1899)	
		Age-Adjusted Incidence OR (95% CI)	Multivariable-adjusted OR (95% CI)	Age-Adjusted Incidence OR (95% CI)	Multivariable-adjusted OR (95% CI)
Food Environment Index (FEI)					
Low		ref	ref	ref	ref
Medium	**(Med vs Low Inc)**	2.33 (1.6, 3.4)	1.67 (1.1, 2.6)	1.32 (0.9, 1.9)	0.94 (0.6, 1.4)
	(High vs Low Inc)	0.81 (0.5, 1.2)	0.75 (0.5, 1.2)	0.92 (0.6, 1.5)	0.62 (0.4, 1.1)
High	**(Med vs Low Inc)**	1.40 (0.7, 2.7)	0.26 (0.1, 0.7)	0.66 (0.5, 0.9)	0.53 (0.4, 0.8)
	(High vs Low Inc)	1.12 (0.6, 2.1)	0.37 (0.1, 1.0)	0.56 (0.3, 0.9)	0.46 (0.3, 0.8)
		P_{int}=0.11			
Food Environment Index (FEI) + Fast Food					
Low		ref	ref	ref	ref
Medium	**(Med vs Low Inc)**	1.68 (1.2, 2.4)	1.10 (0.7, 1.7)	0.80 (0.6, 1.1)	0.64 (0.4, 0.9)
	(High vs Low Inc)	0.69 (0.5, 1.0)	0.62 (0.4, 1.0)	0.80 (0.5, 1.3)	0.66 (0.4, 1.1)
High	**(Med vs Low Inc)**	1.12 (0.6, 2.1)	0.36 (0.1, 0.9)	0.33 (0.2, 0.4)	0.32 (0.2, 0.5)
	(High vs Low Inc)	0.96 (0.5, 1.8)	0.57 (0.2, 1.4)	0.42 (0.3, 0.7)	0.46 (0.3, 0.8)
		P_{int}=0.21			

In the stratified binomial model including only counties without suppressed gastric cancer rates, we did not observe any significant variation in associations across rurality (all $p_{int} \geq 0.11$) or socioeconomic status (all $p_{int} \geq 0.20$). After accounting for risk factors, FEI, both with and without fast food per capita, was not associated with gastric cancer incidence in most strata; however, contrary to our hypothesis, several significant positive associations of the FEI, both with and without fast food per capita, and gastric cancer risk, were observed in age-adjusted models. As seen in **Table VII**, associations between FEI and FEI with gastric cancer incidence were not significant in analyses stratified by county rurality, different from the multinomial model.

Table VII: Age-adjusted and multivariable odds ratios and 95% confidence intervals for associations of Food Environment Index (FEI) and gastric cancer incidence rates defined as > 6.6 vs ≤ 6.6 cases for 100,000 (n=911 U.S. counties) stratified by rurality with interaction p-values. For binomial analysis, rural counties were defined by a rural code of just 6, different from multinomial regression using codes 5 through 6 for rural counties.

	Rural (n=56)		Urban (n=796)	
	Age-Adjusted Incidence OR (95% CI)	Multivariable-adjusted OR (95% CI)	Age-Adjusted Incidence OR (95% CI)	Multivariable-adjusted OR (95% CI)
Food Environment Index (FEI)				
Low	ref	ref	ref	ref
Medium	1.25 (0.3 5.3)	0.19 (0.0, 1.3)	2.03 (1.4, 2.9)	1.16 (0.7, 1.8)
High	6.00 (1.7, 26.0)	0.83 (0.1, 6.1)	1.65 (1.1, 2.4)	0.66 (0.4, 1.1)
	P_{int}=0.16			
Food Environment Index (FEI) + Fast Food				
Low	ref	ref	ref	ref
Medium	3.03 (0.7, 14.5)	1.73 (0.3, 10.2)	2.14 (1.5, 3.1)	1.13 (0.7, 1.8)
High	8.23 (2.2, 35.9)	2.62 (0.4, 16.4)	1.60 (1.1, 2.3)	0.59 (0.4, 1.0)
	P_{int}=0.11			

Table VII (cont'd):

Age-adjusted and multivariable odds ratios and 95% confidence intervals for associations of Food Environment Index (FEI) and gastric cancer incidence rates defined as > 6.6 vs ≤ 6.6 cases for 100,000 (n=911 U.S. counties) stratified by socioeconomic status with interaction p-values. For binomial analysis, rural counties were defined by a rural code of just 6, different from multinomial regression using codes 5 through 6 for rural counties.

	Low SES (n=285)		High SES (n=567)	
	Age-Adjusted Incidence OR (95% CI)	Multivariable-adjusted OR (95% CI)	Age-Adjusted Incidence OR (95% CI)	Multivariable-adjusted OR (95% CI)
Food Environment Index (FEI)				
Low	ref	ref	ref	ref
Medium	1.96 (1.1, 3.5)	1.35 (0.7, 2.7)	1.05 (0.6, 1.8)	0.95 (0.5, 1.7)
High	1.07 (0.5, 2.3)	0.48 (0.2, 1.4)	0.92 (0.5, 1.5)	0.75 (0.4, 1.3)
	P_{int}=0.26			
Food Environment Index (FEI) + Fast Food				
Low	ref	ref	ref	ref
Medium	1.91 (1.1, 3.4)	1.29 (0.7, 2.4)	1.35 (0.8, 2.3)	1.13 (0.6, 2.0)
High	1.16 (0.6, 2.4)	0.43 (0.2, 1.1)	1.00 (0.6, 1.7)	0.74 (0.4, 1.3)
	P_{int}=0.20			

CHAPTER 4: DISCUSSION

Findings from the ecological study suggest that a higher quality food environment is associated with lower gastric cancer incidence rates. Observed inverse associations were slightly stronger when incorporating information on fast food density per capita, particularly in rural counties and those with lower socioeconomic status. Of note, excluding counties with data suppressed on gastric cancer incidence rates substantially changed the results, which may be attributed to selection bias, with smaller rural counties more likely to be censored.

Our results are generally in accordance with our hypothesis, which was based on prior evidence suggesting the role of specific dietary factors relevant to the food environment and gastric cancer risk (e.g., salt, ultra-processed foods).[8] Given the stronger inverse associations observed for the measure of the food environment including fast-food outlets in more socioeconomically deprived counties, our findings also suggest the potential role of the food environment in socioeconomic disparities in gastric cancer incidence.

More research is needed to expand our understanding of the role of specific attributes within the food environment and gastric cancer risk. The Food Environment Index composite could also be modified and compared by the indicators (e.g., farmers market-per capita, SNAP-household rate, or even vehicle access) to investigate which components are potentially more relevant for gastric cancer risk. This assessment should also consider what is already known about specific dietary factors related to gastric cancer risk. For example, understanding how the food environment relates to healthy lifestyle index and healthy dietary choices, which are also relevant for gastric cancer risk, [27] is an important next step. Moreover, studies to evaluate how established dietary risk factors for gastric cancer (e.g., salt consumption and alcohol consumption), vary by food environment features can help to inform precision prevention efforts. This information can also help guide policies to target policies to the specific factors within the food environment that are most strongly related to gastric cancer incidence. Given well-described racial and ethnic disparities in gastric cancer incidence, it will also be important to understand whether associations between the FEI and gastric cancer incidence rates also vary based on the county-level racial or ethnicity population distribution. Race, socioeconomic status,[28] and the food environment are closely linked, and further research will be necessary to disentangle the independent and joint impact of these factors on gastric cancer risk.

Strengths of this study include the use of validated data collection instruments (i.e., FEI) and robust multivariable regression methodology. Moreover, our data collection plan allowed for the consideration of latency period between exposure to food environments and gastric cancer incidence. An additional study strength includes the examination of an under-researched cancer site characterized by stark disparities; our findings can help generate and expand studies focused on prevention of a disease that disproportionally burdens individuals with low socioeconomic status. This study expands upon prior studies of individual dietary factors and dietary quality, by providing a population health focus on accessibility of healthy foods. Finally, gastric cancer incidence rates used in this study reflect population-based cancer registry data that is generalizable to the US.

A limitation of the study is the potential for ecological bias, given that the exposure, covariate and outcome measures were aggregated at the county-level. Thus, inference at the individual-level based on aggregated county-level data is inappropriate.[29] However, the FEI is meant to reflect differential availability and access to healthy foods at the county-level and is not designed to assess individual dietary intake of healthy foods. Additionally, we were unable to adjust for all known gastric cancer risk factors (e.g., H pylori), and residual confounding is possible.

In conclusion, our findings suggest that the quality of the food environment is inversely associated with gastric cancer incidence rates, with potentially stronger associations for rural counties and those with lower socioeconomic positions. Further research is warranted to elucidate the role of FEI components on gastric cancer risk, and to develop targeted policy recommendations to reduce cancer risk through improved healthy food access.

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APPENDIX: LIST OF FIGURES

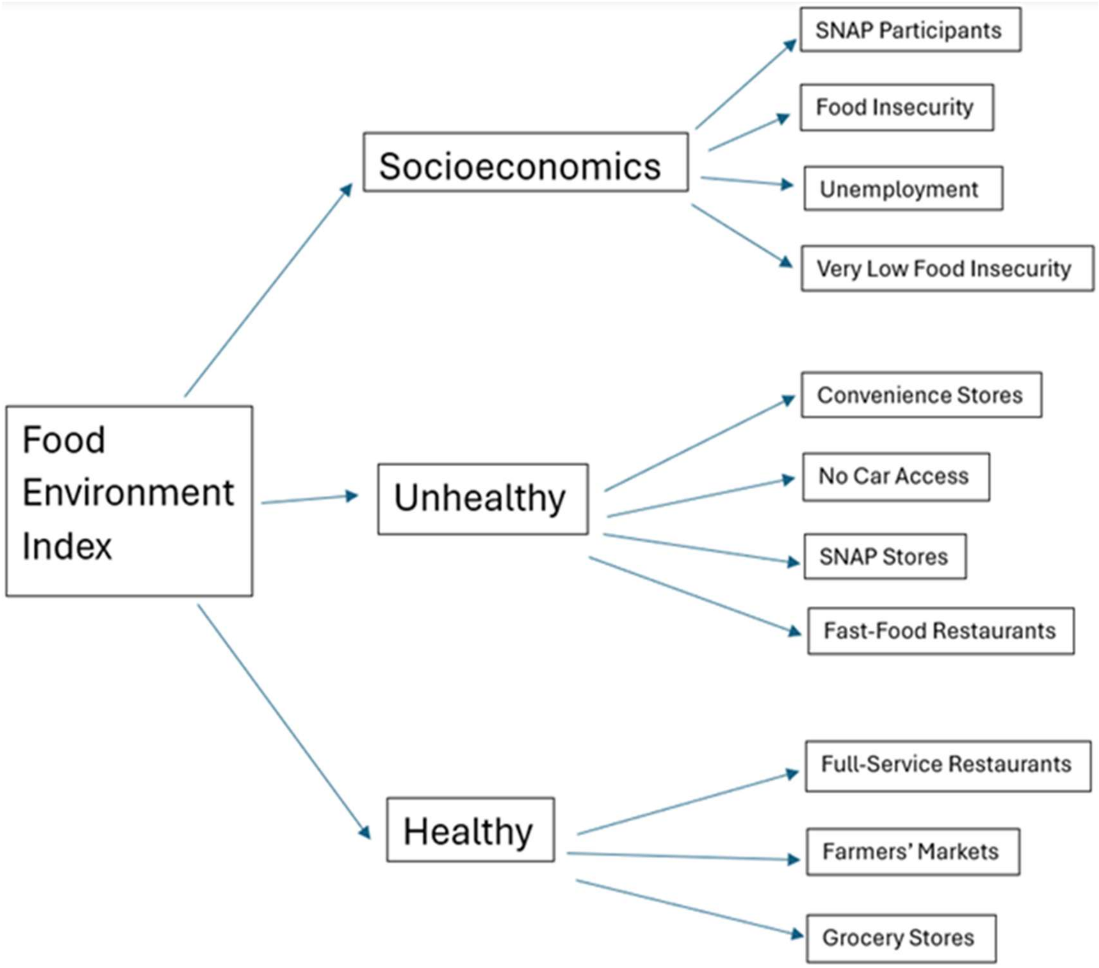

Figure 1: Model of construction of the Food Environment. The Food Environment Index is comprised of Socioeconomics, Unhealthy, and Healthy latent variables. Scaling is based on each latent variable's indicator's position, as standard deviation, from the mean of that indicator.

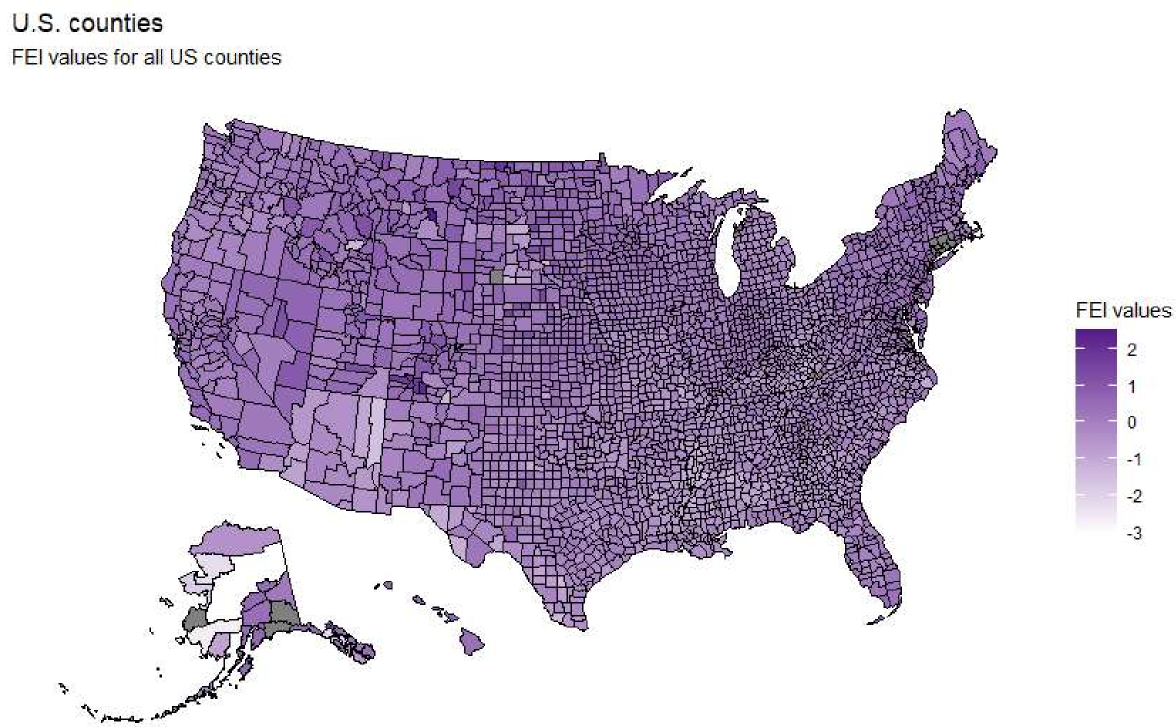

Figure 2: Food Environment Index 2, color-scaled based on value, mapped across all counties in the United States. Food Environment Index 2, comprised of Socioeconomics, Unhealthy, and Healthy latent variables. Scaling is based on each latent variable's indicator's position, as standard deviation, from the mean of that indicator. Darker shades indicate a healthier food environment, whereas lighter shades indicate an unhealthier food environment.

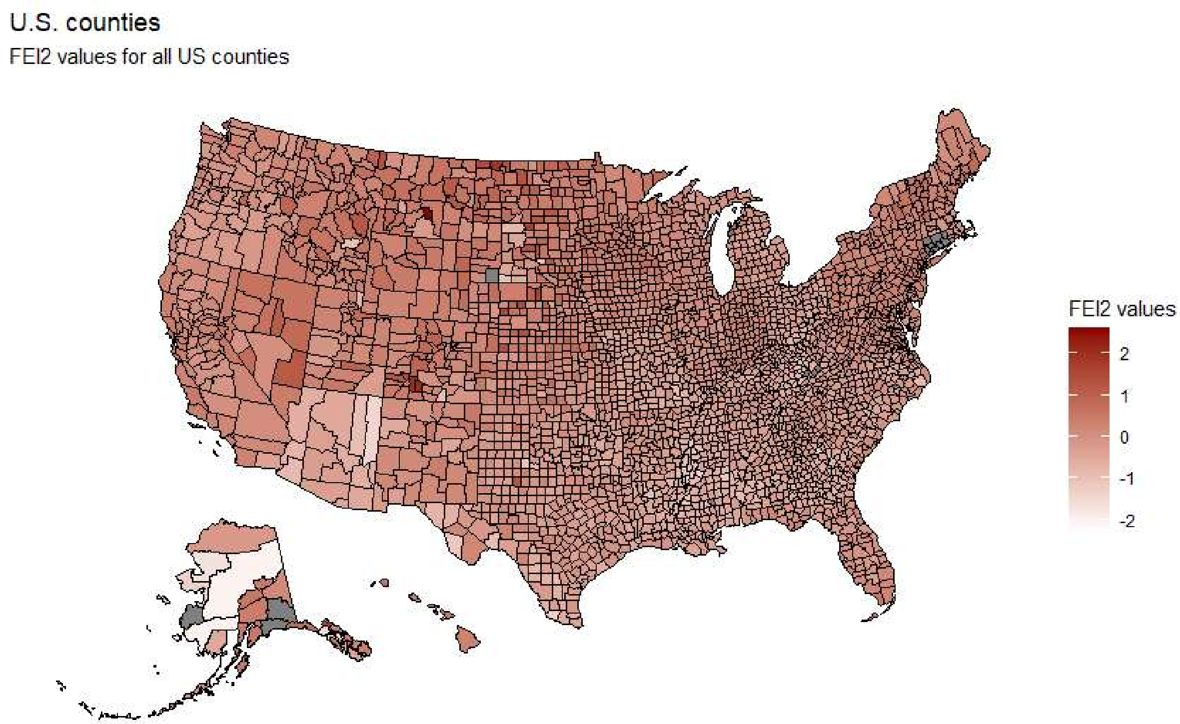

Figure 3: Food Environment Index 2, color-scaled based on value, mapped across all counties in the United States. Food Environment Index 2, comprised of Socioeconomics, Unhealthy, and Healthy latent variables. Scaling is based on each latent variable's indicator's position, as standard deviation, from the mean of that indicator. Darker shades indicate a healthier food environment, whereas lighter shades indicate an unhealthier food environment. For Food Environment Index 2, the Unhealthy latent variable contains a Fast Food per 1,000 capita component whereas the original Food Environment Index does not.

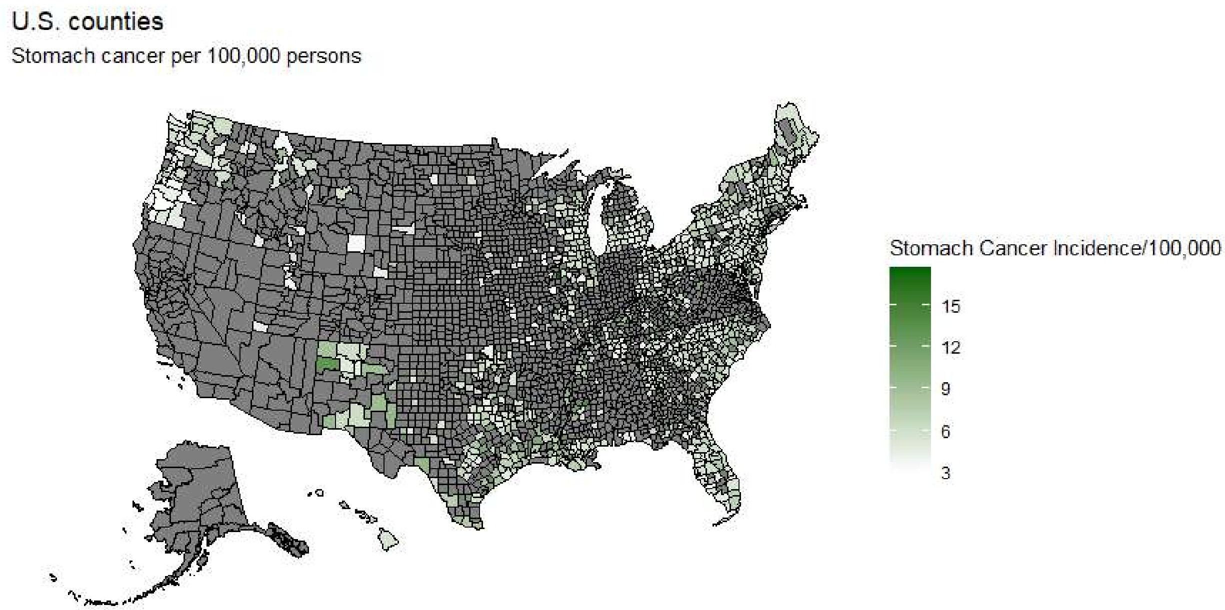

Figure 4: 2016-2020 Gastric cancer Incidence per 100,000 persons, color-scaled based on value, mapped across all counties in the United States. Colored counties indicate that county has at least one 2016-2020 case of gastric cancer incidence, with darker green color being higher incidence per 100,000 persons and lighter color being less incidence per 1000,000 persons. Gray counties indicate that county having a suppressed incidence rate from 2016-2020.

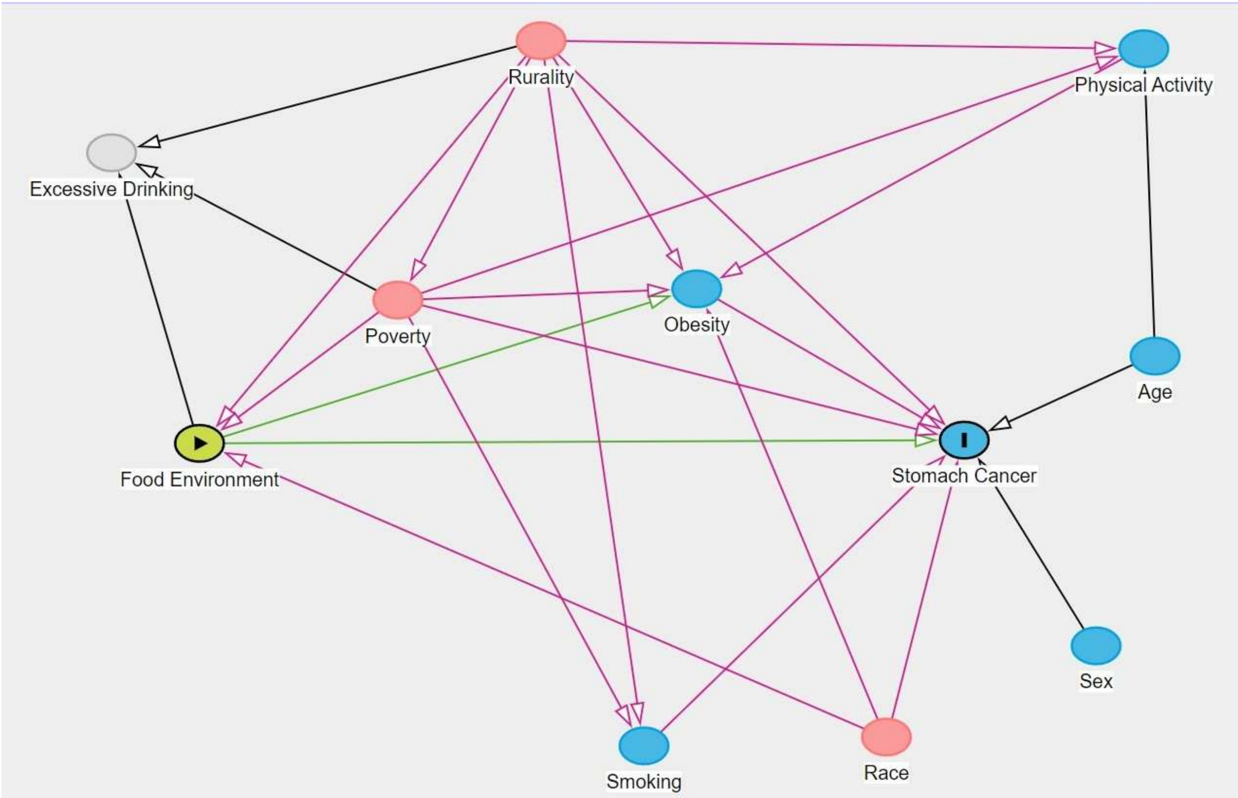

Figure 5: DAG-model of Food Environment Index, gastric cancer incidence and gastric cancer risk factors available in the combined dataset. Confounding pathways that were chosen for further multivariable analysis were rurality, poverty, Asian, Hispanic and Non-Hispanic Black race. DAGITTY software was used for the creation of the model.