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Good for the Air, Bad for the Water: The Effect of Ethanol Production on Surface-Water Quality

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Abstract: This paper examines the direct effect changing ethanol production has had on changes in nitrogen (N) and phosphorus (P) fertilizer use and on the concentration of these nutrients in surface water. I employ the fact that due to the high transportation cost of corn, ethanol facilities utilize corn grown nearby. In a county-level model I account for the unobserved heterogeneity that influences both corn production and ethanol facilities' location decisions. I observe changes in N and P fertilizer use in a county as nearby ethanol-production capacity changes. I use this variation to estimate the direct impact ethanol production has on local fertilizer use and nutrient concentration in surface water. I find that a 10% increase in ethanol production capacity results in a 1.34% increase in N fertilizer use. Today, a typical Midwestern county faces exposure to 269 million gallons of ethanol production per year. My results indicate that increasing that exposure by 27 mgpy will result in in 101.3 tons more nitrogen fertilizer use annually in the county.

Introduction

The Energy Independence and Security Act of 2007 mandated the production and use of 36 billion gallons of ethanol in the U.S. by 2022 with 15 billion gallons coming from corn. At the current conversion rate, 42 billion bushels of corn will be required to meet this mandate. Because corn is a nitrogen-fertilizer intensive crop, many worry that ethanol will harm the environment if the nitrogen runs off fields into surface water. The National Research Council (2002) warned that, "if projected future increases in the use of corn for ethanol production do occur, the increase in harm to water quality could be considerable." Since this warning, myriad studies have attempted to predict the effect increased corn production might have on surface-water quality. Specifically, these studies have employed hydrological transport models to predict riverine nitrate. They do not, however, account for behavioral changes along margins other than increased corn production, such as fertilizer use or conservation practices.

In contrast, this paper examines the direct effect changing ethanol production has had on changes in nitrogen (N) and phosphorus (P) fertilizer use and on the concentration of these nutrients in surface water. This approach has several advantages. First, I employ the fact that due to the high transportation cost of corn, ethanol facilities utilize corn grown nearby (McNew and Griffith 2005). In a county-level model I account for the unobserved heterogeneity that influences both corn production and ethanol facilities' location decisions. I observe changes in N and P fertilizer use in a county as

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nearby ethanol-production capacity changes. I use this variation to estimate the direct impact ethanol production has on local fertilizer use and nutrient concentration in surface water. Knowing the direct impact on local fertilizer use is important because 65% of ethanol production takes place in counties with extensive subterranean drainage systems (known as 'tile drainage'), which "is the dominate source of riverine nitrate N yields in the upper Mississippi River Basin" (David, Drinkwater, and McIsaac 2010). In other words, fertilizer use near ethanol facilities runs the highest risk of contaminating surface water.

This paper uses a simple, transparent approach to provide policy makers the information needed to make effective environmental policy. The approach provides a direct answer to the question, "how would fertilizer use change if we increased the ethanol mandate by a billion gallons per year?" I find that a 10% increase in ethanol production capacity results in a 1.34% increase in N fertilizer use. Today, a typical Midwestern county faces exposure to 269 million gallons of ethanol production per year. My results indicate that increasing that exposure by 27 mgpy will result in in 101.3 tons more nitrogen fertilizer use annually in the county.

Background

Ethanol Production in the United States

Since the late 1990s, the U.S. ethanol industry has experienced substantial expansion. The Clean Air Act Amendments of 1990 (CAA) provided the impetus for the eventual expansion of ethanol production. The CAA required a higher oxygen content in gasoline to combat air pollution. Several chemicals, including ethanol, can be blended with gasoline to increase the oxygen content. Initially MTBE (methyl tertiary-butyl ether) was the oxygenate of choice, but refiners started moving away from MTBE to ethanol in 1996, when the city of Santa Monica learned that its drinking water was contaminated with MTBE.

By 2005 the transition from MTBE to ethanol as the main oxygenate added to gasoline was complete. The Energy Policy Act of 2005 removed the oxygen content requirement for reformulated gasoline and instead required a certain amount of ethanol to be blended with gasoline (up to 7.5 billion gallons by 2012). The Energy Independence and Security Act of 2007 extended the target to 36 billion gallons by 2022.

The impact of these events on ethanol production can be seen in figure XX. The left axis of figure XX measures the cumulative ethanol production capacity, and the right axis measures the annual change of ethanol production capacity. The spikes in production capacity growth illustrate the effect of the discovery of MTBE in drinking water and the mandates to blend ethanol with gasoline.

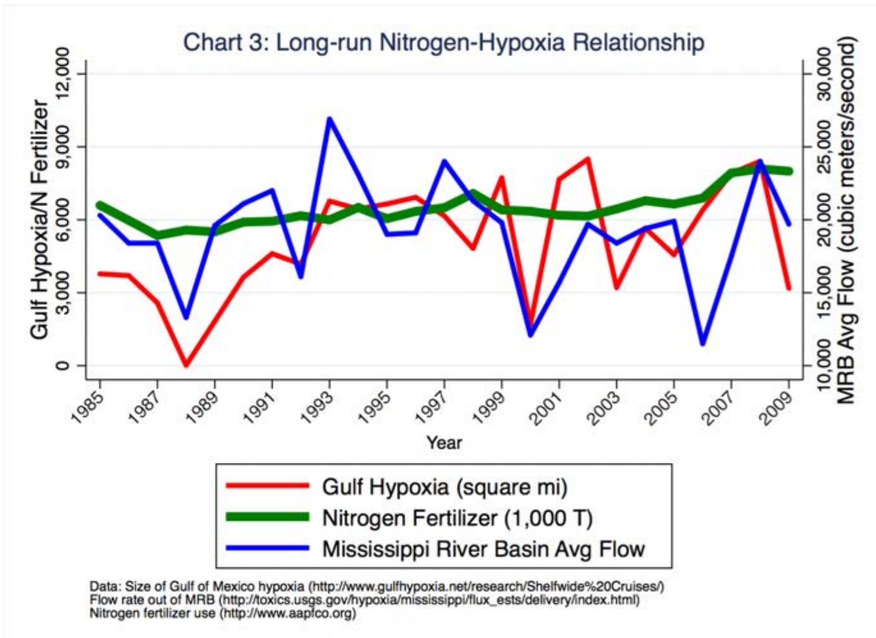
The vast majority of U.S. ethanol production relies on corn. Roughly 12.5 billion gal/yr, 83% the total capacity, is based on corn. Due to the cost of transporting feedstock, producers prefer to be located near corn production. In the U.S., 91% of the total capacity is produced in the second Petroleum Administration for Defense District (PADD II), which essentially comprises the Corn Belt. Once built, ethanol facilities are likely to stimulate local demand and cause nearby farms to produce more corn.

Water Pollution and Health

The health consequences of water pollution can be severe. Once in groundwater, numerous health problems can result from the ingestion of the nutrients. The biggest worry is infant methemoglobinemia, commonly referred to as blue-baby syndrome, an oxygen-depleted state yielding a bluish tinge in the skin. Left unchecked in extreme forms, methemoglobinemia can result in death and can be sufficiently unrecognized to go untreated (Winneberger 1982). Aside from methemoglobinemia, long-term ingestion of nitrates is indicated in adult cases of bladder, stomach, ovarian, and liver cancers, as well as adult central nervous system tumors (Wolfe and Patz 2002). Additionally, the Centers for Disease Control (1996) suggest that nitrate-contaminated well-water is responsible for elevated rates of spontaneous abortion in humans.

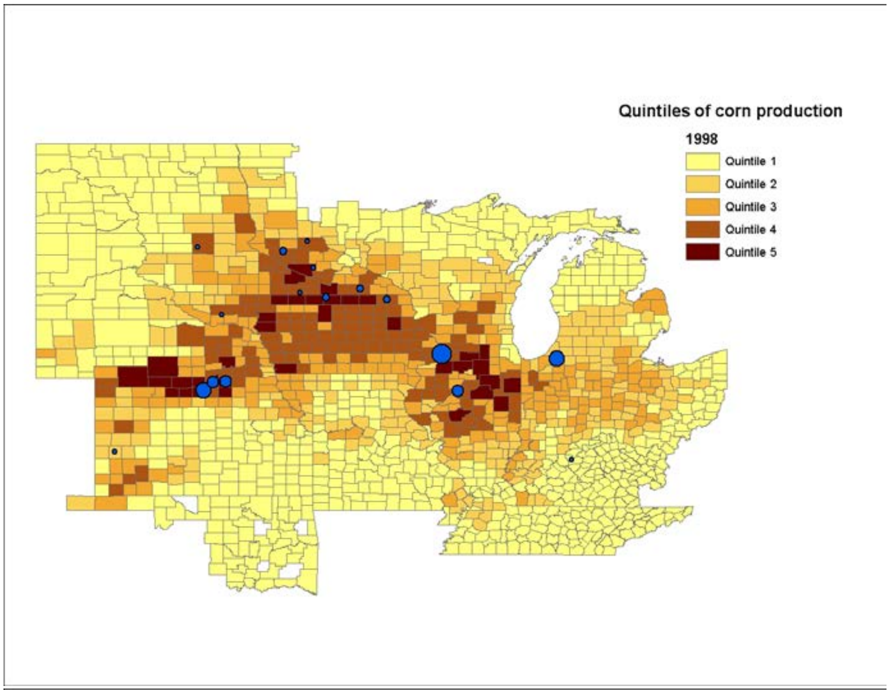
Fertilizer Use and Gulf Hypoxia

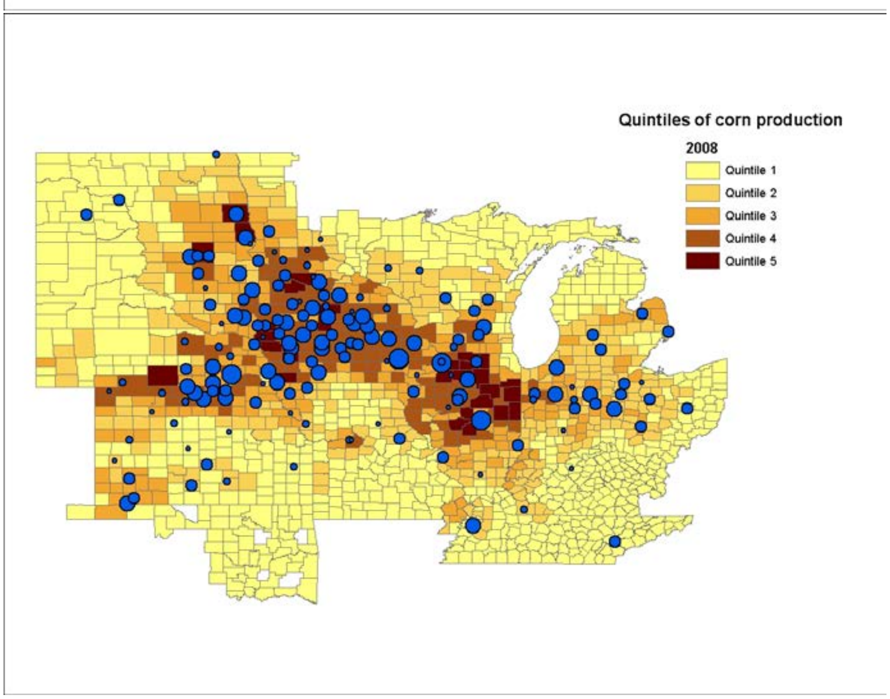
Figure illustrates the complex relationship between nitrogen application, precipitation, and Gulf of Mexico hypoxia. The blue line in the graph shows the size of the "dead zone" each year in 1985-2009, as measured in square miles on the left axis. The year-to-year variability in the amount of Gulf hypoxia is evident. The red line illustrates the quantity of nitrogen (N) fertilizer used in the Mississippi River Basin, as measured in thousands of tons on the left axis. In contrast to the Gulf hypoxia, <change colors, hypoxia red, N fert green>, year-to-year nitrogen fertilizer usage remains relatively flat. How are we to reconcile these facts, the amount of hypoxia changes dramatically from year to year while nitrogen fertilizer usage does not. The answer lies in the blue line on the graph, which represents the flow rate (amount of water) of the Mississippi River as it leaves the Mississippi River Basin (MRB). Year-to-year variation in precipitation in the MRB leads to variation in the amount of water leaving the MRB, carrying with it nutrients applied months if not years earlier. [then say something about the difficulty this causes for regulating nutrient usage based on ambient standards.]



Indentifying the Effect of Ethanol Production on Fertilizer Use and Water Pollution

The fundamental concern when identifying the effect of ethanol production on fertilizer use and water pollution is that ethanol production facilities choose to locate in areas that initially have high corn production. This can be seen by comparing figure with figure . Each figure is a map of the counties in the corn belt. Darker shaded counties represent greater total corn production. The circles represent the location of ethanol plants, and the size of the circle is proportional to the plant capacity. Figure shows the spatial distribution of corn production and ethanol production in 1998, and figure shows the spatial distribution in 2008. The figures illustrate that ethanol facilities typically locate where corn production is already high. The simple correlation between ethanol production and fertilizer use/water quality may be positive not because ethanol production causes higher fertilizer use, but because corn production requires high amounts of fertilizer and ethanol facilities locate where corn production is high.





To address this issue, we note that the climatic and soil conditions conducive for profitable corn production are essentially constant over the relatively short period we consider. We account for these time-invariant crop-production conditions with county-level fixed effects in the estimation equation. Intuitively, we thus are examining the correlation between the *change* in ethanol production and the *change* in fertilizer use.

Our empirical approach relies on the following identifying assumption: in the absence of ethanol-induced demand for corn, the *proportional change* in fertilizer use would have been the same in areas exposed to high ethanol production relative to areas not so exposed.

Data

We collect data from a variety of sources to investigate the local effects ethanol production has on fertilizer use. The smallest unit of observed fertilizer use is the county; consequently, we collect and construct data at the county level.

Ethanol Production

We collect data on the location and capacity of ethanol production facilities from three sources. Since 2005, the Nebraska Energy Office has released monthly ethanol production capacity by state and by plant.[1] We use data from 2002–2005 from the Renewable Fuels Association Annual Outlook reports.[2] We compiled pre-2002 data from company websites and by directly contacting individual production facilities.

We employ production capacity and the distance between ethanol plants and each county centroid in a gravity model to measure the magnitude of the ethanol-induced demand for corn. Specifically,

$$EthanolExposure_{it} = \sum_j \frac{EthanolCapacity_{jt}}{f(Distance_{i,jt})} \tag{1}$$

$EthanolExposure_{it}$ is the sum of the ethanol production capacity in every city j in year t, divided by a function of the distance from the centroid of county i to city j. In the following analysis, we use two measures of ethanol exposure, one denominated by the distance and the other by the distance squared. Table XX reports the summary statistics of these measures.

[1] www.neo.ne.gov/statshtml/122.htm

[2] www.ethanolrfa.org/pages/annual-industry-outlook

Synthetic Fertilizer Use

The Association of American Plant Food Control Officials (AAPFCO) maintains annual data based on fertilizer consumption information, in terms of fertilizer sales or shipments, reported by state fertilizer control offices to AAPFCO. In the Midwest, farmers typically apply anhydrous ammonia in the fall in anticipation of the following crop year, and fertilizer purchased in September through December is typically used in the following year's production. Thus, the annual data are recorded based on the "fertilizer year," which runs from July 1 of the year before the crop year to June 30 of the crop year.

For most Midwestern states, the AAPFCO data are maintained at the county level. Where only state-level data are available, we allocate the data to counties in proportion to each county's share of total fertilizer expenditure in the state according to the most recent Census of Agriculture. In the robustness section we examine the results when we restrict the data to the non-imputed counties. The summary statistics for these data are reported in table XX.

Water Quality

We use water quality data from the reports filed by states to the U.S. Environmental Protection Agency (EPA) under sections 303(d) and 305(b) of the Clean Water Act. The section 305(b) data contain the state's findings on the status of all its assessed waters. The section 303(d) data contain a listing of the impaired waters and the causes of impairment. The Clean Water Act requires states to monitor surface-water quality and report their findings to the EPA every two years.[3]

We measure each county's water quality as the share of surface water in the county classified as "impaired."

$$\text{Water Quality}_{it} = \frac{\sum \text{Impaired Waters}_{it}}{\sum \text{Assessed Waters}_{it}} \tag{2}$$

Water Quality$_{it}$ is the ratio of the total length (miles) of impaired (303(d)) surface water to the total length (miles) of assessed (305(b))surface water in county i in year t.

[3] Although potentially comprehensive, it should be noted that on the EPA's website they caution that, "The methods states use to monitor and assess their waters and report their findings vary from state to state and even over time." County-level fixed effects account for state-to-state variation, but variation over time may cause bias.

Empirical Model

The estimating equation is:

$$Y_{it} = \alpha + \beta \text{Ethanol Exposure}_{it} + \gamma_t + \delta_i + \phi' \text{X} + \varepsilon_{it} \tag{3}$$

Where Y represents the outcome, either Fertilizer Use or Water Quality. The variable γ_t is a year effect that accounts for aggregate shocks in year t, and δ_i is a county fixed effect that accounts for unobserved county characteristics that don't change during our sample period. X represents the control variables, and ε_{it} is the error term.

Results

Nitrogen fertilizer use

Tables 1 and 2 report the results of estimating equation (3) where the outcome variable is the (log) tons of nitrogen fertilizer used in the county. The model is estimated using data in 1998–2009. The first row reports the effect when transportation costs make it impractical to source corn from farther than 75 miles from the ethanol plant. The second row puts the cutoff at 125 miles, and the third row cuts off the effect of ethanol production beyond 250 miles. The final row reports the results when the demand effect of ethanol production is not limited by distance.

The results of both tables show a clear pattern. The OLS estimate reveals a strong association between ethanol production and fertilizer use. Accounting for time-invariant county characteristics, however, reduces the estimated effect by an order of magnitude. The fixed effects estimates are all highly statistically significant and reveal an elasticity of nitrogen fertilizer use with respect to ethanol production ranging from 0.03 to 0.11.

Table 1: The relationship between nitrogen fertilizer use and ethanol production normalized by distance

	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
Log Ethanol Exposure (75 miles)	0.309***	0.035***						
	(0.010)	(0.008)						
Log Ethanol Exposure (125 miles)			0.374***	0.042***				
			(0.010)	(0.009)				
Log Ethanol Exposure (250 miles)					0.429***	0.064***		
					(0.011)	(0.012)		
Log Ethanol Exposure							0.805***	0.113***
							(0.025)	(0.023)
Observations	12,518	12,518	12,518	12,518	12,518	12,518	12,518	12,518
R^2	0.634	0.939	0.645	0.939	0.657	0.939	0.645	0.939
County Fixed Effects	No	Yes	No	Yes	No	Yes	No	Yes

Significance levels: * 10 percent, ** 5 percent, *** 1 percent. Standard errors (in parentheses) clustered by county. Outcome variable is (log) tons of nitrogen fertilizer. All regressions include year fixed effects and control for log population, per capita income, lagged farm income, and the price of fertilizer.

Table 2: The relationship between nitrogen fertilizer use and ethanol production normalized by $distance^2$

	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
Log Ethanol Exposure (75 miles)	0.389***	0.071***						
	(0.033)	(0.019)						
Log Ethanol Exposure (125 miles)			0.428***	0.076***				
			(0.033)	(0.019)				
Log Ethanol Exposure (250 miles)					0.475***	0.082***		
					(0.033)	(0.020)		
Log Ethanol Exposure							0.494***	0.091***
							(0.034)	(0.020)
Observations	12,518	12,518	12,518	12,518	12,518	12,518	12,518	12,518
R^2	0.622	0.939	0.622	0.939	0.623	0.939	0.623	0.939
County Fixed Effects	No	Yes	No	Yes	No	Yes	No	Yes

Significance levels: * 10 percent, ** 5 percent, *** 1 percent. Standard errors (in parentheses) clustered by county. Outcome variable is (log) tons of nitrogen fertilizer. All regressions include year fixed effects and control for log population, per capita income, lagged farm income, and the price of fertilizer ($/ton).

Water quality

Tables 3 and 4 report the results of estimating equation (3) where the outcome variable is the share of assessed surface water in a county that is classified as impaired. Here, the coefficients are more difficult to interpret. Both tables reveal that failure to account for county fixed effects results in a negative estimate, i.e., greater ethanol-induced demand for corn is correlated with *lower* water pollution. Accounting for time-invariant county characteristics, however, results in a less clear-cut relationship. Table 3 reports a positive, statistically significant relationship when influence of ethanol production is limited to a 75-mile radius. Widening the radius, however, reduces the relationship until the estimate is negative and statistically significant when the influence of ethanol production is unlimited by distance.

Table 4 consistently reveals a positive, but statistically insignificant, effect of ethanol production on water pollution when county fixed effects are included in the model.[4]

Table 3: The relationship between water pollution and ethanol production

	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
Log Ethanol Exposure (75 miles)	-0.031***	0.027**						
	(0.007)	(0.014)						
Log Ethanol Exposure (125 miles)			-0.044***	0.020				
			(0.007)	(0.016)				
Log Ethanol Exposure (250 miles)					-0.056***	-0.012		
					(0.008)	(0.022)		
Log Ethanol Exposure							-0.158***	-0.175***
							(0.019)	(0.059)
Observations	1,749	1,749	1,749	1,749	1,749	1,749	1,749	1,749
R^2	0.169	0.200	0.178	0.199	0.188	0.198	0.198	0.203
County Fixed Effects	No	Yes	No	Yes	No	Yes	No	Yes

Significance levels: * 10 percent, ** 5 percent, *** 1 percent. Standard errors (in parentheses) clustered by county. Outcome variable is (log) tons of nitrogen fertilizer. All regressions include year fixed effects and control for log population and per capita income.

[4] About half of the county-year observations were unable to be used in this analysis due to an error in the Python script used to extract the water quality data from the EPA shape files. It is plausible that once the error is corrected and all of the data are available, the results in table 4 will become statistically significant.

Table 4: The relationship between water pollution and ethanol production

	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
Log Ethanol Exposure (75 miles)	-0.040*	0.026						
	(0.023)	(0.033)						
Log Ethanol Exposure (125 miles)			-0.052**	0.025				
			(0.024)	(0.033)				
Log Ethanol Exposure (250 miles)					-0.061**	0.025		
					(0.024)	(0.034)		
Log Ethanol Exposure							-0.063**	0.026
							(0.025)	(0.035)
Observations	1,749	1,749	1,749	1,749	1,749	1,749	1,749	1,749
R^2	0.163	0.198	0.164	0.198	0.165	0.198	0.165	0.198
County Fixed Effects	No	Yes	No	Yes	No	Yes	No	Yes

Significance levels: * 10 percent, ** 5 percent, *** 1 percent. Standard errors (in parentheses) clustered by county. Outcome variable is (log) tons of nitrogen fertilizer. All regressions include year fixed effects and control for log population and per capita income.

Conclusion

Most gasoline in the U.S. contains about 10% ethanol, which increases the oxygen content and reduces harmful emissions. For these benefits and in the name of energy independence, the Renewable Fuels Standard mandates the blending of ethanol with gasoline. While this standard reduces air pollution, it also encourages intensive corn production. Because corn is a ”nitrogen-thirsty” crop, intensive production raises the concern that more nitrogen will pollute surface waters.

This paper uses the exogenous increases in corn-ethanol production to investigate the effect on nitrogen fertilizer use and water quality. The results show a clearly positive effect of ethanol production on fertilizer use. The effect on water quality is less clear, but the evidence suggests it might increase water pollution, but further analysis is needed to confidently determine the impact of ethanol production on surface-water quality.

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