Summer 8-3-2022

How Federal Pollution Discharge Permits Affect U.S. Water Quality: A Study on Concentrated Animal Feeding Operations

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How Federal Pollution Discharge Permits Affect U.S. Water Quality: A Study on Concentrated Animal Feeding Operations

by

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Submitted in partial fulfillment
of the requirements for the degree of
Master of Arts in Economics
Hunter College, City University of New York

2022

Thesis sponsor:

August 3, 2022
Date

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August 3, 2022
Date

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Acknowledgements

The completion of this thesis would not be possible without the guidance and expertise of both Partha Deb and Bipasha Chatterjee, my beloved thesis advisors. Dr. Deb pushed me to think critically and provided me with the econometrics necessary to use and analyze such big data. Meanwhile, Dr. Chatterjee taught me everything I know about environmental economics, inspiring me to explore interdisciplinary studies.

I would also like to thank my professors and peers from the Economics Department at Hunter College for their encouragement this past year, particularly Ingmar Nyman and Karna Basu. A special thank you to William Ball for reading and providing continuous feedback on this thesis.

Abstract

The EPA's review of the Clean Water Act in the late 1990's determined that Concentrated Animal Feeding Operations (CAFOs) are a point source of water pollution and are thus subject to regulation. By 2009, all U.S. states with CAFOs that discharge into waterways were required to obtain National Pollutant Discharge Elimination System (NPDES) permits; despite this requirement, some states acquired NPDES permits after 2009, others did not get their reissuance approved, and a couple of states never implemented the regulation at all. This paper uses difference-in-difference regression models to examine the effect of this policy on copper, zinc, fecal coliform, inorganic nitrogen, ammonia, nitrate, nitrite, oxygen, and phosphorus concentrations in water. I ultimately deem the permitting to be ineffective at improving water quality, calling attention to the need to re-evaluate the "socially optimal level of pollution."

Contents

1 Introduction

As commercial fertilizer for agricultural production became widely available due to the invention of the Haber-Bosch process, crop farmers no longer needed to rely on local manure to provide nutrients to their crops [43, 48]. Crop and animal production effectively separated, allowing farms to specialize and the value of manure to decline [47]. The resulting low value and high supply of manure along with technological advancements led to the industrialization of the livestock industry [22]. There has since been significant consolidation in the industry, leading to a shift towards larger, more concentrated animal production operations [8]. Animal feeding operations (AFOs) refer to agricultural enterprises that keep and confine livestock (beef or dairy cattle, hogs, and poultry); the animals are confined to a small land area with their feed, urine, manure, and dead animals and without access to open pastures for grazing [34]. A concentrated animal feeding operation (CAFO) is a large-scale AFO with more than 1,000 animal units (where one animal unit equals 1000 pounds of live animal weight) or any AFO that discharges wastewater or manure into a waterway regardless of size [34]. In 1997, CAFOs generated $75.4 billion in sales, which accounted for 76% of all animal production sales and 38% of all farm sales in the U.S. [42]. By 2010, CAFOs made up only 5% of all AFOs, but raised over 40% of all U.S. livestock, reflecting their long-standing influence and market power [8].

This paper explores the effect of federal permitting on reducing the water pollution generated by this prominent industry. Meat and dairy operations play a key role in global food systems and human well-being by providing food, employment, and income to people everywhere [19]. The manure produced at AFOs can provide many benefits through its use as a fertilizer, compost, biofuel, and construction [31]. However, AFOs pose several public health and environmental risks. With a high concentration of livestock, AFOs produce massive amounts of waste, which accumulates on the ground and is eventually stored in pits, lagoons, or liquid/solid storage structures for aforementioned uses [37, 39, 42]. These structures can leak and are vulnerable to climate shocks, such as flooding and heavy precipitation, which lead to overflow and runoff, causing contaminants from the waste to infiltrate the soil, groundwater, and waterways [5, 46].

Manure contains and contributes to odors and pathogens in the soil and water that can cause infections of the skin, eyes, ears, nose, and throat, posing a large public health risk [8, 42, 48]. Fecal coliform bacteria, like *Escherichia coli*, are the most common pathogens found in manure and if found in water, an indicator of contamination from CAFOs [5, 53]. As the fecal coliform density increases, so does the risk of contracting disease [29]. Even more, due to being added in animal feed, heavy metals, particularly copper and zinc, are other contaminants from manure that can enter water and are toxic to aquatic life in high concentrations [4, 27]. Additionally, while nutrients, like nitrogen and phosphorus, from manure can improve crop production and provide other benefits to the environment, these nutrients are pollutants in excessive and concentrated amounts, particularly in rivers, lakes, and other water sources [6, 50]. The nitrogen from animal waste enters water in both inorganic (nitrate, nitrite, ammonium, ammonia) and organic forms. Nitrate and nitrite can lead to a blood disorder in infants called Methemoglobinemia [51]. Moreover, the inorganic forms, ammonia, nitrate, and nitrite, are especially toxic to aquatic life [51]. Excess nitrogen and phosphorus cause algal blooms in water sources through eutrophication, which can dramatically deplete oxygen levels, ultimately killing massive numbers of fish [5, 8, 42, 46, 47].

In 1997, CAFOs contributed to 65% of excess nitrogen and 68% of excess phosphorus [42]. Consequently, as a point source of pollution, CAFOs that discharge into U.S. waters are regulated under the Clean Water Act (CWA), which was determined during a review of the Act by the U.S. Environmental Protection Agency (EPA) in the late 1990s [8, 17, 42]. The Clinton Administration thus set forth a proposal to regulate CAFOs in 2000, which was ultimately issued by the Bush Administration in 2002 [8]. Starting in February 2003, the National Pollutant Discharge Elimination System (NPDES) permit program extended to CAFOs to regulate their pollution discharge into water sources [17]. The 2003 CAFO Rule required CAFOs to apply for an NPDES permit with a nutrient management plan

(NMP), detailing site-specific processes for manure storage and wastewater management and complying with performance expectations set by the EPA for nutrient discharge [12]. Under the NPDES program, CAFOs apply for individual permits for single operations or general permits for groups of operations with similar characteristics, both of which cannot exceed 5 years in duration [30]. With authorization from the EPA, states become the permitting authority and determine which permit its CAFOs will use, which often depends on the number of CAFOs and the kinds of operations [33]. While the permitting can be general for CAFOs, an individual NMP is required for each operation within the general permit [12]. States were required to have up-to-date programs complying with the 2003 CAFO Rule by February 2005 [12].

In 2005, however, the regulation was put on hold due to the court ruling in *Waterkeeper Alliance et al. v. EPA*, 399 F.3d 486. Groups from the CAFO industry along with several environmental organizations petitioned for judicial review when the 2003 CAFO Rule was issued, and their petitions were consolidated, proceeding before the Court of Appeals for the Second Circuit [15]. The CAFO industry petitioners contested the EPA's definition of "point source" pollution and "agricultural storm runoff," while the environmental groups challenged the EPA's effluent guidelines; the Court upheld the EPA's stance on these matters [52]. The Court also affirmed that in alignment with the CWA, a NMP should be required alongside the permit and needs to be reviewed by the permitting agency and made available for public input [52]. Finally, the Court needed clarification from the EPA on the guidelines for best technologies that limit the spread of fecal coliform, performance standards for swine and poultry CAFOs, and "water quality-based effluent limitations" [52]. The 2005 ruling ultimately required the EPA to revise the 2003 CAFO Rule, which would not go into effect until November 2008. During this time, states could voluntarily monitor nutrient discharge from CAFOs, but they were not mandated to do so by the EPA.

The 2008 revision clarifies that any CAFO "that discharges or proposes to discharge must apply for an NPDES permit" and if a CAFO does not discharge, it must disclose this to the permitting authority [13]. A revision made in 2012 states that a permit is only required for CAFOs that actively discharge and is not necessary for CAFOs *proposing* to discharge until they begin discharging [14]. The 2008 final rule also notes that discharge due to agricultural stormwater runoff is exempt from permitting [13]. Regarding the court affirmations associated with NMPs, CAFOs must submit their plans alongside their application for the permit, whether individual or general, emphasizing that the permitting authority is required to review the NMPs and provide ample time for public consultation [13]. The 2008 revision allows for CAFOs to determine its own "best management practice no discharge effluent limitations" [13]. States were required to meet these changes by February 2009 if they were not already complying; despite this requirement, some states acquired NPDES permits after 2009, others did not get their reissuance approved, and a couple of states never implemented the regulation at all. The 2008 CAFO Rule was estimated to cost $326 million and provide estimated economic benefits ranging from $204 to $355 million annually (in 2001 dollars) [8].

This paper examines the effect of the 2008 CAFO Rule on U.S. water quality on a state level using econometric tools and analysis; states with NPDES permits serve as the control group, whereas states without permits any year between 2000-2020 serve as the treatment group, analyzing the impact of a *lack* of government intervention. More specifically, the water quality indicators (WQIs) I use to examine this policy effect include copper, zinc, fecal coliform, inorganic nitrogen, ammonia, nitrate, nitrite, oxygen, and phosphorus concentrations. Section 2 provides a review of the economic theory regarding government intervention to reduce negative externalities, namely water pollution, created by the CAFO industry. For my data in this analysis, as presented in Section 3 of this paper, I use the annual NPDES CAFO program status reports [32] in combination with water quality data from the Water Quality Portal [35], both of which are provided by the EPA. Section 4 presents the difference-in-difference regression models created to analyze this quasi experiment, whereas the results are presented in Section 5. Finally, in Section 6 of this paper, I conclude that the 2008 CAFO Rule does not substantially improve the overall water quality, particularly with regards to nitrogen and phosphorus, the two most concerning contaminants from the CAFO industry.

2 Theory

The CAFO industry undoubtedly creates pollution when manure enters U.S. waterways, leading to environmental and public health hazards. This water pollution is commonly known as a negative externality, which is defined as an unintended, third-party loss in welfare without compensation [9]. An externality is an indicator of market failure, arising because water and its ecosystem services are a public good without market value so its degradation is not financially quantifiable [3, 45]. The “total waste-disposal cost” of water pollution is the sum of the “control cost,” or the cost associated with pollution cleanup using technology, and the “damage cost,” or the cost associated with the environmental degradation [20]. For example, a control cost for CAFOs could be the cost of the more durable storage structures that lessen leakage, whereas a damage cost could be the diminished water quality and resulting decrease in fish populations, which is often difficult to quantify.

Theoretically, the total cost is internalized by either the producers of pollution compensating those incurring the loss or the victims paying the polluter to reduce or halt polluting activities [39]. The Coase theorem states that either way, the negotiation between the polluter and victim will result in an optimal level of pollution and does not require government intervention [7]. This optimum will occur when the marginal control cost equals the marginal damage cost, thus minimizing the total waste-disposal cost; society will spend another dollar on pollution cleanup costs only if the cost of damage to the environment is equal to a dollar [20]. In reality, however, the different costs associated with water pollution are extremely high and difficult to calculate. Excess nutrient discharge from CAFOs in Iowa, for example, can travel down the Mississippi River, not only affecting downstream states, but also ending up in the Gulf of Mexico, contributing to the presence of the “dead zone” [39, 41]. It is incredibly complex and practically impossible to understand who all the victims of water pollution are due to the free flow of water. Thus, the high costs, large number of participants, and information asymmetry associated with water pollution demand government intervention to address the externality [7, 9].

The NPDES permitting is a form of government regulation that attempts to internalize the externality caused by the CAFO industry. Instead of imposing taxes on CAFOs for polluting, the EPA chooses to restrict their nutrient discharge through permitting, known as a quantity regulation [16, 24]. Since states are the permitting authorities, not the EPA, this type of quantity regulation is not rigid and represents a form of self-regulation [38]. Permits are a common regulatory tool, giving landowners freedom over their property and practices while protecting public goods, namely the environment [49]. The self-regulatory nature of NPDES permits reflects the "invisible-hand-spirituality of economic operations" [1]. This less-stringent form of quantity regulation is less costly to discover violations compared to taxing, encouraging greater enforcement and monitoring, particularly when addressing market failure [16, 38]. The permitting process, however, can be practically difficult and complex, especially when local, state, and federal agencies are required to cooperate, like with NPDES permits, leading to tedious review times, high administrative costs, and delayed gains from permitting [10].

Government regulation needs to be prevalent and stringent, especially as the finiteness and scarcity of water are felt on a global scale. As a potentially excludable and rival good, water has become more and more privatized, which raises ethical concerns, because it is also non-substitutable and necessary for survival [9]. The preservation of water's quality and quantity is essential, especially as war and violence are predicted to increase as the scarcity of water becomes more prominent [2]. This paper ultimately contributes to research on the efficacy of U.S. government regulation that attempts to preserve water, looking specifically at NPDES permitting on CAFOs. An effective NPDES permit will achieve a socially optimal level of water pollution. This means the marginal social cost equals the marginal damage cost of CAFO pollution, resting on the assumption that these costs can be accurately predicted and that some level of pollution is acceptable.

3 Data and Variables

This section presents the CAFO and water quality data used to examine the effect of the NPDES CAFO permits on U.S. water quality. The data are examined from 2000 to 2020, providing a large enough period to analyze before and after the implementation of the 2008 CAFO Rule.

3.1 Annual NPDES CAFO Program Status Reports

The EPA releases annual status reports regarding the implementation of the 2008 CAFO Rule, which are made publicly available online at `https://www.epa.gov/npdes/npdes-cafo-regulations-implementation-status-reports` [32]. I use these reports as a data source on NPDES permitting of U.S. CAFOs. The reporting starts in 2011 and ends in 2020. In each report, the total number of CAFOs as well as the number of CAFOs with NPDES permits are disclosed for each U.S. state, tribe, and territory. The earlier reports also include the year in which each state updated their regulations to comply with the 2008 CAFO Rule.

States with fewer than 25 CAFOs are eliminated from the dataset; this limit removes the states with few CAFOs where a CAFO regulation will most likely have little effect on the water quality. The 39 remaining states of interest are highlighted in green in Figure 1 to provide a visual of the sample. Table 1 outlines the years when these states had NPDES permits for their CAFOs; these years are not an indicator of the proportion of CAFOs with NPDES permits, simply whether any NPDES permits are approved in each state, reflecting the implementation of the 2008 CAFO Rule to some degree. These data provide the basis for the independent variable of interest in the difference-in-differences (DiD) regressions called “No permits”; this binary variable equals 1 when a state does not have NPDES permits, reflecting a *lack* of EPA control and regulation. As seen in Table 1, a majority of states have NPDES permits from 2009 to 2020, which means they implement the 2008 CAFO Rule on time and their permit reissuance is approved by the EPA every 5 years. Some states, however, implement CAFO regulation later than others, like Washington; some have NPDES permits in the beginning and then do not receive approval on their reissuance, thus lacking permits in later years, like New York; and others never have any NPDES permits despite having a significant number of CAFOs, like South Carolina and North Dakota. Table 2 presents the states and years in which the "No permits" variable equals 1.

3.2 Water Quality Portal

The National Water Quality Monitoring Council (NWQMC), United States Geological Survey (USGS), and Environmental Protection Agency (EPA) combine efforts to make U.S. water quality data publicly available via the Water Quality Portal (WQP) at `https://www.waterqualitydata.us` [35]. The goal of the NWQMC, EPA, and USGS is to provide information to agencies, utilities, researchers, and the public for resource management purposes. The data are submitted to the WQP by various organizations, like state agencies and universities, and are collected at millions of sites across the country. A site is given a unique monitoring location identifier, which is used as the cluster variable for the regression models presented in Section 4. I use the WQP to retrieve data on the copper, zinc, fecal coliform, inorganic nitrogen, ammonia, nitrate, nitrite, oxygen, and phosphorus concentrations in all 39 states of interest between January 1st, 2000 and December 31st, 2020. The summary statistics for all variables are presented in Table 3, including the units of each WQI. These data are records of measurements at a given monitoring location; some locations have many measurements across several points in time and some can have as few as one measurement. I collapsed the data to monthly averages by monitoring location, generating the variable "obs" which reflects the count of observations within a month for a location. Across outcomes, the number of measurements at a station per month vary from 1 to 69876 with a mean of about 9 measurements per month. I use "obs" as a weight for all regression analysis.

4 Methods

This section presents and explains the reasoning for the regression models used to understand the effect of the NPDES CAFO permits on U.S. water quality. To examine this policy effect, I will use DiD models with WQIs as the dependent variable, state, month, and year fixed effects, and "No permits" as the DiD estimator. The state-time fixed effects control for variation in entities across the seasons and years that occur in conjunction with the CAFO Rule. Table 3 reveals the summary statistics of WQIs used as outcome variables in the regression models presented in this section.

As seen in the distribution of each WQI in Table 4, copper, zinc, fecal coliform, inorganic nitrogen, ammonia, nitrate, nitrite, and phosphorus are highly right-skewed; since the variables are continuous, I thus use log-linked gamma generalized linear models (GLMs) for these indicators. Meanwhile oxygen has a relatively normal distribution, so I instead use a log-linked gaussian GLM for this variable's regression. No matter the model type, each WQI has the same regression model:

$$log(WQI_{imt}) = \beta_0 + \beta_1 state_{mt} + \beta_2 year_{im} + \beta_3 month_{it} + \delta_4 nopermits_{imt} + u_{imt} \tag{1}$$

for states $i = 1, \ldots, 39$, months $m = 1, \ldots, 12$, and years $t = 2000, \ldots, 2020$.

WQI_{imt} refers to one of the water quality outcome variables: copper, zinc, fecal coliform, inorganic nitrogen, ammonia-nitrogen, nitrate, nitrite, and phosphorus. β_1 is the coefficient on the state trend, β_2 on the year trend, and β_3 on the monthly/seasonal trend. δ_4 is the coefficient on the interaction term between the treated group and the treatment period; the "treatment" for this model refers to a *lack* of NPDES permitting on the CAFO industry. For each WQI, the regression is clustered by monitoring location identifier and weighted by "obs" to place greater importance on multiple observations collected from one location. Even more, the regression is run twice for each WQI: once with all observations and another when "obs" is greater than 1. I chose to run the second regression because "obs" = 1 for more than 50% of the data set and while these data are important, they are not as reliable and may not portray as accurate a picture of the water quality as the data that have multiple sample collections at one monitoring location over time.

A significance test on δ_4 for each regression determines whether NPDES permitting had any effect on U.S. water quality. The threshold (α) for statistical significance is a 5% probability of a Type I error occurring.

5 Results

This section analyzes the regression results and marginal effects of the models outlined in Section 4 for each WQI.

5.1 Heavy Metals

I chose to examine the effect of NPDES permitting on the concentrations of copper and zinc, two common heavy metals found in animal waste that can impair water quality. Tables 4 and 5 present the marginal effects of "No permits" on copper and zinc concentrations, respectively. Regression results (C-1) and (C-2) reveal that copper concentrations increase by 6.318 μg/L and 10.429 μg/L, respectively, when there is a lack of EPA control. Similarly, the "No permits" marginal effects from (Z-1) and (Z-2) indicate that zinc concentrations increase by 31.553 μg/L and 46.879 μg/L, respectively, when NPDES permits are not mandated. All results are statistically significant at the 1% level, indicating that the probability of a Type I error is very low.

These results suggest that NPDES permitting on CAFOs is effective in reducing heavy metals in U.S. waters, on average. This effect is larger for zinc concentrations than for copper. Interestingly, the marginal effects from (C-2) and (Z-2) are larger than (C-1) and (Z-1), respectively, which could imply that when there is only one observation per monitoring location, this observation might make the data more "noisy" and diminish the effect of the policy. Either way, the marginal effects of “No permits” for both copper and zinc tell an optimistic story, seeing as these heavy metals can be toxic in high concentrations [27, 4].

The EPA defines a Maximum Contaminant Level (MCL), which is an enforceable limit for each water contaminant to protect human and aquatic health. For copper, the MCL is 1.3 mg/L which is equivalent to 1300 μg/L [18]. This threshold shows that the decrease in copper concentrations due to NPDES permitting, while important, does not carry drastic implications, as seen in the magnitude of the regression results, (C-1) and (C-2). For zinc, however, the EPA limits the concentration to a 24-hour average value of 47 μg/L in freshwater and 58 μg/L in saltwater [36]. As indicated by regression results (Z-1) and (Z-2), the decrease in zinc arising from NPDES permitting on the CAFO industry is relatively large, carrying great economic and environmental significance.

5.2 Fecal Coliform

The density of fecal coliform bacteria serves as another WQI to examine the effect of NPDES permitting on the CAFO industry. Table 6 reveals the regression results, (FC-1) and (FC-2), of the log-linked gamma GLMs with fecal coliform as the outcome variable. The marginal effects of “No permits” imply that the bacterial concentration decreases by 26.128 CFU/100 mL and 23.916 CFU/mL with all observations and with more than one observation per monitoring location, respectively. Both results are statistically significant at the 5% level.

These results suggest that when the EPA is actively regulating CAFOs using NPDES permits, the fecal coliform density increases in U.S. waters, on average. While the effect is not as large when “obs” > 1, both effects indicate an inefficacy in NPDES permitting. The MCL for fecal coliform is undefined, but the Maximum Contaminant Level Goal (MCLG), which is a non-enforceable public health goal set by the EPA, is zero [18]; this goal was set in 1990 because researchers found that even with low levels of fecal coliform, outbreaks occurred [11]. The MCLG shows how any level of the fecal coliform bacteria is harmful to human and aquatic health, meaning the regressions results, (FC-1) and (FC-2), have meaningful and hazardous implications.

5.3 Nitrogen

Excess nitrogen discharged from CAFOs is a concerning environmental issue and one of the main reasons for the 2003 and 2008 CAFO Rules that instilled NPDES permitting [42]. Inorganic nitrogen is the more common form of nitrogen that comes from animal waste and is an important WQI used as a outcome variable[51]; the regression results are presented in Table 7. The marginal effects of "No permits" in regressions (IN-1) and (IN-2) suggest that, on average, the lack of NPDES permitting decreases the inorganic nitrogen concentration by 0.203 mg/L and 0.177 mg/L, respectively, which are statistically significant at the 1% level. These results suggest that inorganic nitrogen concentrations increase when the CAFO industry is regulated by the EPA on nutrient discharge, which is contrary to the desired effect.

The inorganic nitrogen concentration from the WQP data set is a sum of the nitrate and nitrite concentrations. Tables 8 and 9 present the log-linked gamma GLM regression results for outcomes, nitrate and nitrite, respectively. The coefficient on the DiD estimator is negative for regression (Na-1) and positive for (Na-2), which provides conflicting interpretations, but both results are statistically insignificant at the 5% level. In contrast, the regressions, (Ni-1) and (Ni-2), indicate that nitrite concentrations increase on average by .005 mg/L and .008 mg/L, respectively, without NPDES permitting. These results, unlike that for nitrate, are statistically significant at the 1% level. Seeing as the EPA aims to limit nitrate and nitrite concentrations in water to 10 mg/L and 1 mg/L, respectively, these findings are important but indicate the effects are relatively small [51]. The nitrite results suggest that the 2008 CAFO Rule is effective, but they contrast with the inorganic nitrogen results; this difference is most likely due to the fact that nitrate is much more common and prevalent in waters than nitrite, so the nitrate results influence the overall inorganic nitrogen results [51].

Typically, inorganic nitrogen concentrations also include ammonia and ammonium concentrations [51]. Table 10 reveals regression results with ammonia as the outcome variable. The marginal effect of “No permits” is positive for both (A-1) and (A-2), but neither result is statistically significant at the 5% level. Overall, the regression results for inorganic nitrogen and nitrite are the only significant findings and create ambiguity around how NPDES permitting on CAFOs affect nitrogen concentrations. The inefficacy of the 2008 CAFO rule in decreasing excess inorganic nitrogen discharge is meaningful, considering nitrogen from CAFOs is a primary point of concern.

5.4 Phosphorus

Similarly to nitrogen, phosphorus is another target contaminant from animal waste that can lead to disastrous environmental consequences [5]. Phosphorus is thus a WQI used in log-linked gamma GLM regression analysis to examine the effect of the 2008 CAFO Rule. As seen in Table 11, the coefficients on the DiD estimator, “No permits,” in regressions (P-1) and (P-2) indicate that without NPDES permitting, states discharge 0.01 mg/L and 0.004 mg/L less than under the 2008 CAFO Rule. The first result is statistically significant at the 5% level whereas the second is not. This inconsistency could either suggest that the data with only one observation per monitoring location may bias the data toward a significant result or that they provide a larger sample size, creating consistency and painting a more full picture. Either way, both results imply that the 2008 CAFO Rule is ineffective, because phosphorus concentrations have increased on average in the U.S. since its implementation. The threshold for phosphorus determined by the EPA to prevent eutrophication is 0.05 mg/L in streams and 0.10 mg/L in flowing water [26]; if the result from (P-1) is true, then a change in the phosphorus concentration by 0.01 mg/L is relatively large, carrying important economic and environmental significance.

5.5 Oxygen

The eutrophication that occurs from excess nitrogen and phosphorus discharge directly leads to hypoxia, creating dead zones and killing aquatic life [41]. Oxygen levels in waters are thus important to monitor, indicating an indirect effect of the 2008 CAFO Rule. The distribution of oxygen appears normal, so I use a log-linked gaussian GLM to examine the effect of NPDES permitting on oxygen concentrations. As seen in Table 12, regressions (O-1) and (O-2) suggest that oxygen levels are 0.254 mg/L and 0.317 mg/L lower without EPA regulation than with it, which signifies that the 2008 CAFO Rule is effective in combatting hypoxia. These results are statistically significant at the 1% level. The marginal effect of "No permits" also carries economic significance, considering hypoxia is defined when oxygen levels are below 2 mg/l [41]. While the nitrogen and phosphorus regressions results are inconsistent, the oxygen results imply that NPDES permitting achieves some of the desired effects.

6 Conclusion

This paper examines how the implementation of NPDES permitting on CAFOs affects the water quality of 39 U.S. states. I run two regressions for each WQI relevant to CAFOs, one with all observations and another if there is more than one observation within a month for a location. Each regression includes state, month, and year fixed effects. I create a binary variable called "No permits," which serves as the DiD estimator and equals 1 when the NPDES permitting on CAFOs is *not* in effect in each state from 2000 to 2020. The DiD regression results ultimately reveal that this EPA quantity regulation is effective at improving the average copper, zinc, nitrite, and oxygen conditions, but ineffective for reducing fecal coliform, inorganic nitrogen, and phosphorus concentrations; these findings are all statistically significant at the 5% level. The ammonia and nitrate results, however, are statistically insignificant.

There are differences in coefficient magnitudes and significance levels that arise when all observations are included versus when only observations with more than one sample collection per monitoring location (“obs” > 1) are included. By including observations from one sample collection per monitoring location, the sample size becomes 2-3 times larger, which theoretically leads to greater consistency and more accurate results. However, these observations could also paint an unreliable picture of a location’s water quality from one moment in time, which could be abnormal due to weather conditions, for example. I use “obs” as a weight in the regression models to place greater emphasis on monitoring locations with more than one observation. This paper also presents both kinds of regressions for each WQI to present readers with the full information. Whether the correct decision is to include or exclude these observations needs to be further examined.

All in all, the lower average copper, zinc, and nitrite concentrations along with the higher average oxygen levels in waterways resulting from the 2008 CAFO Rule offer an optimistic story. These results imply that the quantity regulation imposed by the EPA is effectively bringing the pollution levels of these WQIs closer to a social optimum, which is best represented by the MCLs and MCLGs that the EPA sets for contaminants. The increase in fecal coliform density, inorganic nitrogen, and phosphorus, however, offer a different story: NPDES permits do not effectively reduce excess nutrient discharge from CAFOs, particularly for the main targets of this policy (nitrogen and phosphorus). While all the regression results offer conflicting analyses, I argue that fecal coliform, inorganic nitrogen, and phosphorus concentrations in water are more directly related to CAFOs than zinc, copper, and oxygen, thus taking precedence and deeming the 2008 CAFO Rule ineffective.

This inefficacy suggests NPDES permitting is not properly designed and enforced. The anthropocentrism entrenched in the U.S. political economy diminishes the importance of environmental preservation, which influences the “socially optimal level of pollution” [1, 20, 44]. The optimum is based on *human* preferences, creating a bias toward larger levels of pollution, especially since CAFOs have enormous economic power and influence [8, 20]. Neoclassical economic analysis of optima regarding environmental issues places emphasis on pollution cleanup, not preventative measures [20]. While CAFO permitting is a quantity regulation that can be seen as pollution prevention, its self-regulatory nature in the U.S. demonstrates a lack in rigidity and government control.

The regulation across states varies in stringency, indicating no universal perception of environmental value. If the entire nation does not function under the same level of regulatory implementation, the externality can never fully be internalized, especially due to the free flow of water [9]. For example, states who may comply with the 2008 CAFO Rule may still experience poor water quality due to upstream states who do not take stringent enough measures. Moreover, self-regulation in NPDES permitting confines policies to the local level, preventing the country from addressing the root causes of water pollution, like CAFOs [38]. Meanwhile, more sustainable and small-scale animal husbandry practices reduce water and air pollution while conserving biodiversity [21, 23]. The inability to correct this market failure arising from the CAFO industry is likely due to a lack of information [9]. As the permitting authority, states are in charge of data collection regarding NPDES permitting for CAFOs [13]; however, these self-reported data are often limited and sometimes missing, which makes enforcement and monitoring of the policy intractable [28]. A federal agency thus needs to be established to collect and analyze CAFO data, looking closely at excess nutrient discharge to ensure adequate and effective results.

Despite the irreversibility of climate change, the finiteness of natural resources, and the essential need for water, society continues to pollute, choosing short-term wealth over long-term health [9]. The welfare risks to people and the environment generated by the CAFO industry clearly do not outweigh the benefit of polluting under the current paradigm. The true socially optimal level of pollution is zero, which means that the marginal damage cost is always greater than the marginal cleanup cost for any positive level of pollution [20]; this optimum can be reflected and achieved through more adaptive, strict, and science-based benchmarks. Pollution thresholds for water quality are complex to set and carry a large amount of uncertainty, because they cannot realistically be set at zero but need to ensure a safe level for aquatic life and human health [25, 40]. Stakeholder engagement is a crucial factor in establishing and meeting benchmarks, which requires the EPA to more actively consult and speak with CAFO operators, especially regarding their NMPs [25]. Even more, as climate change progresses, benchmarks need to be re-evaluated to prevent greater externalities and asymmetrical information. To reach the true social optimum and ultimately improve water quality, I thus believe the EPA should impose a stringent quantity restriction with rigid pollution thresholds and establish a federal agency for greater enforcement measures.

7 References

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8 Tables

Table 1: When States have NPDES permits, 2000-2020

State	Years with NPDES permit
Alabama	2011-2020
Arizona	2009-2020
Arkansas	2009-2010, 2012-2016
California	2008-2020
Colorado	2009-2020
Delaware	2009-2020
Florida	2009-2020
Georgia	2009-2020
Idaho	2008-2012
Illinois	2009-2020
Indiana	2009-2015
Iowa	2009-2020
Kansas	2009-2020
Kentucky	2009-2020
Louisiana	2009-2020
Maryland	2009-2020
Michigan	2009-2020
Minnesota	2009-2020
Mississippi	2009-2020
Missouri	2009-2020
Montana	2009-2020
Nebraska	2009-2020
New Mexico	2009-2020
New York	2010-2018
North Carolina	2009-2020
North Dakota	None
Ohio	2009-2020
Oklahoma	2014-2020
Oregon	2011-2020
Pennsylvania	2009-2020
South Carolina	None
South Dakota	2009-2020
Tennessee	2009-2020
Texas	2009-2020
Utah	2009-2013, 2018-2020
Virginia	2009-2010, 2014-2020
Washington	2011-2020
Wisconsin	2010-2020
Wyoming	2009-2020

Table 2: No permits = 1, By State & Year

State	Years without NPDES permit	Reason
All states	2000-2003	Pre-NPDES Permits
All states	2003-2005	States not required to meet 2003 CAFO Rule until Feb. 2005
All states	2005-2008	Waterkeeper v. EPA trial; 2003 CAFO Rule put on hold
Alabama	2009-2010	
Arkansas	2011, 2017-2020	
Idaho	2013-2020	Under EPA authorization until 2013
Indiana	2016-2020	
New York	2009, 2019-2020	Reissuance not approved
North Dakota	2009-2020	
Oklahoma	2009-2013	Under separate EPA program (special case)
Oregon	2009-2010	
South Carolina	2009-2020	
Utah	2014-2017	
Virginia	2011-2013	
Washington	2009-2010	
Wisconsin	2009	

Table 3: Summary Statistics

Variable	N	SD	Mean	Min	Max	Units
Copper	424,193	58.32094	7.938143	0	2000	μg/L
Zinc	422,644	283.1189	56.65542	0	5000	μg/L
Fecal Coliform	639,085	305.7085	160.7109	0	2000	CFU/100 mL[1]
Inorganic Nitrogen	1,598,207	2.659827	1.346148	0	20	mg/L
Ammonia	584776	2.571572	.4346173	0	100	mg/L
Nitrate	647790	3.443103	2.010545	0	25	mg/L
Nitrite	480,514	.1231012	.04306	0	1.5	mg/L
Oxygen	518,561	3.25892	7.972827	0	25	mg/L
Phosphorus	1,620,927	.2299009	.1404618	0	2	mg/L

[1] CFU/100 mL = (number of colonies counted ÷ sample volume filtered in mL) x 100

Table 4: Copper Regressions - Marginal Effects, 2000-2020

Variables	(C-1) All observations	(C-2) “Obs” > 1
No permits	6.318	10.429
	(1.975)	(3.645)
Year Fixed Effects	Yes	Yes
Seasonal Fixed Effects	Yes	Yes
State Fixed Effects	Yes	Yes
N	424,193	172,428

Cluster-robust standard errors in parentheses

Table 5: Zinc Regressions - Marginal Effects, 2000-2020

Variables	(Z-1) All observations	(Z-2) “Obs” > 1
No permits	31.553	46.879
	(9.690)	(16.026)
Year Fixed Effects	Yes	Yes
Seasonal Fixed Effects	Yes	Yes
State Fixed Effects	Yes	Yes
N	422,644	181,653

Cluster-robust standard errors in parentheses

Table 6: Fecal Coliform Regressions - Marginal Effects, 2000-2020

Variables	(FC-1) All observations	(FC-2) “Obs” > 1
No permits	-26.128	-23.916
	(9.442)	(10.800)
Year Fixed Effects	Yes	Yes
Seasonal Fixed Effects	Yes	Yes
State Fixed Effects	Yes	Yes
N	639,085	282,206

Cluster-robust standard errors in parentheses

Table 7: Inorganic Nitrogen (nitrate & nitrite) Regressions - Marginal Effects, 2000-2020

Variables	(IN-1) All observations	(IN-2) "Obs" > 1
No permits	-0.203	-0.177
	(0.037)	(0.042)
Year Fixed Effects	Yes	Yes
Seasonal Fixed Effects	Yes	Yes
State Fixed Effects	Yes	Yes
N	1,598,207	645,715

Cluster-robust standard errors in parentheses

Table 8: Nitrate Regressions - Marginal Effects, 2000-2020

Variables	(Na-1) All observations	(Na-2) "Obs" > 1
No permits	-0.096	0.014
	(0.065)	(0.084)
Year Fixed Effects	Yes	Yes
Seasonal Fixed Effects	Yes	Yes
State Fixed Effects	Yes	Yes
N	647,790	311,172

Cluster-robust standard errors in parentheses

Table 9: Nitrite Regressions - Marginal Effects, 2000-2020

Variables	(Ni-1) All observations	(Ni-2) "Obs" > 1
No permits	0.005	0.008
	(0.001)	(0.002)
Year Fixed Effects	Yes	Yes
Seasonal Fixed Effects	Yes	Yes
State Fixed Effects	Yes	Yes
N	480,514	223,879

Cluster-robust standard errors in parentheses

Table 10: Ammonia Regressions - Marginal Effects, 2000-2020

Variables	(A-1) All observations	(A-2) “Obs” > 1
No permits	0.012	0.023
	(0.041)	(0.042)
Year Fixed Effects	Yes	Yes
Seasonal Fixed Effects	Yes	Yes
State Fixed Effects	Yes	Yes
N	584,776	227,699

Cluster-robust standard errors in parentheses

Table 11: Phosphorus Regressions - Marginal Effects, 2000-2020

Variables	(P-1) All observations	(P-2) “Obs” > 1
No permits	-0.010	-0.004
	(0.003)	(0.004)
Year Fixed Effects	Yes	Yes
Seasonal Fixed Effects	Yes	Yes
State Fixed Effects	Yes	Yes
N	1,620,927	651,732

Cluster-robust standard errors in parentheses

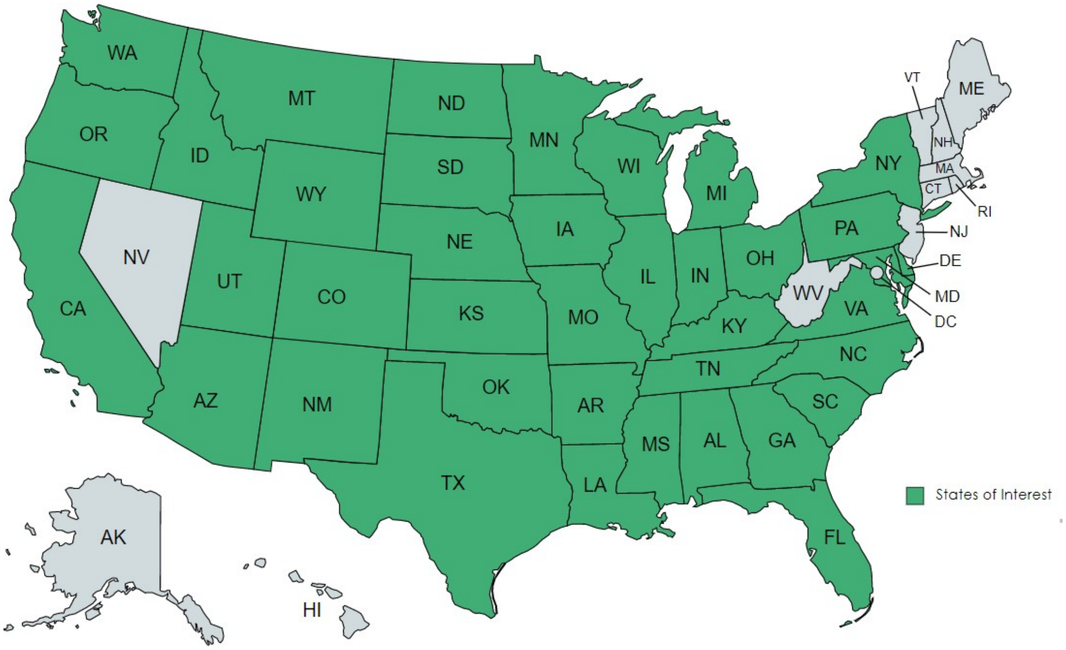
Table 12: Oxygen Regressions - Marginal Effects, 2000-2020

Variables	(O-1) All observations	(O-2) “Obs” > 1
No permits	-0.254	-0.317
	(0.066)	(0.077)
Year Fixed Effects	Yes	Yes
Seasonal Fixed Effects	Yes	Yes
State Fixed Effects	Yes	Yes
N	518,561	275,885

Cluster-robust standard errors in parentheses

9 Figures

Figure 1: U.S. States with more than 25 total CAFOs



Created on MapChart (`https://www.mapchart.net/usa.html`).