Linking Variations in Wisconsin's Cancer Incidence Rates and Environmental Carcinogens Present in the Lower Fox River Valley

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Abstract

Located in Northeastern Wisconsin, the Fox River represents one of many examples of environmental mismanagement directly caused by industrial and governmental negligence towards a natural resource. Over 100 years of waste disposal in the river, which included toxins such as arsenic, lead, mercury, and polychlorinated biphenyls (PCB's) has severely damaged the Fox River and the wildlife which rely on it in well documented ways. However, the river's direct quantitative effect on human health has yet to be determined. Given that multiple substances, namely PCB's and arsenic, are known carcinogens and exist in the Fox River and Fox River Valley ecosystem, this study sought to explain that cancer rates experienced by the counties through which the river flows are higher compared to all other Wisconsin counties. Ordinary Least Squares regression was utilized to explain variation in the dependent variable, cancer cases per 100,000 people in a given county, using measurable factors which oncological research has shown to impact cancer incidence in individuals. The variable of interest, a dummy variable accounting for counties which contain the heavily polluted Lower Fox River, was shown to have a statistically significantly positive impact on cancer incidence rates. Subsequent robustness checks, holding constant other environmental factors, did not alter the significance of the variable of interest. Such a result implies there is a statistically significant relationship between populations which inhabit the Fox River Valley region and higher cancer incidence rates.

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The Fox River is located in Northeastern Wisconsin, and flows northward through Lake Winnebago and past cities such as Oshkosh, Wrightstown, De Pere, and Green Bay before dumping into Green Bay of Lake Michigan. The lower section of the river stretches approximately 39 miles, drops 168 feet in elevation, and runs 20 feet deep in some sections (Environmental Protection Agency, 2001). While the Lower Fox River has maintained its status as an economic centerpiece for this region of Wisconsin, it also represents one of the many examples of environmental mismanagement in recent history caused by a mixture of industrial and governmental negligence.

Water quality issues have plagued the Lower Fox River since communities began to settle on its banks and in its watershed in large numbers (EPA, 2001). A 1927 Wisconsin Conservation Commission report stated the river appeared dark and turbid, emitting a foul odor (EPA, 2001). The observations made in this report can be largely attributed to the prevalence of paper mills located along the river as well as poor waste water treatment standards in this period. Following the 1950's, the Lower Fox River became polluted with a toxic mixture of polychlorinated biphenyls (PCB's), pesticides such as DDT, arsenic, lead, and mercury (EPA, 2001). Of these chemicals, PCB's were of primary ecological and human health concern as PCB's have been studied to be a potent carcinogen, causing a range of cancers including liver and gastrointestinal cancers (Cogliano, 1998). Internationally, PCB's have been placed on the United Nation's list of chemicals marked for elimination due to their negative environmental and human health effects (United Nations Environment Programme Stockholm Convention, 1951).

In the Lower Fox River itself, efforts to reduce PCB contaminated river sediments with an estimated cost of $1 billion are approaching their 2017 completion date. A multifaceted action plan utilized different strategies in order to reduce settled PCB's, and these strategies were used in different sections of the river. Some sections, such as the river mouth and contaminant plume extending into Green Bay, were chosen for monitored natural recovery. This process is a watching and monitoring process which aims to track contaminants and ensure sediment movements do not mobilize the now settled PCB's (EPA, 2001). Other sections utilized capping; a process which covers contaminated sediments with a mixture of sand and gravel (EPA, 2001). A select few sections were selected for sediment dredging, which is the physical removal of contaminated sediments from the river bottom (EPA, 2001). These efforts were funded primarily by the Environmental Protection Agency with volunteered contributions from liable paper mill corporations such as Kimberly Clark and Georgia Pacific. The United States federal government is currently pursuing more funds through a settlement with other liable companies, townships, and the State of Wisconsin.

While the negative effects of PCB's, DDT, arsenic, lead, and mercury have been observed in the environment, little quantitative research has been pursued to discover whether the pollutants in the Lower Fox River are negatively impacting human health or not. Understanding the impact on human beings is an obvious and important aspect of environmental study. The toxicity of the Lower Fox River represents a serious hazard for surrounding communities; yet no study to date has attempted to quantify the effects, if any, that the known carcinogens in the river are causing on Fox River Valley residents. This study will attempt to fill this notable gap in empirical research on the effects of pollutants in the Lower Fox River on cancer incidence.

The question posed is such: Do the carcinogenic compounds found in the Lower Fox River, primarily PCB's, have a quantifiable effect on human cancer incidence rates for the communities surrounding the affected area? Any tangible results could breach an interesting discussion among economists, experts in the natural sciences, politicians, and lawyers by suggesting that what is primarily considered an ecological and environmental issue is, in reality, a very human concern. Epidemiology in particular could benefit greatly from an answer to the proposed question, for any relationship discovered could illuminate novel environmental or biological pathways through which carcinogens enter human populations from a contaminated environmental resource. However, of all fields which would benefit from such research, the growing field of environmental economics is likely the greatest beneficiary. The manners in which local, state, national, and international economies are tied to the environment are constantly being studied and considered within standard micro and macroeconomic frameworks. Theories such as the Coase Theorem and externalities are increasingly being called upon by environmental economists seeking to offer policy corrections for environmental phenomena. The discovery of a relationship between an environmental contaminate and human health in a developed nation with an effective healthcare system could offer commentary on the delicate balance between economic growth and human health.

This study will rely on pertinent economic and oncological research in order to construct a model which effectively describes variations in cancer incidence rates across the state of Wisconsin. The academic background and construction of this model, along with a discussion of relevant data limitations, will occur in the Literature Review Modeling Section. Next, the results of the statistical analysis will be presented in the Results Section. The results will then be interpreted and explained using a mixture of economic, oncological, and scientific theory in the Discussion Section. A summary of all sections will be provided in the Conclusion Section.

The preliminary conclusions showed a statistically significantly positive relationship between cancer incidence rates and populations living in the affected area compared to those living outside of the affected area. However, this result failed to identify a specific source of increased cancer incidence. Subsequent robustness checks, holding constant environmental factors such as air pollution, the number of concentrated animal feeding operations in an area, and the existence of an arsenic advisory zone succeeded in narrowing down possible factors. An F-Test of equivalent estimated parameters in the final robustness check signaled equal cancer incidence impact across the affected area. The outcome of the initial model, when combined with the outcomes of the robustness checks, indicates that the Lower Fox River likely has some impact on cancer incidence rates in the affected Lower Fox River Valley region.

Literature Review and Modeling

The goal of this study is to determine whether carcinogenic substances, specifically polychlorinated biphenyls (PCB's), in the Fox River cause higher rates of cancer in the affected counties compared to the rest of Wisconsin. Given this goal and given the data limitations present in the state of Wisconsin, ordinary least squares (OLS) multiple regression can be argued to be the best option for analyzing data on this topic.

The literature studying the effects of pollutants on cancer rates and mortality in various parts of the world have utilized different models. One study, Chen et al (2013), chose to use a regression discontinuity model. However, the study lacked the ability to accurately measure air pollutants in various areas of China, and OLS proved to be an ineffective method for estimating coefficients due to the inconsistent data collection regions for different variables (Chen et al., 2013). Some variables were measured at the city level, others at the individual level, and others yet at the regional level. By using a regression discontinuity model, the study was able to assume their dependent variable, mortality rates, increased smoothly in the form of a polynomial as distance from the affected area increased (Chen et al., 2013). OLS was abandoned due to limited data. The limited census data the Chinese government takes in tandem with the likelihood of omitted variable bias inherent in estimating mortality rates made OLS an ineffective model for the Chen et al (2013) study. However, this is not an issue given availability of consistent, county level data for this study.

Another study, Krestinina et al (2005), studied cancer rates in the Techa River Valley caused by radiation exposure using a different model. This study chose to use an excess relative risk (ERR) model over OLS due to time factors of exposure (Krestinina et al., 2005). The affected area was impacted mid-life for many of the observations and not all residents were exposed to the same amount of radiation. Another factor which contributed to the use of the ERR model was the need to use individual residents as observations (Krestinina et al., 2005). The nature of radiation exposure, in that exposure and its effects are intense and restricted in physical area, forced the need to account for migration to and from the affected area. The ERR model was the best method to account for this nature of exposure and migration, where use of OLS would likely result in omitted variable bias and estimation bias caused by migration of residents to other non-affected areas.

The nature of this study is to examine the effects of carcinogenic PCB's on the resident populations surrounding the affected Fox River, and the dependent variable is cancer cases per one hundred thousand residents. In contrast with prior literature, this dependent variable is arguably less prone to omitted variable bias. Although carcinogens and other causes of cancer are continuously discovered, the scientific community in general agrees on a short list of factors which contribute the most to the contraction of various types of cancer.

Due to the nature of how PCB's cause cancer, as proven in laboratory studies, migration rates and the subsequent need for individualized observations is not required. PCB ingestion has repeatedly proven to be the primary cause of cancer by PCB's (Cogliano, 1998), and it is unlikely that cancer cases increase or decrease in the form of a polynomial as distance from the Fox River increases or decreases. Because the primary mode through which PCB's enter humans is ingestion of contaminated wildlife, distance from the river does not necessarily impact likeliness of ingestion in the form of a polynomial. Rather, residents are more to likely consume contaminated wildlife if the contaminated Lower Fox River is within reasonable distance. This allows for the use of the linear model, OLS, and the variable of interest to exist in the model as a dummy variable for affected area or non-affected area.

This study will utilize scientific research on the causes of cancer to choose its independent variables. Irigaray et al summarizes and analyzes the scientifically suggested causes of cancer, settling on two important characterizations of factors which contribute to cancer causation.

The first group of variables can be defined as individual level variables pertaining to cancer causation for a specific individual. These variables include lifestyle choices such as tobacco use, alcohol use, and diet, as well as genetic factors such as age, ethnicity, and sex (Irigaray et al., 2007). Variations in these variables have been repeatedly shown to cause cancer in a number of ways. Tobacco use, as stated by Irigaray et al. (2007), is one of the most significant individual level variables linked with higher risk of cancer. The cancerous effects of alcohol consumption have shown to be similar to tobacco use (Irigaray et al., 2007). Ethnic variation, such as being of African American or Hispanic descent, being male, and being of greater age have all been linked with higher incidence of cancer, although they do not necessarily imply direct causation (Irigaray et al., 2007). For the purposes of this study, individual level variables will occupy the position of explanatory variables in the model, implying these factors cause cancer.

Of the first group of variables, their effects on cancer incidence rates for a population are intuitive. Population of greater age should positively impact cancer incidence rates in that older human beings are exposed to more carcinogens over their lifetime. As stated in Irigaray et al. (2007), males of African American or Hispanic descent have a greater chance of developing cancer than females of Caucasian or Asian descent. A population which contains greater incidence of diseases linked with cancer incidence, such as Hepatitis B and C, should have higher cancer incidence rates. A population with a greater rate of tobacco use should similarly exhibit higher cancer incidence rates.

The second group of variables can be thought of as population level variables or environmental variables. In this grouping, exposure to carcinogenic substances or sources is considered, as there are many carcinogens which populations are exposed to in the air or water. This includes radiation or radioactive material exposure, infectious disease epidemics which are linked with cancer causation, air pollution, drinking water contamination, and exposure to carcinogenic substances such as PCB’s (Irigaray et al., 2007). From economic theory, income disparity could indicate populations with less access to modern preventative medicine or cancer screenings. Such an instance could arguably impact cancer incidence rates, and thus must be included in the model. Again, this group of variables will occupy the explanatory variable portion of the final model. Environmental population level variables also affect cancer incidence rates in intuitive ways. Low income populations, given the previous argument relating income and cancer incidence rates, would increase cancer incidence rates in a given population and affect the entire population. Air pollution would similarly affect cancer incidence rates in an entire population if the air pollution contained known carcinogens. Contaminated drinking water, contaminated by point source polluters via direct dumping or via aquifer drawdown, would likely affect all aquifer users in a population.

The final variable, an environmental population variable and the independent variable of interest, must measure the physical boundaries which divide the affected population exposed to the effects of the Lower Fox River and the non-affected population. Given that this study will employ OLS and given the argument for a definite affected and non-affected area, this variable of interest will be represented by an indicator variable. The indicator variable will account for the proposed “on/off” nature of the affected area, attempting to distinctly separate areas into affected and non-affected areas geographically. The consulted literature notes the carcinogenic effects of PCB’s, and this study hypothesizes the existence of these chemicals in the environment will result in a positive estimated coefficient on the variable of interest. The carcinogenic nature of the chemicals found in the Lower Fox River would raise the cancer incidences in populations living in close proximity to the contaminants if residents consumed the PCB laden wildlife. Although the nature of OLS demands the effects of carcinogenic chemical interaction with residents be linear, or “on/off” in nature, this can be reconciled given the logistics of contamination. Lower Fox River Valley residents would be more likely to consume contaminated fish and wildlife given that they live in close proximity to the river. They have ease of access to carcinogenic contaminants which people living outside a certain radius simply do not have.

Given the multiple sources of potential environmental carcinogens unique to the state of Wisconsin at the county level, this study will employ 4 models with varying combinations of independent variables. A base model is used and contains independent variables most closely linked with cancer incidence as indicated by economic and oncological research. The base model will include all pertinent individual level explanatory variables including age, ethnicity, sex, cancer related diseases, and tobacco use. The environmental variables included in the base model will be income per capita and the indicator variable for affected and non-affected populations. Figure A shows the base model, Y_1, with its explanatory variables and their measures listed below.

Other environmental factors with the potential to explain variation in cancer incidence rates unique to Wisconsin will be added onto subsequent models in the form of independent variables. This list of unique independent variables includes air pollution of particulate matter 2.5 micrograms and the number of concentrated animal feeding operations (CAFO's) in a given county. These subsequent models containing unique environmental factors will be considered robustness checks to attempt to control for extraneous sources of cancer causing factors not directly indicated in pertinent literature but of relevance in the region.

Figure A: Primary model (Y_i) and robustness check models (Y_2, Y_3, Y_4)

$$Y_i = \beta_0 + \beta_1 Age_i + \beta_2 Ethnicity_i + \beta_3 Sex_i + \beta_4 Disease_i + \beta_5 Income_i + \beta_6 Tobacco_i + \beta_7 County_i + e_i$$

$$Y_2 = \beta_0 + \beta_1 Age_i + \beta_2 Ethnicity_i + \beta_3 Sex_i + \beta_4 Disease_i + \beta_5 Income_i + \beta_6 Tobacco_i + \beta_7 County_i + \beta_8 PM2.5_i + e_i$$

$$Y_3 = \beta_0 + \beta_1 Age_i + \beta_2 Ethnicity_i + \beta_3 Sex_i + \beta_4 Disease_i + \beta_5 Income_i + \beta_6 Tobacco_i + \beta_7 County_i + \beta_8 CAFO_i + e_i$$

$$Y_4 = \beta_0 + \beta_1 Age_i + \beta_2 Ethnicity_i + \beta_3 Sex_i + \beta_4 Disease_i + \beta_5 Income_i + \beta_6 Tobacco_i + \beta_7 County_i + \beta_8 PM2.5_i + \beta_9 CAFO_i + e_i$$

The dependent variable is in the form of invasive cancer cases, those most likely to be associated with carcinogen ingestion or exposure, per 100,000 residents in a given county. It must be noted that this is not the age adjusted cancer incidence rate often reported, as Age is an independent variable itself on the explanatory side of the regression.

The first group of variables, individual level variables, is comprised of Age, Ethnicity, Sex, and Disease, and Tobacco. Age is calculated as the percentage of residents over the age of 65 in a given county, and as noted earlier, will not be included on the left-hand side of the equation. The second individual level independent variable, Ethnicity, is calculated in a similar fashion as the percentage of African American and Hispanic residents in a given county. Sex functions in much of the same manner, as it is calculated by the percentage of females in a given county. Disease is an individual level independent variable and is calculated using cases of Hepatitis B and Hepatitis C per 100,000 residents in a given county. The final individual level independent variable is Tobacco, which measures tobacco deaths per 100,000 residents in a given county.

The second group of independent variables, environmental population level variables, includes Income, County, PM2.5, and CAFO. Income is simply defined as the income per capita in a given county. County, the independent variable of interest, is an indicator variable with 1 indicating an affected county through which the polluted Lower Fox River flows, and 0 indicating a non-affected county. The third environmental level independent variable, PM2.5, is defined as the annual average ambient air conditions of parts per million of particulate matter 2.5 micrograms. This is based on seasonal averages and daily measurements in a given county, and it must be noted that some county's annual average ambient air conditions are modeled using stations located in other counties. The final environmental level independent variable, CAFO, is defined as the number of concentrated animal feeding operations in a given county.

With the model constructed from economic and oncological theory, the nature of the data itself becomes an important factor. The source, type, and functional form of the data for each variable alter subsequent interpretation of results. Data limitations will ultimately impact interpretation as well, and these limitations must be equivalently considered.

The Wisconsin Department of Health Services provides annual health public health profiles at the county level in Wisconsin. This is the smallest physical area for which the dependent variable, cancer incidence rates per 100,000 people, can be recorded. Thus the independent variables must be of the same county level quality when using the OLS model. County level data is sufficient when describing variation in cancer incidence rates by geographical location; however city level data would be preferred. City level data could illuminate environmental hazards or extreme population differences which impact the dependent variable and investigating city level cancer incidence rate data for cities directly on the Lower Fox River would be ideal. In general, any smaller scaled description of the affected physical area would yield a better analysis. Given the previous argument regarding PCB interactions with human beings, defining a strict affected area when considering city level data would present nearly as many issues as benefits it provides. Here, county level data will suffice and work well in an OLS model, with the affected area being the county through which the Lower Fox River flows. These counties include Winnebago County, Outagamie County, and Brown County.

Cross sectional data, the type of data chosen for this study, allows for the inspection of cancer rates across all Wisconsin counties in a given year with each of the 72 counties serving as an observation. Inspection of all counties in the region or nation would be ideal; however the issue of interstate policies regarding cancer reporting, cancer treatment, and data collection becomes an issue. The state of Wisconsin, and particularly the Wisconsin Department of Health Services, takes consistent annual data on figures including cancer rates and types, population statistics, demographics, morbidity, birth rates, and mortality rates. This allows for a full inspection of Wisconsin counties in a cross sectional manner with the knowledge that there is minimal variation in data collection methods. While this method notably offers only one year of data, which could be considered to be problematic depending on the county level fluctuation in cancer rates, variation in the independent variables would be minimal. The Wisconsin Department of Health Services also notes that non-invasive and invasive cancer rates are available in reports prior to the 2011 report, meaning that cancer incidence rates pre-2011 would appear to be much greater given the inclusion of non-invasive cancers.

Using OLS also gives the option of whether to use time series data, cross sectional data, or time series cross sectional data. Strictly time series data would require the inspection of one county over a period of time; for example, the change in Brown County cancer incidence rates could be inspected over a period of time to highlight how the introduction of PCB's into the Fox River in the 1950's altered this rate. However, the earliest available date for the county level data provided by the Wisconsin Department of Health Services is 2005, allowing only a 10 year time frame for inspection. In addition to the lack of observations and the statistical issues created by this, cancer incidence and many of the independent variables would likely not exhibit enough variation to warrant a time series analysis. Time series cross sectional data would contain the same issue of minimal variable variation, although it would be more statistically viable given the greater number of observations and could yield an interesting analysis of cancer incidence over the past 10 years if the issue of non-invasive cancer inclusion could be accounted for.

It must be noted that not all variables are perfect measures of the features they attempt to capture, and the preciseness with which the model describes these individual or environmental phenomenon suffers as a result. The first of these imprecise variables is the proxy for tobacco usage rates, measured as tobacco death rates per 100,000 people in a given county. The argument that the dependent variable actually describes the independent variable is valid; however it could also be the opposite case. Deaths associated with tobacco, if tobacco is truly linked with cancer at a high level of significance, should be able to take the place of actual tobacco usage rates in lieu of county level data on tobacco usage rates. In this case, there are no reliable sources which report on tobacco usage rates in Wisconsin counties in 2012, and thus the proxy of tobacco related death rates must be used instead.

The next variable which attempts to describe an observed phenomenon is the air pollution variable. This variable is a measure of air particulates with a mass of 2.5 micrograms (PM2.5) and does not differentiate between carcinogenic air pollution and non-carcinogenic, but still harmful, dust particulates. Data on carcinogenic emissions in Wisconsin counties in 2012 is not yet available, and even then the measure may be flawed. Air particulate measures are often modeled based on air currents and point source polluters' location within those air currents, and thus true county level data is not available. PM2.5 models are regularly conducted, and thus using the more commonly modeled PM2.5 approximations can be justified on the basis of availability and accuracy of approximation.

CAFO, the variable measuring the number of concentrated animal feeding operations in a given county, is another approximation for an environmental phenomenon. CAFO's are widely criticized for their roles in creating toxic runoff which contains nitrogen, phosphorous, hormones, ammonia, and other chemicals toxic to humans and ecosystems. While they obviously have the potential to pollute surface water, recent studies have yet to determine their exact impact on aquifer water quality. This variable essentially attempts to explain any possible variations in cancer rates caused by potential aquifer pollution; however actual, but publicly unavailable, county level data on well water would serve this aspect of the model much better.

A table of summary statistics for all counties is available in Appendix A. Appendices B and C include summary statistics for non-affected counties only and affected counties only respectively. A heat map illustrating age adjusted cancer incidence rates by Wisconsin county is available in Appendix D.

Results and Discussion

Table A: All White corrected estimation outputs and significance levels.

Variable	Model 1 (Y1)	Model 2 (Y2)	Model 3 (Y3)	Model 4 (Y4)
Age	2149.098***	2128.934***	2193.437***	2159.218***
Ethnicity	264.326**	274.987*	270.962**	291.2692*
Sex	1321.662	1307.956	1378.969	1357.709
Disease	-0.748	-0.758	-0.734	-0.751
Income	0.002	0.002	0.002	0.002
Tobacco	1.427***	1.427***	1.428***	1.427***
County	77.108***	77.464***	69.897***	70.0288***
PM2.5		-1.617		-3.006
CAFO			1.273	1.367
β_0	-715.799	-693.207	-754.928	-715.812
Adjusted R Squared	0.696	0.691	0.692	0.688
F-Statistic	24.226***	20.872***	20.981***	18.3702***

(***=1% Level of Significance, **=5% Level of Significance, *=10% Level of Significance)

Estimation outputs for models 1 through 4 indicate results consistent with the proposed hypothesis, that the counties through which the polluted Lower Fox River flows report higher cancer incidence rates. The estimated coefficients imply these counties experience from 69 to 77 more cancer cases per 100,000 residents than other non-affected Wisconsin counties holding all other factors constant.

However, as the models do not control for all environmental factors, the results indicate that some factor, holding all other factors constant, is causing higher cancer incidence rates in the affected counties. This does not necessarily implicate the contaminants in the Lower Fox River as the primary factor in these results. Although the 4 models did control for a wide variety of potential sources which explain variations in cancer incidence, they do not control for every single factor. There may be some uncontrolled source of variation in the dependent variable which was not included in the set of explanatory variables. Statistically speaking, this could introduce omitted variable bias and thus the estimated coefficients are incorrect and would lead to incorrect hypothesis testing. However, this study's model was constructed on pertinent literature and even utilized further environmental variable robustness checks to account for extraneous sources of variation in the dependent variable with little change in overall model significance as indicated by the strong 1% level significance of the F-statistic. In general, omitted variable bias is an issue which every statistical analysis of sociological data must contend with. It is highly unlikely that a model will perfectly explain a given situation due to unrelated and random differences within the observed populations themselves.

Even with the lack of a definitive cause of variation in cancer incidence rates, the significance of the County variable, which is significant at the 1% level in the primary model and in environmental variable robustness checks, must be considered. The chance of County representing a statistical anomaly is 1%, or conversely, the estimated coefficients on County are 99% confident. This result implies that we can be 99% confident in attributing higher cancer incidence rates in Winnebago, Outagamie, and Brown Counties to a common factor. Such a result points us to examine factors which affect populations that are common between these three counties. A common factor is likely an environmental factor, as it is highly unlikely that significant differences in social practices at an individual level give us the strong significance of the estimated coefficient. In essence, we must begin to consider environmental factors which cause cancer that affect Winnebago, Outagamie, and Brown Counties.

The most obvious common carcinogenic environmental factor is the PCB contaminated Lower Fox River. PCB's in the river represent the carcinogenic substance and the physical location of the river, which flows through the affected counties, could represent the commonality we are searching for. Given that cancer caused by PCB's is due to ingestion of PCB contaminated wildlife, considering the PCB's in the Lower Fox River as the common factor implies that residents in the affected counties ingest PCB's far more often than residents in neighboring counties. Ingestion would occur in such a frequency as to cause from 69 to 77 more cancer cases per 100,000 residents in these counties. In Winnebago County alone, these extra 69 to 77 cases, holding all else constant, would represent approximately 12.2% to 13.6% of all cancer cases per 100,000 residents. In Outagamie County, 13.4% to 14.9% of all cancer cases per 100,000 residents would be caused by PCB ingestion holding all else constant. In Brown County, 13.9% to 15.5% of all cancer cases per 100,000 residents would be caused by PCB ingestion holding all else constant.

Such a conclusion necessitates an important question: is this variation in cancer incidence rates explained by PCB ingestion? In other words, we must consider if such a percentage of cancer cases caused directly by PCB ingestion are of a reasonable amount. For Brown County, there were 1,242 total invasive cancer cases reported in 2012 (Wisconsin Department of Health Services, 2012). Using our previous analysis of the percentage of extraneous cancer cases caused by PCB ingestion, we would conclude that 172 to 192 cancer cases were caused directly by PCB ingestion. In other words, such a result implies that from 172 to 192 individuals forewent the public warnings on wildlife consumption and ingested enough dangerously contaminated wildlife to cause cancer. This offers one explanation for the strong significance of the County variable. There may still be a better explanation for the strong significance of the County indicator variable which is more likely to affect an entire population instead of only individuals which does not rely on the negligence of residents. One assumption in all economic models is that actors in the model are rational actors, and assuming actor negligence in order to explain a phenomenon such as cancer rates becomes a relatively weak argument.

One such factor for which this study was unable to account for was private well water quality, although it was attempted to be controlled for in the CAFO variable. However, the CAFO variable did not directly control for private well water quality, and it assuredly did not control for the existence of carcinogenic substances in private well drinking water. Instead, it captured the effects of CAFO's, whatever effects those may be, on cancer incidence rates and was not statistically significant in either of the models it was included in.

In order to control for carcinogenic substances in private well water and the aquifers from which private wells draw, we must first consider which carcinogens are likely to exist in aquifers. Likely culprits are radium, radon, and arsenic (Wisconsin Department of Health Services, 2015). Radium is a naturally occurring element which, over long term exposure, aggregate in the bones and cause bone cancers ("Radium in Drinking Water Brochure," 2015).

Radon can occur in water or in the air, and represents a 1 in 100 cancer risk to those exposed over a long period of time ("Radon in Private Well Water Brochure," 2015). Arsenic is a naturally occurring and industrial waste chemical associated with paper production (EPA, 1998) which, over long term exposure, can cause a wide range of sicknesses and cancers ("Arsenic in Drinking Water Brochure," 2015). Any of these toxic carcinogens could contaminate drinking water, drawn from aquifers in the affected counties, and cause the strong statistical significance of the County indicator variable. Of these potential sources, arsenic is likely the carcinogen of interest as it is associated with cancer causation, natural occurrence in the state of Wisconsin, and the type of industry most prevalent in the three counties.

According to the Wisconsin Department of Health Services, arsenic in levels greater than 10 parts per billion (ppb) in drinking water pose a serious health risk to consumers. Potential health risks include immediate ailments such as unusual skin pigmentation, stomach pain, and tremors; however the long term diseases include cancers including skin, bladder, prostate, and lung cancers ("Arsenic Brochure," 2015). One noteworthy fact is that Wisconsin has naturally occurring levels of arsenic in groundwater above 10 ppb in nearly every county ("Arsenic Brochure," 2015).

Perhaps most important is how arsenic in groundwater affects the affected counties compared to the rest of Wisconsin counties. While the model was unable to overtly control for arsenic contamination in private well water, the County indicator variable was able to control for the region of Wisconsin most associated with naturally occurring dangerous levels of arsenic in groundwater. The Wisconsin Department of Natural Resources issued an arsenic advisory for areas in Winnebago and Outagamie counties in December of 2000 due to dangerously high levels of arsenic found in the St. Peters Sandstone sub-crop (Wisconsin Department of Natural

Resources, 2000). This geological feature is a narrow underground shelf of sandstone stretching northeast to southwest through Winnebago and Outagamie counties. The advisory was declared for wells within a five mile radius of the St. Peters Sandstone sub-crop, as wells within this area tested for arsenic levels greater than 10 ppb and some for 50 ppb (WDNR, 2000).

In essence, the County indicator variable controlled for the existence of this naturally occurring geological feature which contains a serious cancer risk worthy of an issued warning. The strong significance of this variable could potentially be linked to the epidemic level arsenic contamination of drinking water, and the overlapping of the affected areas and the arsenic advisory areas represents a strong argument for this correlation. While this occurrence may seem to disprove the hypothesis that the pollution in the Lower Fox River is related to higher cancer incidence rates, arsenic in the river could explain why the inclusion of Brown County, a county not included in the arsenic advisory, still rendered an estimation significant at the 1% level. Arsenic was found to be a byproduct of industrial paper pulp processing (EPA, 1998), and these processes were conducted in the Lower Fox River region of Wisconsin. Arsenic dumped into the river could have entered the aquifers from which private wells draw through a geological process known as drawdown. A 2004 Woods Institute Environmental Venture Projects grant study found arsenic transported to low lying regions of Cambodia was drawn down through 100 to 130 feet of soil, entering the aquifers from which private wells draw (Young, 2009). If this process occurred is the Lower Fox River region of Wisconsin, the prevalence of arsenic in aquifers could be a result of both naturally occurring arsenic as well as industrial arsenic drawn down through the soil.

In order to more definitively implicate a single environmental factor, a secondary set of robustness checks was performed. These checks included several variable forms for County, attempting to extricate any effects of the arsenic advisory zone from potential carcinogenic effects seen in Brown County. Figure B shows these robustness check models built upon the primary model described in Figure A. Note that County is divided into Arsenic and BrownCounty, where Arsenic contains Outagamie and Winnebago Counties in the first robustness check. This divides the counties amongst those outside the arsenic advisory zone, Brown County, and those in which it lies. The second robustness check divides all counties as separate indicator variables in an attempt to utilize an F-Test of equivalent parameters.

Affirmation that the arsenic advisory zone is the primary driver of higher than normal cancer incidence in the original models would appear as statistical significance on the Arsenic variable and statistical insignificance on BrownCounty. Co-significance Arsenic and BrownCounty would indicate a common factor among the two areas, of which the arsenic advisory zone plays no critical role. The third possibility, significance on BrownCounty and insignificance on Arsenic would indicate Brown County to be individually driving high cancer incidence rates in the original models. Insignificance on both variables would not be expected given the results of the primary model. Given the initial hypothesis that the Lower Fox River is causing higher than normal cancer incidence rates in the Lower Fox River Valley region, the first or second possibilities are expected.

Equivalent parameter estimations on all the counties in robustness check two would implicate that a common factor not only exists in all three counties, but also impacts cancer rates equally. Such a result would rule out coincidental cancer causation by different factors in different counties.

Figure B: Set of Robustness Checks

$Y_i = \beta_0 + \beta_1 Age_i + \beta_2 Ethnicity_i + \beta_3 Sex_i + \beta_4 Disease_i + \beta_5 Income_i + \beta_6 Tobacco_i + \beta_7 Arsenic_i + \beta_8 BrownCounty + e_i$

$Y_i = \beta_0 + \beta_1 Age_i + \beta_2 Ethnicity_i + \beta_3 Sex_i + \beta_4 Disease_i + \beta_5 Income_i + \beta_6 Tobacco_i + \beta_7 OutagamieCounty_i + \beta_8 BrownCounty + \beta_9 WinnebagoCounty + e_i$

Table B: White corrected estimation outputs and significance levels for Robustness Checks.

Variable	RC1	RC2
Age	2149.199***	2150.167***
Ethnicity	264.493**	265.462**
Sex	1321.172	1318.998
Disease	-0.747	-0.746
Income	0.002	0.002
Tobacco	1.427***	1.427***
Arsenic	77.361***	
BrownCounty	76.599***	76.565***
OutagamieCounty		81.577***
WinnebagoCounty		73.258***
β_0	-715.572	-714.751
Adjusted R-Squared	0.691	0.686
F-Statistic	20.866***	18.256***

(***=1% Level of Significance, **=5% Level of Significance, *=10% Level of Significance)

Robustness check one (RC1) shows statistical significance at the 1% level for both Arsenic and BrownCounty, indicating that the arsenic advisory zone is not a significantly different contributor to higher cancer rates than those observed in Brown County. Note the similar estimated coefficients, which, when F-tested for equivalent parameter estimates, signal equivalent carcinogenic effects in both areas. Robustness check two (RC2) shows statistical significance at the 1% level for all three counties. Although the estimated coefficients range from 73.258 in Winnebago County to 81.577 in Outagamie County, an F-Test of equivalent parameters proved the coefficients to be statistically equivalent.

The results of these robustness checks, when taken together, paint a more detailed picture than the original set of models and robustness checks. The original models, holding constant factors indicated to be related to cancer incidence on a variety of levels, pointed to a common factor without definition. The secondary set of robustness checks details a common factor which is not the arsenic advisory zone, a conclusion unreachable under the first set of models.

Given the results of the secondary robustness checks examining the impacts of the arsenic advisory zone, we must revisit the PCB's in the Lower Fox River as a potential source of cancer incidence. The highly carcinogenic presence of PCB's in marine life, which some residents of all affected counties consume at an unknown rate, is the strongest argument for the results presented. Where the initial argument that ingestion was the primary causal factor was considered weak, we must now reconsider in light of the robustness check results.

The initial model estimated that 172 to 192 cases of cancer were the result of a carcinogenic factor in Brown County. Given the robustness check results, this would mean that 172 o 192 individuals consumed enough PCB contaminated wildlife, likely fish, to cause cancer in themselves. Where at first this may seem wildly irrational, misperceptions over the nature of PCB contamination dangers over time and complex advisory systems may contribute to agents in the affected counties consuming dangerous levels of wildlife.

First, a reconstruction of the PCB contamination timeline will aid in illuminating the issue at hand. Contamination of the Lower Fox River began in 1950 and continued until the Clean Water Act of 1972 (EPA Report). Conditions in the river in terms of PCB concentration in fish drastically improved following this legislation and subsequent cleanup. The Wisconsin Department of Natural Resources issued its first fish advisory in 1976 due to PCB contamination in marine wildlife populations; however, as illustrated in Appendix E, concentrations of PCB's in fish did not decline from the mid-1980's through 2000 (EPA Report).

Examining the fish advisory, it can be noted that the Wisconsin Department of Natural Resources does not warn against the ingestion of fish. Rather, they give guidelines as to how much fish of which fish may be consumed for a certain demographic (WDNR). This system is designed to keep PCB bioaccumulation in humans low, especially for women of childbearing age or younger, and help residents in calculating how much fish they may consume. Advisory amounts are based on age, sex, the type of fish, the age of the fish (WDNR).

The chronology of contamination and potential consumption patterns bolsters the implication of the river in population level carcinogenic effects. Clearly, prior to the fish advisory issued in 1976, residents may have been consuming dangerously large amounts of fish at high frequencies. These fish may have contained concentrations of PCB's higher than those indicated in the first year PCB concentrations were recorded, and thus these residents would have been at extreme risk of developing cancer. After the fish advisory, individuals in all three counties continued to consume with no indications that these fishermen and women were consuming safe amounts. Residents may either not understand the advisory system, be overwhelmed by its intricacy, or lack the knowledge about fish required to interact with it. Even with the fish advisory, 172 to 192 residents in Brown County may have contracted cancer due to greater-then-normal consumption of PCB contaminated fish at some point or over the course of their lives.

This study found that cancer incidence rates per 100,000 residents in Winnebago, Outagamie, and Brown counties are statistically significantly higher holding all other factors constant and that cancer rates are equivalently impacted by a common factor in each county.

Given this result, several important questions are raised that necessitate further study. Geological, biological, and social studies could further the findings of this study and add important commentary on the state of cancer incidence in the state of Wisconsin.

One potential direction future studies could pursue is to examine the geological feasibility of arsenic contamination in the affected counties by industrial means. While naturally occurring arsenic is the current culprit in the arsenic advisory zone issued by the Wisconsin Department of Natural Resources, industrial arsenic drawdown must also be examined. Levels of arsenic in the Lower Fox River, arsenic drawdown rates in the affected counties, and distinguishing between what could be naturally occurring arsenic and arsenic from industrial processes could yield information on how the St. Peters Sandstone sub-crop became as contaminated as it currently is. In addition, such a study could predict future levels of arsenic in the advisory zone.

Biological studies may also aid in the explanation of the results found in this study. Examination of PCB levels in fish, game, and waterfowl must continue to be tracked in order to determine the toxicity of wildlife to humans. Given that PCB ingestion by residents in the affected counties is the strongest argument for higher than normal cancer incidence rates, studies examining PCB’s in any form are critical. Biological studies must continue to track PCB levels in wildlife and drive the recommendations made by the fish advisory. New infrastructure projects along the river continue to re-introduce contaminated sediments into the ecosystem, and these impacts must be examined from a biological perspective.

Another potential research direction could be pursued from sociological, psychological, and environmental sciences perspectives. Given the results of this study, sociologists could utilize surveys to examine real human interaction with the river in terms of fish consumption and how these interactions align with the recommendations of the fish advisory. Psychologists could examine the advisory itself in order to determine how individuals interact with the advisory. From an environmental sciences perspective, scientists could examine actual bioaccumulation levels of PCB's in the human population within the affected counties. Such results could aid all other studies in contextualizing the efficacy of fish advisories.

To continue building on the findings of this study, further economic analysis must be conducted. Such studies need to more accurately define the affected areas by zooming in using city level, household level, and individual level data. Geographic affected areas are a possibility; however the individual nature of PCB exposure would likely yield household level contamination. Apart from the contamination, the conclusion of higher than normal cancer incidence rates in the three identified counties could produce economic impact studies. Human health affects worker productivity, population growth, healthcare expenditures, and government expenditures; thus the economic impact of extraneous cancer could be analyzed.

Conclusion

The initial hypothesis, that cancer incidence rates in the counties through which the polluted Lower Fox River flows are significantly higher than all other Wisconsin counties, was accepted given the results of the model. Using OLS and 2012 data for Wisconsin counties, a method supported by previous literature, yielded a statistically significantly positive relationship between populations which reside in the affected area and cancer incidence rates. Subsequent robustness checks, controlling for air pollution and the number of CAFO's in a given county, did not affect the significance of the original result and were not significant themselves.

The inability of the original model and robustness checks to extricate a common factor, given the existence of an arsenic advisory zone in two of the affected counties, led to further investigation. County level data restricted the ability for the original model to control for private well water quality, and thus further specification was pursued. Specification variations in the variable of interest allowed for the extrication of the effects of the arsenic advisory zone. Combined with individualized county indicator variables in a second robustness check, the investigation disproved the likelihood that arsenic contamination of private well water is the culprit for higher than normal cancer incidence rates in the affected counties. An F-test of equivalent parameters proved that a carcinogenic factor in the three counties affects cancer incidence equivalent statistically speaking.

Given the cumulative results, direct ingestion of PCB's by residents in the affected counties is the most likely explanation for the variations in cancer incidence. An analysis of the timeline proved that residents ages 62 and older could have ingested dangerous amounts of PCB's in their lifetime, leading to the observed cancer incidence variation. While fish advisories currently in place control PCB ingestion by varying demographics to reduce carcinogenic hazards, agents could incorrectly interact with the advisory and consume dangerous levels of PCB's.

Beyond Wisconsin, other states and regions can analyze cancer incidence using the methods exemplified in this study. They may potentially find undiscovered sources of cancer or cancer risk, allowing for the implementation of precautionary measures and public policies. In the broadest sense, understanding cancer is critical knowledge as human beings begin to understand the effects of the environment on the body. This study was able to provide one more crucial link in defining our continual relationship with nature.

Appendices

Appendix A: Summary statistics for 2012 cross sectional data set including all 72 counties.

Variable	Mean	Median	Maximum	Minimum	Standard Deviation
Cancer	575.702	562.950	1099.600	277.900	147.180
Age	0.166	0.161	0.261	0.112	0.036
Ethnicity	0.050	0.033	0.405	0.008	0.056
Sex	0.498	0.499	0.530	0.460	0.010
Disease	50.567	43.964	184.581	0.000	31.039
Income	25081.000	24602.000	42180.000	14479.000	3728.838
Tobacco	168.152	157.000	391.000	89.000	60.758
PM2.5	9.391	9.500	11.200	7.100	1.078
CAFO	3.847	3.000	20.000	0.000	4.346

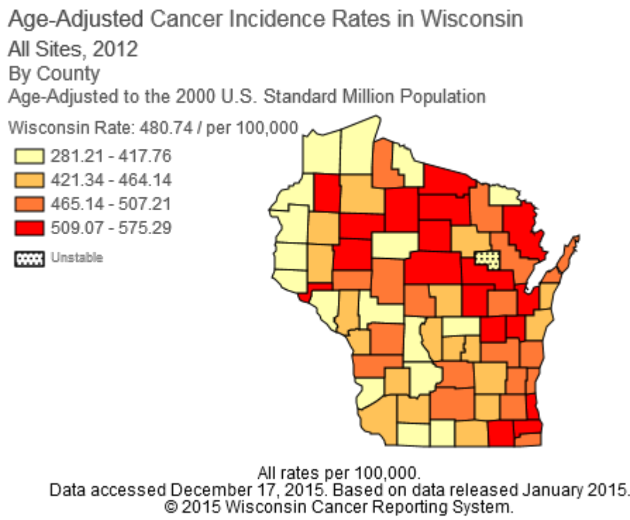
Appendix B: Summary statistics for 2012 cross sectional data set including 69 non-affected counties.

Variable	Mean	Median	Maximum	Minimum	Standard Deviation
Cancer	577.928	564.500	1099.600	277.900	149.873
Age	0.168	0.162	0.261	0.112	0.035
Ethnicity	0.049	0.033	0.405	0.008	0.057
Sex	0.498	0.500	0.530	0.460	0.011
Disease	50.733	43.859	184.581	0.000	31.590
Income	24966.101	24278.000	42180.000	14479.000	3766.791
Tobacco	169.536	158.000	391.000	89.000	61.614
PM2.5	9.347	9.500	11.200	7.100	1.079
CAFO	3.536	3.000	16.000	0.000	3.901

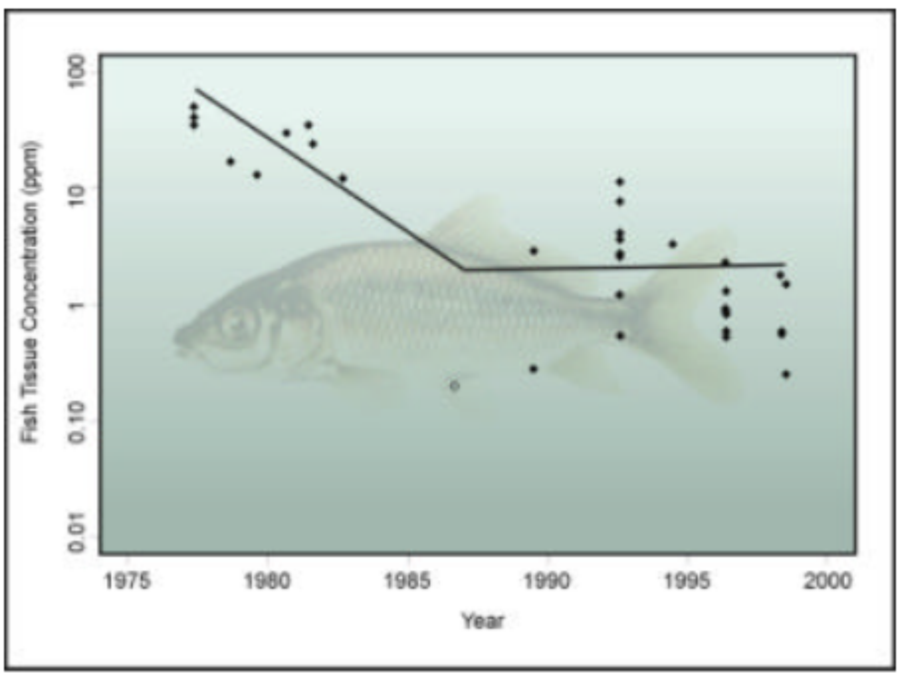
Appendix C: Summary statistics for 2012 cross sectional data set including 3 affected counties (Brown, Outagamie, and Winnebago).

Variable	Mean	Median	Maximum	Minimum	Standard Deviation
Cancer	524.500	514.500	562.800	496.200	34.407
Age	0.125	0.121	0.135	0.118	0.008
Ethnicity	0.058	0.058	0.104	0.013	0.045
Sex	0.497	0.498	0.500	0.494	0.002
Disease	46.750	51.669	59.481	29.100	15.776
Income	27716.666	27862.000	28185.000	27103.000	555.447
Tobacco	136.333	132.000	158.000	119.000	19.857
PM2.5	10.400	10.500	10.700	10.000	0.360
CAFO	11.000	10.000	20.000	3.000	8.544

Appendix D: Heat map of age-adjusted cancer incidence rates in Wisconsin by county in 2012. Created using Wisconsin Cancer Reporting System data and heat map tool.



Appendix E: PCB Concentration (ppm) in Little Lake Butte des Morts Carp, Whole Body, versus Time (EPA Report)



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