Size-Based Regulations and Environmental Quality: Evidence from the U.S. Livestock Industry

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PRELIMINARY AND INCOMPLETE

Abstract

The United States livestock industry has experienced dramatic structural changes over the past three decades. Among the most concerning trend to the public and regulators is the growing prevalence of concentrated animal feeding operations (CAFOs). This paper studies the effects of the 2003 Clean Water Act regulations on water pollution associated with hog CAFOs in Iowa. We compile a novel dataset that includes regulatory records of hog operations and pollution readings from monitoring sites, and links all hog operations to monitoring sites along the same river in Iowa. We find that the regulations have led to a 3 to 6 percentage points decrease in ammonia concentration since 2003, and such effect is stronger during heavy precipitation seasons than lower precipitation seasons.

Keywords: Iowa, Clean Water Act (CWA), concentrated animal feeding operations (CAFOs), size-based regulation, livestock.

JEL codes: C10, Q15, Q53, Q58

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1. Introduction

The United States livestock industry has experienced dramatic structural changes over the past three decades (MacDonald and McBride 2009). Among the most concerning trends to the public and regulators is the growing prevalence of large, confined feeding operations in Midwestern states. These facilities, the largest of which are known as concentrated animal feeding operations (CAFOs), feed a large number of animals in relatively small, enclosed spaces. They are characterized by a high degree of specialization and can feed animals at a lower cost than historical practices. Concentrating feeding, however, also generates concentrated externalities. The operations are often associated with intense local water pollution. In 2003, the U.S. Environmental Protection Agency (EPA) estimated that CAFOs, which accounted for only 5% of the total number of animal feeding operations (AFOs), were responsible for half of more than 500 million tons of manure production (EPA 2003). When manure is applied excessively to local soils for fertilization, it can lead to surface run-off and eventually results in acute water pollution.

The historical response to these concerns was to tighten regulations for feeding operations above a certain size under the Clean Water Act (CWA). In 2003, the EPA updated the CWA regulations so that only CAFOs face more stringent pollution control and permitting requirements. Such size-based regulations, however, could lead to unintended consequences. The regulations incentivize existing and new operations to restrict the size of their operations to avoid monitoring and regulation (Sneeringer and Key 2011). In 2017, the Iowa Department of Natural Resources (DNR) ‘discovered’ 5,000 previously undocumented animal confinements after being directed to monitor smaller facility sizes than its previous threshold. This raises concerns among surrounding communities about the effectiveness of CAFO regulations (Eller 2017; Guess 2018).

This paper seeks to address the above issues by studying the impacts of the 2003 updates to the CWA regulations on local water quality associated with hog CAFOs in Iowa. Iowa is the largest hog producing state in the U.S., producing around one-third of the nation’s hogs (USDA-NASS 2012). We examine the impacts of the regulation on a key measure of surface water quality, ammonia
concentrations. To do so, we compile a comprehensive database on monthly surface ammonia concentration readings at the monitoring station level as well as animal feeding operation regulatory status for more than 10,000 AFOs in Iowa from 2000 to 2016. The longitudinal nature of the data motivates using a difference-in-differences (DiD) research design. We first use the facility and monitor coordinates to identify the locations of monitors along a surface waterbody and link these to the number of regulated AFOs at the respective upstream. We then exploit the variation in the number of regulated operations upstream of a monitor both before and after the 2003 CWA updates to test whether the more stringent water-quality stipulations improve water quality.

Our empirical results show that federal regulations reduced ammonia levels by 3 to 6 percentage points downstream of hog CAFOs after they were updated in 2003. We also observe insignificant effects of the MMP requirements after 2003, which may be due to the avoidance behavior of AFOs around the CAFO threshold as documented by Sneeringer and Key (2011). We also find that, under the new CAFO rules, ammonia concentrations are lower during high precipitation seasons compared to prior to the regulation update.

There is a large and growing literature studying the effects of environmental regulations on the U.S. agricultural sector. Research has studied the CWA regulations on nutrient management practices of CAFOs (Savage and Ribaudo 2013; Yu et al. 2018; Sneeringer et al. 2018) as well as the costs of compliance with such management practices (Fleming et al. 1998, Ribaudo et al. 2003; Wang and Baerenklau 2014). Another strand of the literature studies the regulations on the livestock industry structure. For example, Roe et al (2002) and Isik (2004) find that regulation stringency affects operations’ location choices. Perhaps the mostly closely related work in the literature is Sneeringer and Key (2011), who study the impacts of the same size-based regulations as we do on the U.S. hog industry, and document substantial sorting behavior around the 2003 CAFO threshold.

Little research, nonetheless, has studied the impacts of the CWA regulations on local water quality associated with CAFOs. Agricultural nutrients (e.g., animal manure) are one of the primary
sources of water pollution in the United States; however, most agricultural pollutants are classified under the CWA as “nonpoint” sources and are, therefore, exempted from CWA permitting requirements (Kling 2011). CAFOs are an exception and are classified as point-source polluters. Therefore, CAFOs must obtain permits to discharge into waterways and comply with manure management requirements. Studies in both the economics literature (Sneeringer 2009; 2010) and other disciplines (Burkholder et al. 2007; Zirkle et al. 2016) highlight an association between CAFOs and degraded nearby water and air quality, as well as negative human health impacts. Our research extends this literature to test whether these requirements are effective in improving local water quality.

Our empirical results also improve the understanding of the benefits of size-based regulations. The EPA estimated the costs of the 2003 CAFO regulations to be about $335 million annually, and the estimated benefits ranged from $204 to $355 million (EPA 2003). These numbers yield benefit to cost ratios that are roughly one. However, the analyses conducted by EPA do not consider the adverse incentives created by the CAFO rules, as evidenced by Sneeringer and Key (2011), suggesting both potential overestimation of the benefits as well as underestimation of the costs. Our findings of the effects on water quality can add to the assessment of size-based regulations on CAFOs.

Finally, our empirical evidence from Iowa sheds light on the design of environmental regulations. Iowa is a leading state in livestock sales and inventories, particularly for the hog industry (USDA-NASS 2012). It is also a leader in the number of CAFOs (EPA 2017). Thus, the lessons learned here can be used to guide the design and implementation of these types of regulations in other states.

The paper proceeds as follows. In Section 2, we provide background information on both the federal and state regulations on CAFOs, and the livestock industry in Iowa. Section 3 describes our data construction process and presents summary statistics. Section 4 lays out our empirical settings and then discusses the results. Finally, Section 5 concludes and discusses potential caveats that can be addressed in future research.
2. Background

2003 EPA Size-Based CAFO Rules

An animal feeding operation (AFO) is an agricultural operation that keeps and raises animals in confined spaces. As with Clean Air Act requirements, the EPA delegates enforcement of CWA regulations to state authorities, the Iowa DNR in our study. While states may impose more stringent and additional regulations on AFOs, they must all adhere to minimum reporting and enforcement guidelines outlined by the EPA. As a result, there is substantive variation in implementation and enforcement of CWA rules for CAFOs across states (GAO 2003). Regulatory stringency can sometimes differ even within a state and among different types of operations.

The EPA designates AFOs that keep more than 1,000 animal units (AU) as CAFOs. Animal unit measurements standardize the regulation across different types of feeding operations. For example, one finished steer and 2.5 market hogs both count as one AU. In addition to the 1,000 AU threshold, a state agency may designate an AFO as a CAFO if it is a significant contributor of water pollution. This occurs if the facility is in susceptible areas, and the designation depends on various factors such as the slope and vegetation of the land surrounding an AFO, and the proximity of an AFO to nearby surface waters.

CAFOs are classified as point source polluters under the CWA, and the facilities must participate in the CWA National Pollutant Discharge Elimination System (NPDES) permitting program. The program requires operations to obtain permits to discharge any pollutants into local waterways. Before 2003, reports suggested that manure runoff and pollution discharge problems persisted around CAFOs, partly due to inadequate enforcement (EPA 2003). In April 2003, EPA updated two of the CWA stipulations for CAFOs. First, all CAFOs were required to apply for a NPDES permit, known as the “duty-to-apply”, regardless of the intent to discharge or not. Second, CAFOs were required to design comprehensive nutrient management plans (CNMPs) to ensure proper manure management. For instance, a CAFO would have to acquire more lands on which to spread manure to prevent potentially excessive
application, or have to engage in more contracts to sell manure to local farmers. The EPA revised the CAFO rules again in 2008.¹

_Iowa’s Hog Industry_

Iowa is a national leader in livestock production by many measures. Hog sales in the state exceeded $6.8 billion in 2012, the first largest state for the category (USDA-NASS 2012). Iowa’s strong economics in the hog industry features consolidation and regional concentration in production. Where many of the largest hog-producing states, such as North Carolina and Minnesota, have seen modest increases or even declines in total hog inventories over time, Iowa has seen a steady increase in inventories since 1982. In fact, Iowa hog inventories reached 20 million head in 2012, accounting for around one-third of the total number of hogs produced (USDA-NASS 2012). As Iowa’s hog industry has grown, the size composition of producers has also shifted. In 1982, only 9 percent of hog inventories in Iowa were produced on a farm with more than 2,000 head. Fast forward to 2012, and these statistics show a very different story. More than 40 percent of hog inventories are on farms with more than 2,000 head (USDA-NASS 2012). Not surprisingly, Iowa has been the leading state in the number of hog CAFOs. In fact, Iowa also leads the nation in the total number of CAFOs. As of 2017, Iowa had around 3,500 CAFOs, which were more than the numbers of the second and the third leading states combined² (NPDES CAFO Permitting Status Report 2017).

_Iowa AFO Rules_

While regulatory authority over CAFOs ultimately resides with the EPA, much of the design and enforcement activities of AFOs are delegated to states. In Iowa, the DNR enforces most AFO standards.

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¹ EPA revised the CAFO rules again in 2008 in response to the issue found by both the industries and environmental groups. The duty-to-apply requirements were loosened, such that only CAFOs proposing to discharge and CAFOs that are deemed not able to avoid discharging due to the structure of the facilities have to apply for a NPDES permit. On the other hand, EPA strengthened nutrient management requirements.

² The second and third leading states have been Minnesota and North Carolina from 2011 to 2017.
Iowa DNR categorizes AFOs into two types:③ confinements (roofed facilities) and open feedlots. Nearly all hog AFOs in Iowa are confinements.④ While both types of AFOs face the same 1,000 AU CAFO threshold, the requirements and stringency of CAFO regulations differ across the two types of facilities. One common feature is that Iowa DNR requires land-apply of the manure, prohibiting direct discharge into nearby water bodies. Therefore, management of the manure usually impose constraints on operation of AFOs.

In addition to CAFO requirements, the DNR requires all confinement AFOs with more than 500 AUs to develop a manure management plan (MMP) and submit annual updates. Additionally, a confinement proposing to construct a new facility or to expand an existing facility beyond 1,000 AUs must apply for a construction permit and, in most counties in the state, must fill out a form known as the Master Matrix.⑤ The Master Matrix is a scoring system used to evaluate the siting of confinement AFOs. The form scores proposals based on their proposed location (e.g., distance from water sources), practices (e.g., covered liquid manure storage structures), and size. Producers may commit to different site characteristics and manure management practices to earn points. The more points a proposed project receives, the fewer impacts the operations will be evaluated to have on nearby communities, as well as local water and air quality. A proposed site is approved for construction only if it scores at least 50 percent of the full available score and at least 25 percent for each of three subcategories (water, air, and community impact). With these regulations in effect, Iowa DNR does not require confinements to apply for an NPDES permit, even designated as CAFOs.

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③ There is also a combined operation, where a producer keeps some animals in a confinement and some in an open feedlot facility. Such AFO faces regulations on both operations, and the applicability depends on the size of operations in each facility type.

④ On the other hand, most open feedlots in Iowa keep cattle, only few of them keep hogs.

⑤ Similar to the federal CAFO rules, confinements smaller than 1,000 AU can still be required to apply for a construction permit prior to building/expanding a facility, based on the manure storage structure. Confinements that do not use/propose to use the formed storage structure will need to apply for a construction permit if it is between 500 and 1,000 AU.
DNR regulations for open feedlots follow more closely the federal CAFO rules. Open feedlots face only the 1,000 AU threshold. If designated a CAFO that must obtain an NPDES permit, these operations need to obtain a construction permit prior to initial construction or any expansion. Unlike confinement operations, open feedlots do not need to fill out a Master Matrix. As a CAFO, though, they need to develop nutrient management plans (NMPs), which are equivalent to the federal CNMPs requirement. These measures are deemed as sufficient to ensure that open feedlots appropriately apply nutrients to nearby land.

3. Data

We combine several data sources to create a monitor-level longitudinal surface water quality database from 2000 to 2016 to evaluate the effectiveness of the 2003 CWA update targeting on CAFOs. We first describe the construction of these datasets, and then discuss the data matching procedure.

Animal Feeding Operations (AFOs) Database

Iowa DNR maintains an operation-level database of all AFOs above 500 AUs in the state. We combine two DNR databases: (1) a cross-section of all 11,121 active AFOs that provides operational type and size, geographic coordinates, and the date when the operation was first surveyed; (2) a longitudinal database of all past construction permits and manure/nutrient management plan approval dates. We merge the two datasets to construct a panel database on facility characteristics and monthly regulatory status from January of 2000 through April of 2018.

Ideally, we would observe the initial construction, or entry date. This information, however, is not directly observable. We instead proxy for entry using the permit/management plan approval date. We designate a facility’s entry date as the earliest date that the DNR issued a construction permit. If an AFO was initially 500 to 1,000 AU, we instead use the earliest date when it was issued a manure management plan. Finally, if an AFO was initially smaller than 500 AU and did not require either a construction permit
or a management plan, we assign its entry date as the earliest date the AFO was documented by DNR. There are some limitations to this strategy. First, small AFOs might have started operating before the DNR first collected their data. Second, when we have a record of when an AFO was approved to construct a CAFO facility, we do not observe whether that AFO downsizes later on, as the operators are not obligated to report to the DNR for reducing the size of the operation.

In this study, we define AFOs as operations that keep at least 100 AU, excluding small farms that potentially raise animals for leisure or non-commercial purposes only. The final dataset contains 8,090 hog operations. Figure 1 presents the size distributions of active hog AFOs as of April of 2018. The red vertical lines correspond to the CAFO limit. Immediately apparent is that many producers avoid regulation by limiting their sizes to below the CAFO threshold. In addition, a majority of the producers seem to only choose relatively large sizes once they exceed the regulatory threshold.

[Insert Figure 1: Hog AFOs Size Distribution]

A majority of the permitting records for AFOs of other animal types are not as comprehensive as those for hog AFOs. For instance, entry dates for most large cattle AFOs only come from when they were first documented by DNR in 2008, which were after the major CAFO rules update in 2003, instead of the actual dates they were first permitted. Due to the limited information on regulatory status of these AFOs prior to 2003, we focus only on regulatory impacts on hog AFOs and the associated water quality impacts. The number of regulated and unregulated AFOs of other animal types are instead included as control variables to account for other operations around hog AFOs.

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6 Not all small AFOs of these sizes are unregulated. As discussed in the background section, a small operation can still be designated as a CAFO and fall under federal/state regulation if it is deemed a significant contributor to a nearby water body. For these small AFOs, dates of construction permits and/or management plans approved would be available.
7 See figure 1a in the appendix for the histogram of entry dates for cattle and hog AFOs.
8 Because almost all hog AFOs are confinements, we estimate the similar regression model, but looking at the impacts on confinement AFOs and include open feedlots as control variables. Table 1a in the appendix shows the results for this specification.
Surface Water Quality Database

We obtain surface water quality data from the EPA STOrage and RETrieval (STORET) and the Iowa DNR AQuIA, both of which serve data collected by the DNR. The present research focuses on ammonia concentrations in surface water. Ammonia mostly comes from discharges of animal waste or manure runoff from croplands, which can have direct toxic effects on aquatic life with excessive concentration in the water (EPA 2013).

We observe more than 40,000 daily ammonia concentration measurements from 1,628 distinct monitoring stations in Iowa between 2000 and 2018. We process the data in several ways. Ammonia concentrations come in two forms: ammonia and ammonia as nitrogen. For consistency, we convert all values to ammonia as nitrogen and refer to ammonia as the concentration of nitrogen for the rest of this paper. Many observations are false detections, typically because concentrations are below detectable levels. We replace these values with half the minimum detection limit values in our main specifications. There are also measurements that take zero values despite detection limits, though these constitute less than 0.5% of total observations. We replace these values with 0.00001.

Spatial Database

We use the National Hydrography Dataset (NHD) to construct a network of rivers and streams in Iowa where flow directions are identified. Each water body is composed of river nodes connected by straight lines. This information allows us to observe the upstream and downstream relationship, as well as the distance between two nodes along the same river/stream.

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9 Monitoring station observations are unbalanced, varying from year-to-year. Here we assume monitoring station reporting is uncorrelated with nearby water quality outcomes. We discuss potential issues which can be addressed in future work.

10 Ammonia (NH3) uses the weight of the entire molecular ammonia, while ammonia as nitrogen (NH3-N) uses only the weight of the nitrogen atoms. Weight conversion: NH3 = NH3-N * 1.12589.

11 See Keiser and Shapiro (2019) for discussion of the use of NHD in detail.
We also obtain the Iowa GIS boundary data at 12-digit hydrologic unit code (HUC) level from the United States Geological Survey (USGS). HUC12 is the sixth and finest level in the hierarchy of the hydrologic system; each HUC12 is a unique sub-watershed.

*Crop Production Database*

Local land use, in particular lands involved in crop production, can also contribute to regional ammonia concentration levels in surface water. Animal manure is a common source of crop fertilizer, which is often only applied on local croplands surrounding AFOs due to high transportation cost. Therefore, we would expect the number of AFOs, as well as the size of the operations, to correlate with availability of land in crop production in a region.

We collect county-level annual data on corn and soybean production from the USDA National Agricultural Statistics Service (NASS) from 2000 to 2018. We collect both total areas planted measured in acres as well as total production measured in bushels for each commodity. We use land areas planted with corn and soybean for our main specification.

*Weather Database*

Weather is less likely to correlate with the selection of treatment (i.e., more stringent CWA CAFO rules) from livestock operations as compared to local land use. However, ammonia concentrations in the water body are also affected by weather outcomes such as precipitation and temperature, which differ across regions and over time. Therefore, we also include local precipitation and temperature levels as control variables.

The historic weather data is derived from Parameter-elevation Regressions on Independent Slopes Model (PRISM), available from Oregon State University. We aggregate the data from 2000 to 2016 to monthly observations at HUC12 level to be consistent with the AFO permitting database.

*Data Matching*
Because geographic coordinates are available for both AFO facilities and monitoring stations in the AFO database and the surface water database, we link each AFO and monitoring station to the nearest river node along a water body in Iowa. In doing so, we construct upstream-downstream relationships between AFOs and monitoring stations. We keep only monitoring stations that are within 1 kilometer of a water body, so the samples taken at the stations are good indicators of the water quality outcomes at the linked river nodes. We then calculate the distances between AFOs and all monitoring stations along the same river/stream, and categorize these distances into three groups — within 25, within 50, and within 100 miles, respectively. Finally, for each monitoring station, we count the number of upstream AFO facilities in the three distance categories. Along the way, we also overlay the geographic coordinates of monitoring stations to identify their respective HUC regions and counties in order to merge the data with weather and crop production datasets.

[Insert Figure 2: Water quality monitors and AFO density]

The final database includes 1,010 surface water ammonia monitoring stations, and 8,927 AFOs of different animal types. Figure 2 displays the monitoring station locations in our final dataset as well as the density of matched AFOs. This includes AFOs of not only hog and cattle, but also other animal types (e.g., poultry). Spatial distribution of AFOs features intense regional concentration, where most AFOs are located in the northwest region of Iowa. On the other hand, monitoring stations are distributed equally across the state.

12 To be precise, the distance between an AFO and a monitoring station refers to that between the two river nodes linked to AFOs and monitoring stations, not the actual distance measured between an AFO and a monitoring station.
13 The number of Iowa AFOs far exceeds that of water quality monitoring stations. Whereas we can pair almost all AFOs with monitoring stations downstream, very few of them are effectively paired with a monitoring station upstream. Fewer than 600 AFOs (of any animal types) are paired with monitoring stations upstream and downstream at the same time. In addition, given the unbalanced panel of the water quality database, only 119 paired up-downstream monitoring stations have water quality measurements available in the same period. Therefore, we exclude the monitoring stations upstream of AFO facilities from our final database.
4. **Empirical Analyses**

*Empirical Settings*

Our empirical method uses a difference-in-differences (DID) research design to examine the effects of the 2003 federal CAFO regulations. This method exploits the change in the number of regulated and unregulated facilities upstream of monitoring stations before and after the regulations became more stringent in 2003. This empirical strategy is in the same spirit as Keiser and Shapiro’s (2019) recent analysis of the impact of CWA municipal grants.

We estimate the following equation:

\[
Y_{ym} = \beta_0 + \beta_1 MPM_{ym} + \beta_2 CAFO_{ym} + \beta_3 [Post03] + \\
\beta_4 (MPM_{ym} \times [Post_{03}]) + \beta_5 (CAFO_{ym} \times [Post_{03}]) + \\
X_{ym}^\gamma + \eta_y + \eta_m + \eta_i + \epsilon_{ym}.
\]

(1)

For each monitoring station \(i\), \(Y_{ym}\) is log ammonia concentration in year \(y\) of month \(m\). \(MPM_{ym}\) is the number of upstream hog AFOs that have obtained an MMP. Similarly, \(CAFO_{ym}\) is the number of upstream hog CAFOs.\(^{14}\) \([Post_{03}]\) is a binary indicator for post treatment period that equals one after April 2003. \(\eta_y\) and \(\eta_m\) are year and month fixed effects, and \(\eta_i\) are station fixed effects. \(X_{ym}\) is a set of control variables, including the number of unregulated hog AFOs and other regulated AFOs of different animal types,\(^{15}\) monthly HUC12-level mean temperature and maximum precipitation, and annual planted acreage of corn and soybean. The main parameter of interest is \(\beta_5\), which estimates the policy effects of the more stringent 2003 federal CAFO rules. Although the federal CAFO rules apply only to CAFOs, we also test whether the 500 AU threshold requirements implemented in Iowa for confinements become more stringent over time (\(\beta_4\)).

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\(^{14}\) Note that a hog CAFO refers to one that is required to have a construction permit (along with the Master Matrix) if it is a confinement operation, and a nutrient management plan if it is an open feedlot.

\(^{15}\) As discussed in the data section, we do not attempt to identify regulation impacts on AFOs of other animal types (e.g., cattle) because of limited permitting records.
Our identification strategy assumes that, conditional on time and station fixed effects and the full set of controls, monitoring stations with more or fewer regulated hog AFOs upstream would have had comparable ammonia concentration levels prior to 2003 in the absence of no regulated hog AFOs upstream at all. This further assumes that no other unobserved factors that correlate with the number of regulated AFOs upstream of a monitoring station also correlate with the ammonia concentration levels.

The specification in equation (1) includes all regulated hog AFOs that entered both before and after 2003, when the regulation went into effect. The aforementioned identifying assumption holds only if unobserved factors that influence the regulatory status of both continuing and newly entering AFOs are common. However, Sneeringer and Key (2011) shows that newly entering AFOs are more likely to select into/out of the regulation as they are not constrained by asset specificity as continuing AFOs. Therefore, we also estimate a similar equation, but separate the treatment effect on those continuing AFOs from those on newly entering operations. We estimate the following alternative equation:

\[
Y_{yim} = \beta_0 + \beta_1 MMP_{contiy} + \beta_2 CAFO_{contiy} + \beta_3 I[Post03] + \beta_4 (MMP_{contiy} \times I[Post03]) + \beta_5 (CAFO_{contiy} \times I[Post03]) + \beta_6 MMP_{newiy} + \beta_7 CAFO_{newiy} + X'_{iy} \gamma + \eta_i + \eta_m + \eta_t + \varepsilon_{ym},
\]

where \(MMP_{contiy}\) and \(CAFO_{contiy}\) are the numbers of regulated AFOs upstream that entered prior to 2003; \(MMP_{newiy}\) and \(CAFO_{newiy}\) are the numbers of those entered after 2003. The rest of the controls and fixed effects are identical to that from equation (1). The parameters \(\beta_4\) and \(\beta_5\) now identify the treatment effects on continuing regulated operations. The interpretations for \(\beta_6\) and \(\beta_7\) are similar to those for \(\beta_4\) and \(\beta_5\). \(\beta_7\) would capture the effect on the number of newly entering CAFOs that comply with the regulation. However, as suggested in figure 1, newly entering AFOs tend to enter at the size right below the CAFO threshold if they are incentivized to avoid the regulation. Therefore, \(\beta_6\) will additionally capture the impacts of those AFOs that downsize.

**Heterogeneous effect**
Extreme weather events such as heavy rainfalls could lead to surface runoff where manure is not spread appropriately, or could lead to overflow or equipment failure of the manure storage structure, all of which potentially contribute to more surface water pollution. Therefore, we can examine whether there exists heterogeneous treatment effects between months with different levels of weather outcomes. In particular, we study whether we observe more significant regulatory impacts during months with high precipitation compared to months with normal precipitation after the regulatory update.

We categorize monthly maximum precipitation into 5 quintiles. We refer to the highest quintile as the high precipitation level, and the lower 4 quintiles as normal precipitation level. Figure 3 shows the distribution of monthly maximum precipitation and the respective quintiles.

Empirical Results

Table 1 presents our estimates of the effect of the 2003 CAFO regulations on hog CAFOs. Columns labeled (1), (3), and (5) show results for equation (1), where we pool continuing and newly entering AFOs together; Columns (2), (4), and (6) show results for equation (2), where we separate continuing AFOs from newly entering ones. For each set of the specifications, we include AFOs within 25 miles, 50 miles, and 100 miles upstream, respectively.

For columns (1), (3), and (5), the coefficient for CAFO is interpreted as the average baseline difference of ammonia concentrations at monitoring stations that have one more regulated CAFO at upstream; MMP is interpreted similarly, but as the average baseline difference of ammonia concentration at monitoring stations that have one more AFOs facing MMP requirements at upstream. The coefficient for CAFO × Post03 is interpreted as the average difference between ammonia concentrations at monitoring station level before and after the rule update in 2003, holding the number of regulated CAFOs constant; CAFO × Post03 is interpreted similarly, but controlling for the number of AFOs that face MMP
requirements instead. For columns (2), (4), and (6), the aforementioned coefficients have the same interpretation, except that they only identify the subset of hog AFOs that entered prior to the regulatory update. CAFO\textsubscript{new} is interpreted as the average effects on the ammonia concentration when there is one more CAFO upstream that entered after the regulatory update; MMP\textsubscript{new} is interpreted similarly, but for newly entering operations that face MMP requirements.

We first discuss the results from the specifications where we pool continuing and newly entering AFOs together in our model. Our regression results show that, holding the number of upstream hog CAFOs constant, and controlling on the full set of covariates and fixed effects, the 2003 CAFO update leads to a 3% average decrease in the ammonia concentration level at the monitoring station downstream, when we include AFOs that are within 25 miles of distance upstream. As expected, this effect decreases when we allow AFOs at a further distance upstream to be included in the model, as ammonia can be decomposed into other forms of organic or inorganic nutrients by the time it reaches the downstream monitoring station. On the other hand, we do not observe statistically detectible effects of both old CAFO regulations and MMP requirements on ammonia concentrations prior to the regulatory update. This seems to be consistent with EPA’s statement that CWA regulations were not effective, likely due to lack of enforcement (EPA 2003).

When we move to the discussion of the results from equation (2), where we separate out the regulatory impacts on continuing and newly entering AFOs, we see similar effects of the 2003 CAFO rules update. For all AFOs within 25 miles upstream, we observe around a 3 percentage points average decrease in the ammonia concentration from the updated CAFO regulations on continuing hog CAFOs. We also observe that an additional regulated CAFO that entered after 2003 leads to a 6 percentage points average decrease in ammonia concentration levels.

Note, however, that after the EPA updated the CWA CAFO rules, the MMP requirements on AFOs have not led to improved water quality. In fact, in some specifications the AFOs regulated by the
MMP requirements are associated with statistically significant increased ammonia concentration after 2003. The empirical evidence from Sneeringer and Key (2011) that operations enter at a size right below the CAFO threshold, or downsize from right above to below the threshold to avoid the more stringent 2003 CAFO rule update, provides a possible explanation to such finding. These AFOs operate at sizes not significantly different from those above the threshold who face the new regulations, and therefore can be associated with higher chances of water pollution.

Figure 4 presents the flexible difference-in-differences results where we interact the high and normal precipitation level with CAFO and MMP regulatory impacts after 2003. The regression includes the same set of control variables as well as fixed effects following column (2) in Table 1.

When we consider the CAFO regulations, for both continuing CAFOs and newly entering CAFOs, the regulation effects after 2003 are larger during months with high precipitation levels at more than a 10 percentage points decrease in ammonia concentration compared to months with normal precipitation levels, where the latter are not significant. On the other hand, different levels of precipitation do not lead to heterogeneous effects of the MMP requirements after 2003. These results are consistent with the average treatment effects shown in Table 1. The significant decrease in the ammonia concentration as a result of the 2003 CAFO rule during months with heavy precipitation also suggests that manure runoff or equipment failure occurring during heavy rainfall seasons are the major mechanisms through which animal waste impairs local water quality. It also suggests that the operations are complying with the appropriate requirements to handle manure storage and application.

5. Conclusion

We use novel facility-level data on AFO regulatory status and monitoring-level data on surface ammonia concentrations in Iowa to study the effects of the 2003 federal CAFO regulations on associated water
quality outcomes. Our results suggest that the federal regulations reduced ammonia levels downstream of hog CAFOs after they were updated in 2003. We also observe insignificant effect of the MMP requirements after 2003, likely due to the increase of AFOs at sizes right below the CAFO threshold. We also find heterogeneous impacts of the CAFO regulation update under different precipitation levels, where ammonia concentrations are lower during high precipitation seasons under the new CAFO rules compared to prior to the regulation update.

The results are subject to several caveats. First, the limitation of the data on AFO entry dates can bias our results, particularly for recovering the regulation impacts on continuing CAFOs. The DNR only documents records of facilities increasing in sizes, but not when they downsize in order to avoid more stringent regulations. Ideally, we could model selection using temporal facility size data. However, this information is not available from our AFO database. Another factor that could introduce noise is grandfathering. AFOs constructed or expanded before May 31, 1985 are not required to obtain MMPs if they are under the 1,000 AU threshold. In this research, we assign them into the control group. As Heutel (2011) suggests, grandfathering can have unintended consequences for the effectiveness of regulations. Finally, the construction of our outcome variables of interest is imperfect. Not every monitoring station records ammonia concentrations in every period. If the availability of observations at each monitoring station correlates with the water quality outcomes, our results will be biased.

Future work will extend the methodology and database in several ways. First, we will add phosphorus, which is also a major water pollutant and a nutrient component from animal manure, and other common water quality indicators (e.g., dissolved oxygen) to the analyses to see if we observe consistent regulation effects. We will conduct placebo tests using other pollutants that should not be impacted by the CAFO regulations, such as mercury and arsenic. The results from placebo tests will provide suggestive evidence that the employed research design is credible.

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16 This is based on a discussion with a staff member at Iowa DNR.
Second, we will use farm-level Agricultural Census data from the USDA to assess the importance of facilities size selection. The Census of Agriculture collects farm-level operational data every four years, and includes the sizes of AFO operations. Third, we will extend the research to also study the impacts on ambient air quality as a result of the CWA update. Neighboring communities and farms near CAFOs often complain of local air quality, particularly stench from CAFOs, and some have sought legal recourse against local facilities (Guess 2018). As manure management is a major focus of the update CWA CAFO regulations, we expect the water pollution program to also affect air quality outcomes. Last, we will extend the work of Sneeringer and Key (2011) and estimate the productivity of AFOs to incorporate the cost of regulations to add insight into the cost-benefit analysis of CWA CAFO rules.
Tables and Figures

Figure 1: Hog AFOs Size Distribution

Figure 2: Water quality monitors and AFO density
Figure 3: Monthly Maximum Precipitation Distribution (N = 206040)

Figure 4: Heterogeneous Effect of Regulation on Hog CAFOs
Table 1: Average Effect of Regulation on Hog CAFOs

<table>
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| Observations     | 22652       | 22652       | 22652       | 22652       | 22652       | 22652       |
| Max distance AFOs to station (miles) | 25 | 25 | 50 | 50 | 100 | 100 |
| Stations         | 798         | 798         | 798         | 798         | 798         | 798         |
| HUC12            | 452         | 452         | 452         | 452         | 452         | 452         |
| Year FE, month FE, station FE | Yes | Yes | Yes | Yes | Yes | Yes |
| Crop controls    | Yes         | Yes         | Yes         | Yes         | Yes         | Yes         |
| Weather controls | Yes         | Yes         | Yes         | Yes         | Yes         | Yes         |
| AFOs controls    | Yes         | Yes         | Yes         | Yes         | Yes         | Yes         |

*, **, and *** denote significance at the 10%, 5%, and 1% level. The dependent variable is the station-level log transformed ammonia (as nitrogen) concentrations. All zero values from the dependent variable are replaced with 0.00001 before log transformations. Ammonia measures below detection limit are replaced with half of the detection limit values in all specifications. In columns (1), (3), and (5), MMP and CAFO include both continuing and newly entering regulated AFOs; in columns (2), (4), and (6), MMP and CAFO include only continuing regulated AFOs. Standard errors (in parenthesis) in all regression equations are clustered at HUC12 level.
Reference


Appendix

Figure 1a: Hog (top) and Cattle (bottom) AFO Entry Dates
Table 1a: Average Effect of Regulation on Confinement CAFOs

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Observations: 22652 22652 22652 22652 22652 22652
Max distance AFOs to station (miles): 25 25 50 50 100 100
Stations: 798 798 798 798 798 798
HUC12: 452 452 452 452 452 452
Year FE, month FE, station FE Yes Yes Yes Yes Yes Yes
Crop controls: Yes Yes Yes Yes Yes Yes
Weather controls: Yes Yes Yes Yes Yes Yes
AFOs controls: Yes Yes Yes Yes Yes Yes

*, **, and *** denote significance at the 10%, 5%, and 1% level. The dependent variable is the station-level log transformed ammonia (as nitrogen) concentrations. All zero values from the dependent variable are replaced with 0.00001 before log transformations. Ammonia measures below detection limit are replaced with half of the detection limit values in all specifications. In columns (1), (3), and (5), MMP and CAFO include both continuing and newly entering regulated AFOs; in columns (2), (4), and (6), MMP and CAFO include only continuing regulated AFOs. Standard errors (in parenthesis) in all regression equations are clustered at HUC12 level.