Effects of CAFO Regulations on Livestock Producers' Behaviors

Stacy Sneeringer[1] (ssneeringer@ers.usda.gov)
Economic Research Service, USDA
and
Nigel Key (nkey@ers.usda.gov)
Economic Research Service, USDA

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[1] Corresponding author. The authors are economists with the Economic Research Service, U.S. Department of Agriculture. The views expressed are the authors' and do not necessarily reflect those of the Economic Research Service or the USDA. Correspondence address: 1800 M St. NW, Washington, DC 20036. Phone: 202-694-5504. ssneeringer@ers.usda.gov.

The U.S. Environmental Protection Agency (EPA) judges agriculture to be a major contributor to the impairment of rivers and streams (EPA, 2002), and the U.N. Food and Agriculture Organization has found the industry to be primarily responsible for some coastal "dead zones" – oxygen depleted waters where fish cannot live (FAO, 2006). Run-off from crop and livestock operations carries excess nutrients, including nitrogen and phosphorus, into surface waters, where it encourages algae blooms that can result in dead zones. Such nutrient pollution not only hurts fisheries and the regional economies dependent on them, it also reduces biodiversity and lowers the recreational value of water resources.

Clean Water Act (CWA) legislation enacted in 2003 and updated in 2008 and 2011 was intended to reduce water pollution from manure produced on large livestock operations. Both environmental and industry groups protested the rules, arguing that the regulations are (if implemented) either too lax or too costly. Additionally, environmental groups have stipulated that the regulations are not enforced, while industry argues that EPA regulations are "suffocating U.S. agriculture."[2] Despite these strong reactions, there has been very little empirical research that estimates the actual (versus projected) effects of these regulations on livestock businesses or environmental quality. This lack of research in part stems from the dearth of data linking an operation's regulatory status to its performance, behavior, or characteristics.

One objective for updating the CWA regulations was to address "non-point source" nutrient pollution. While the original CWA required large-scale livestock producers to construct manure storage ponds such that they would not overflow except in rare, major storms, the Act did not govern the amount of manure that could be spread on fields. The updated regulations require certain livestock operators to apply manure and chemical fertilizers at agronomic rates so that nutrients are absorbed by the soil and plants rather than running off or leaching into nearby waterways. Abiding by the regulations requires livestock operations to buy or rent sufficient land for manure disposal on-farm, or

[2] http://westernfarmpress.com/government/epa-regulations-suffocating-us-agriculture

to transport the manure off-farm for application. Operations that are constrained in their access to land for manure application could satisfy the nutrient application regulations by reducing their applications of commercial fertilizer or by altering their crop mix to increase to increase the quantity of nutrients absorbed.

In this paper we test whether livestock operations altered their behavior in response to Concentrated Animal Feeding Operation (CAFO) regulations. We use farm-level 2007 Census of Agriculture data that enables us to characterize CAFO status and examine manure management behaviors. We identify the effect of the regulations by exploiting an idiosyncrasy in the rules that causes farms with similar amount of manure production to have different regulatory statuses. In particular we exploit differences across farm types in the regulatory size threshold. In general, farms above a certain size threshold are required to apply nutrients at agronomic rates. However, the regulatory size thresholds vary by animal type and to a certain extent animal size. This creates situations where different farms produce the same amount of manure, but face different regulatory statuses. The outcomes of interest include manure management indicators such as the percentage of agricultural acreage to which manure and fertilizer are applied, the amount of land rented, the total amount of nutrients that can be absorbed by the crops planted, and the absorption rate per acre. Identifying behavioral responses to the regulations is the first step in justifying claims from either environmental or industry groups.

Our preliminary results suggest that, controlling for the amount of recovered nitrogen in manure (ie., not lost to atmospheric deposition or transport), the CWA regulations induced operators of large livestock operations to apply manure to a greater percentage of their fields and to apply chemical fertilizer to a smaller percentage. The regulations were also associated with a greater assimilative capacity per acre for the crops planted. These findings suggest that livestock operators are indeed responding to the regulations. Future work will explore whether responses to the CWA regulations vary systematically by state or animal type.

Regulation of Livestock Operations Under the CWA

Agricultural run-off arises when nutrients from livestock manure and fertilizer are carried to surface and ground-water via precipitation. Nitrogen and phosphorus, the two main nutrients of concern, can lead to oxygen-depleted waters where fish cannot live. For example, the Gulf of Mexico has a several-thousand-mile-wide "dead zone" attributed to nutrients from the Mississippi River. Such nutrient loading not only hurts fisheries and regional economies dependent on them, it also contributes to algae blooms, discourages biodiversity, and lowers recreational value.

Large-scale livestock operations have been regulated for water pollution at the federal level since the 1972 Clean Water Act (CWA). The CWA declared livestock operations above a certain size to be "point sources" of pollution, and required them to obtain permits and institute certain manure management practices (see Table 1). Enforcement was devolved to the states, which also adopted their own regulations of livestock operations (GAO, 2003). Some states would deem all operations permitted, without inspection of individual operations. Oversight, implementation, and enforcement of the CAFO rules had been found to be severely lacking (if not absent) (NRDC, 1998; GAO, 2003).

The 2003 regulations were largely aimed at correcting the problems with the previous regulation and updating them to pertain to a livestock sector increasingly dominated by large-scale production and increasingly disaggregated from crop agriculture. Thus one of the main thrusts of the 2003 regulations was greater oversight.

A second portion of the new regulations pertained to "non-point source" pollution. While the original CWA required large-scale livestock producers to build manure storage ponds such that they would not overflow except in major storms, it did not govern the amount of manure that operators could spread on fields. However, precipitation can carry the hazardous aspects of manure off of fields and in to surface and ground water. The updated regulations required operators to apply manure at agronomic rates such that soils and plants would absorb the nutrients in manure before running off into nearby waterways.

Throughout the history of the CWA regulations of livestock operations there have been size stipulations. The original CWA mandated that livestock operations with 1,000 “animal units” or more were required to obtain permits. An “animal unit” is a method of normalizing across animal types and corresponds roughly to 2.5 market hogs, 0.7 dairy cows, or 100 chickens. The 2003 updates added that operations above the size threshold also needed to apply manure at agronomic rates, eliciting potential changes in application behaviors.

The 2003 updates of the portion of the CWA dealing with “concentrated animal feeding operations” or CAFOs elicited negative reactions from environmentalists and livestock industry lobbyists. Environmentalists believed that the updates did not go far enough to protect water quality, while industry lobbyists believed it to go too far, potentially hurting business.

Despite these reactions to the regulation, there is very little empirical research that estimates the effects of environmental regulation of livestock operations either on business or the environment. A relatively extensive theoretical literature has modeled the regulation of the industry (for example, Babcock ; Zilberman…; etc.). However, little literature exists identifying ex post manure management behaviors.

This lack of research in part likely stems from the difficulty in identifying the level of regulatory enforcement and the realized costs associated with abiding by regulation. While CWA requirements for large-scale livestock facilities have existed since 1976, oversight and implementation have been found to be severely lacking (if not absent) (NRDC, 1998; GAO, 2003). Further, states can adopt their own regulations, leading to heterogeneity in the level and stringency of regulation (EPA, 2002c). This makes it difficult to compare similar farms in differing regulatory contexts at the same time. Even if different regulatory environments are understood, the prescribed abatement activities in agriculture are often "best management practices" rather than pollution control mechanisms like filters or scrubbers. Because these practices are often similar to what is already being conducted, it is difficult to ascertain the costs associated with regulation.

Based in part on these complexities, the impact of environmental regulation's effects on agriculture is relatively understudied in the empirical literature, with most analyses focusing on the association between regulatory stringency and location. In panel analyses, Sneeringer (2010; 2009) finds that in North Carolina and California regulations are significantly associated the growth and regional variation in hog and dairy production in those states, respectively. Roe, Irwin, and Sharpe (2002) and Isik (2004) find that relative state-level cross-sectional variation in recorded environmental regulatory stringency is strongly correlated with location of hog production facilities and dairies.

Aside from location, the empirical literature has not examined the effect of environmental regulations on livestock production or industry structure. In contrast, research has studied firm output responses to both domestic and international pollution laws in other industries. For example, Becker and Henderson (2000) use time- and county-variation in Clean Air Act (CAA) ozone regulation status to estimate effects on polluting manufacturing industries. They find relatively more growth in smaller-scale, less-regulated firms as well as the prolonging of firm investment decisions until after the specific regulations are certain.

Another feature of the literature on environmental regulation's interactions with industry is the study of abatement costs or costs associated with regulatory compliance. This literature has benefited from data from the Pollution Abatement Control Expenditures Survey which specifically asks about abatement expenditures (e.g., Berman and Bui, 2001). The difference for the livestock industry is that abatement methods are not "add-ons" to normal operation; rather, they are usually practices that are already performed. For example, land application of manure is regularly performed to fertilize crops; CNMP requirements govern how much manure can be applied to which land. Thus it is difficult to discern what costs of this manure application are related to regulation, and which would have been borne regardless of regulation, even if one knows whether or not the operation falls under regulatory purview. While pre-regulation studies have calculated predicted compliance costs (Ribaudo et al., 2003), no research has attempted to estimate these costs based on observed producer behavior.

Research Design and Empirical Strategy

As noted above, livestock operations that confine animals for a certain portion of the year and with a certain number of head are defined to be "large CAFOs." The large CAFOs are subject to permitting and manure management requirements. However, animals of different sizes and types produce different amounts of manure. This leads to the possibility that there are operations producing the same amount of manure but facing different regulatory statuses. We exploit this possibility to compare the manure management behaviors of regulated versus unregulated operations generating the same quantity of manure.

To understand how the rules enable two farms with comparable amounts of manure to face different regulatory statuses, consider this example. A chicken *layer* operation with 25,000 head would *not* be regulated under "large CAFO" rules, but a chicken *broiler* operation with 125,000 head *would*.[3] However, the *unregulated* layer operation produces an estimated 486 tons of manure, while the *regulated* broiler operation produces an estimated 435 tons of manure. As these two chicken operations produce comparable amounts of manure, they may face similar choices in manure management. The difference is that one faces regulation and one does not.

[3] The method estimation is described in the next section.

Our main empirical strategy is therefore to compare the manure management behaviors of regulated and unregulated operations. Let Y_i refer to the manure management strategy for operation i and let R_i be an indicator variable equal to one if the operation is regulated. The most basic estimating equation:

(1) $$Y_i = \alpha + \beta R_i + e_i$$

If regulation is randomly assigned, then β will provide an unbiased estimate of the effect of regulation on Y_i.

What outcome variables might be affected by regulation status? In order to satisfy regulatory requirements, an operation may modify along the extensive or intensive margins, or both. To modify along the extensive margin, the operation may increase the total number of acreage on the operations, possibly by renting more land from others. The regulated operation may also apply manure to more acres and decrease fertilized acreage. Finally, the operation may plant different crops in order to increase the amount of nutrients that are absorbed. To modify along the intensive margin, the regulated operation may increase the percentage of acreage to which manure is applied, reduce the percentage to which fertilizer is applied, and/or increase nitrogen uptake per acre.

There are two main concerns with this estimation strategy. The first involves issues related to a common base of support. Obviously, operations with only certain range of manure/nutrients will fall into the "random" level where some are regulated and some are not. Operations with a great deal of manure/nutrients will definitely be regulated, while those with hardly any will not. We first correct this by only examining the common support (in manure/nutrients) between the regulated and unregulated operations. We consider this issue at further length with matching techniques (described below).

A second major concern is omitted variable bias. If a variable is correlated with both manure management behavior (Y_i) as well as regulation status (R_i) but it is excluded from Eq. (1), then the estimated effect of regulation will be biased. Even within the common support, operations with more manure/nutrients will be regulated while those with less will not. Because the amount of manure/nutrients generated may affect Y_i as well as R_i, we control for it. A second factor that could be correlated with both R_i and Y_i is type of animal at the operation. Operations with different types of animals may handle manure differently. We control for this first by first restricting our sample to just operations that confine livestock, excluding ones that raise animals only on pasture. We also add controls for the dominant type of animal at the farm. Our adjusted specification includes controls for manure/nutrients as well as animal type:

(2) $$Y_i = \alpha_1 + \beta R_i + \phi M_i + \boldsymbol{Type}'_{\boldsymbol{ik}}\boldsymbol{\gamma_k} + e_i$$

Where M_i refers the amount of manure/nutrients and $\boldsymbol{Type}$ denotes a vector of indicator variables of type of animal at the operation, with k indexing the type of animal.

While the estimation strategy in Equation 2 will control for the effect of operations with more manure in common base of support, it will only accurately control for the potential correlation between M_i and R_i if M_i is linearly correlated with R_i. If we knew, for example, that as the amount of manure created increased, the likelihood of regulation increased in a linear fashion, this specification would work. However, it is possible that regulation is not a linear function of manure. One way of approaching this would be to include different functional form of M_i in Equation 2. We do this first by including the natural log of M_i .

To take a more agnostic approach toward the functional form of the relationship between M_i and R_i , we also estimate results using propensity score matching. Instead of estimating Equation 2, we first match observations in the regulated group with observations in the treatment group on the number of confined animal units, the amount of manure produced, or amount of manure nutrients recovered. For simplicity refer to this as the 'match' variable.

In the first step of propensity score matching, we estimate a logistic regression of whether or not an operation is a large CAFO on the match variable:

(3) $$R_{is} = f(M_i)$$

Using this equation, we predict $\hat{R}_{is}$; this is our propensity score. Following standard propensity score procedures, we then sort by the propensity score and match the regulated and unregulated observations by local linear regression on the common support. We bootstrap the standard errors. We test whether the mean difference in M_i between the groups is statistically different at the 5 percent level.

Data

To find operations with similar levels of manure produced but different regulatory statuses, we need measures of both of these pivotal variables. First consider the characterization of regulatory status. The 2003 CAFO Rule included size-based stipulations regarding the number of animals in confinement at the operation for 45 days in a calendar year. We therefore must have knowledge of these two meaningful features (confinement and number of head) in order to characterize which farms fall under regulatory purview. We use individual farm-level data from the 2007 U.S. Census of Agriculture Data to characterize the number of animals (and therefore the implied regulation status) and confinement status. We use involved procedures from the Natural Resource Conservation Service to predict CAFO status. These procedures are developed from Kellogg, Lander, Moffitt, and Gollehon (2000) and Kellogg, Moffitt, and Gollehon (2012); full details of the procedures we use are described in the supplementary material to Sneeringer (2013).

While the number of head in inventory may be a good measure of the number of head at livestock operation types that maintain a constant population over the course of the year, it may not be as useful when considering livestock types that see several cycles over a year. The inventory number captured on the Census of Agriculture may provide the number of head at either the top or the bottom of a cycle. Hence we estimate the average number of animals on a farm in a year using information on the recorded inventory and sales of livestock, as well as assumptions on the number of cycles of production during a year. We further assume that only operations with very little land per animal as well as a lower bound on the amount of recoverable manure (more on that below) confine animals. Having estimated the number of head at the operation as well as which operations confine animals, we are able to specify whether or not the operation would qualify as a large CAFO.

To estimate the amount of manure and nutrients produced and the nutrient assimilative capacity of the crops planted we follow methods outlined in the above texts. To calculate the amount of (wet weight) manure produced at an operation per year, we multiply the number of animal units of a specific type by the amount of manure produced per year by that specific type of animal. Because our outcome variables deal with manure management, we estimate the amount of manure that can be collected from animals for later spreading on fields or storage; following the authors above we refer to this as "recoverable" manure. The amount of recoverable manure is a function of the amount of manure produced and assumed parameters on the percentage of manure that can be recovered. We also estimate the amount of elemental nitrogen and phosphorus that is recovered. This involves multiplying the amount of recovered manure by assumed parameters for the amount of nitrogen per unit of manure and the percentage of nitrogen that can be recovered in the recovered manure. These parameters vary by animal type, operation size, and region. The percentage of nitrogen that can be recovered in the recoverable manure accounts for losses due to atmospheric deposition and transport.

We construct other outcome measures more directly from Census of Agriculture measures. The Census records the number of acres to which manure is applied and the number to which fertilizer is applied, as well as the total crop and pasture acreage at the operation. We estimate the percentage of crop and pasture acreage to which manure or fertilizer is applied. Note that we do not know the type or amount of manure or fertilizer that is applied, or whether the fertilizer and manure have been applied to the same acres. Using the total amount of crop and pasture acreage, we also estimate the nitrogen uptake per acre as well as the percentage of total acreage rented from others.

Because we would like to compare observations with similar manure management techniques, we limit our sample to just operations that the NRCS methods define as “animal feeding operations.” These operations have more than 12 animal units of confined livestock types or at least 40 tons of manure at hauling weight produced by confined livestock.

Table 2 shows the means and standard deviations between the large CAFOs and the other AFOs. We show means for the entire sample, as well as the sample that include just the common support for each of the match variables (total confined animals units, total amount of manure excreted, and total amount of nitrogen recovered). The differences between means between the two groups are always statistically significant, regardless of the sample.   As expected, large CAFOs have more confined animal units, manure, and nitrogen than other AFOs.   Large CAFOs also have more crop and pasture acreage, more acreage on which manure or fertilizer is applied, and more nitrogen uptake capacity.

When the land amount of farms is controlled for, we see that on average large CAFOs apply manure to a larger percentage of their land and fertilizer to a smaller percentage. They also have a higher nitrogen uptake capacity per acre. Large CAFOs also rent a smaller portion of their acreage from others.

Operations can have multiple types of animals. We examine both the dominant animal types and the different animal types on operations (Table 3). We define the dominant animal type to be the type of animal with the greatest number of animal units. Large CAFOs are more like to have as their dominant animal types poultry or hogs, while other AFOs are more likely to have dairy cows, pastured animals, or confined pasture types. These patterns are also true for the types of animals on large CAFOs versus other AFOs, except for fattened cattle and veal. Other AFOs are more likely to have some fattened cattle and veal on them than large CAFOs.

Results

Table 4 provides results for the three regression models using different 'match' variables and different outcomes. The results of 81 regressions are shown. When a match variable is controlled for, the sample is restricted to just the common support of that variable. For example, when total confined animal units is controlled for, the sample includes just the common support in total confined animal units (80,124 observations). The bottom of the table shows the number of observations in each of the common supports.

Model I regresses the outcome variable on large CAFO status with just a control for the match variable. Results from this model show that large CAFO status is generally correlated with more manure and fertilizer applied acreage as well as more acreage overall, even controlling for the number of confined animals units or the measures of manure or nitrogen generated or recovered. Large CAFOs also have higher total nitrogen uptakes and rent more land from others.

Examining the 'intensive margin' outcome variables, we see that large CAFO status is correlated with a higher percentage of land to which manure is applied, and a lower percentage of land to which fertilizer is applied, even after controlling for how much manure is generated. Large CAFOs also appear to plants crops that allow for more nitrogen uptake per acre.

When controlling for the type of animal that is most common at the operation (Model II), results are largely the same. Finally, controlling for the state-level fixed effects (Model III), results are still largely the same. The only consistent difference is that the percentage of acreage to which fertilizer is applied is no longer statistically significantly related to large CAFO status.

Turning to the propensity score matching results, we see some differences from the regression results. For some outcomes, the results are similar across match variables. For manure-applied acreage large CAFOs are still predicted to have more but by a much smaller amount than predicted by

OLS. The total nitrogen uptake and the nitrogen uptake per acre are also predicted to be greater on large CAFOs compared to all other AFOs.

For other outcome variables, the estimates of the average treatment effect differ according to the match variable. When matching on the total amount of manure excreted, large CAFOs are predicted to apply fertilizer to fewer acres, but when matching on the total amount of nitrogen recovered, large CAFOs are predicted to have more. Different signs are also found for other outcome variables.

Preliminary Conclusions

The results are difficult to interpret in total. OLS regressions predict that when compared to operations with similar numbers of animals, manure excreted, or nitrogen recovered, large CAFOs perform certain behaviors consistent with managing their manure in a more agronomic fashion. They apply manure to more acres and a higher percentage of acres, and apply fertilizer to a smaller percentage of acres. The nitrogen uptake per acre is higher, suggesting they plant crops that absorb more applied nitrogen.

The results are less clear when turning to the propensity-score matched outcomes. While certain qualitative results are similar to those found from OLS, the effect magnitudes are smaller. Furthermore, the finding of large CAFOs applying manure to a greater percentage of fields is no longer statistically significant.

Further research will need to examine how matching on more than just one variable yields different results. We also will examine different outcomes, including the nitrogen uptake on crop acreage (not on crop plus pasture acreage combined).

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Table 1: Size Thresholds for Large CAFO

Livestock Type	Number of Head
Cattle (other than mature dairy cows)[a]	At least 1,000
Mature dairy cows	At least 700
Swine (55 pounds or more)	At least 2,500
Swine (less than 55 pounds)	At least 10,000
Horses	At least 500
Sheep or lambs	At least 10,000
Turkeys	At least 55,000
Chickens (liquid manure handling system)	At least 30,000
Laying hens (no liquid manure handling system)	At least 82,000
Chickens other than laying hens (no liquid manure handling system)	At least 125,000
Ducks (liquid manure handling system)	At least 5,000
Ducks (no liquid manure handling system)	At least 30,000

[a]Refers to cattle, dairy heifers, cow/calf pairs, or veal calves.

Source: EPA 2003

Table 2: Summary Statistics of Large CAFOs versus other AFOs

	All Observations	
	Other AFOs	**Large CAFOs**
Total number of confined animal units	468	2,779
	(8,314)	(18,856)
Total manure excreted	5,035	35,506
	(68,260)	(161,944)
Total nitrogen recovered	44,935	192,136
	(881,610)	(1,989,681)
Acreage to which manure is applied	63	224
	(0,128)	(0,471)
Acreage to which fertilizer is applied	270	590
	(0,584)	(1,329)
Total crop and pasture acreage	499	1,090
	(3,403)	(4,127)
Acres of land rented from others	248	439
	(1,673)	(1,425)
Total nitrogen uptake (lbs)	54,450	156,823
	(248,150)	(1,161,411)
Percent of acreage to which manure is applied	0.22	0.30
	(0.30)	(0.36)
Percent of acreage to which fertilizer is applied	0.50	0.48
	(0.44)	(0.45)
Average nitrogen uptake per acre (lbs)	108	145
	(202)	(274)
Percentage of land rented from others	0.47	0.39
	(7.79)	(0.89)

Note: Standard deviations shown in parentheses.

Table 3: Types of Animals at Large CAFOs and Other AFOs		
	Other AFOs	**Large CAFOs**
Percentage of operations with dominant animal type		
Confined pasture types	0.26	0.00
	(0.44)	(0.05)
Pasture	0.11	0.01
	(0.31)	(0.10)
Fattened cattle and veal	0.08	0.11
	(0.28)	(0.32)
Dairy	0.35	0.20
	(0.48)	(0.40)
Hogs	0.09	0.35
	(0.28)	(0.48)
Chicken, ducks, and turkeys	0.12	0.33
	(0.32)	(0.47)
Total	1.00	1.00
Percentage of operations with animal types present		
Confined pasture types	0.37	0.21
	(0.48)	(0.40)
Pasture	0.52	0.40
	(0.50)	(0.49)
Fattened cattle and veal	0.21	0.17
	(0.41)	(0.37)
Dairy	0.38	0.22
	(0.49)	(0.41)
Hogs	0.15	0.38
	(0.36)	(0.49)
Chicken, ducks, and turkeys	0.19	0.36
	(0.40)	(0.48)

Note: Standard deviations shown in parentheses.

Table 4: Regression Results – Model I

	Outcome variable								
	Manure applied acres	**Fertilizer applied acres**	**Total crop and pasture acreage**	**Total land rented from others**	**Land rented/ Total crop and pasture acreage**	**Total nitrogen uptake**	**Percentage of land to which manure is applied**	**Percentage of land to which fertilizer applied**	**Nitrogen uptake per acre**
Large CAFO = yes	123.5***	222.8***	414.5***	104.6***	-0.146***	82,116***	0.0306***	-0.0674***	29.05***
	(4.604)	(13.21)	(44.04)	(16.34)	(0.0414)	(11,262)	(0.00374)	(0.00476)	(2.818)
Total confined animal units	0.000240*	-0.000842***	-0.000557	-0.00150***	-2.34e-06***	0.0924	-5.64e-08	-1.42e-06***	-0.000241***
	(0.000143)	(0.000251)	(0.000555)	(0.000243)	(4.60e-07)	(0.148)	(1.48e-07)	(2.45e-07)	(5.95e-05)
Large CAFO = yes	134.9***	258.4***	450.9***	133.0***	-0.108***	89,618***	0.0400***	-0.0547***	32.80***
	(4.419)	(12.89)	(42.40)	(15.60)	(0.0311)	(11,032)	(0.00370)	(0.00472)	(2.807)
Total manure excreted	0.000142***	0.000114*	0.000445***	-5.22e-07	-2.23e-07***	0.0708***	2.02e-08	-1.31e-07***	-1.01e-05
	(3.39e-05)	(6.70e-05)	(0.000129)	(4.96e-05)	(4.29e-08)	(0.0254)	(1.86e-08)	(2.53e-08)	(7.02e-06)
Large CAFO = yes	155.8***	319.1***	589.8***	196.7***	-0.0779***	101,327***	0.0870***	-0.0157***	38.03***
	(4.519)	(13.31)	(42.84)	(15.25)	(0.0228)	(11,993)	(0.00373)	(0.00474)	(2.890)
Total nitrogen recovered	1.59e-06	-1.02e-05***	-1.31e-05***	-1.24e-05***	-1.78e-08***	-0.00101	4.62e-09***	-1.20e-08***	-2.80e-06***
	(1.15e-06)	(1.74e-06)	(3.47e-06)	(1.67e-06)	(3.03e-09)	(0.000800)	(1.75e-09)	(2.22e-09)	(5.91e-07)

(continued)

Table 4: Regression Results (continued) – Model II

	Outcome variable								
	Manure applied acres	**Fertilizer applied acres**	**Total crop and pasture acreage**	**Total land rented from others**	**Land rented/ Total crop and pasture acreage**	**Total nitrogen uptake**	**Percentag e of land to which manure is applied**	**Percentage of land to which fertilizer applied**	**Nitrogen uptake per acre**
Large CAFO = yes	143.1***	268.0***	610.0***	170.6***	-0.0139	88,205***	0.0340***	-0.0400***	31.42***
	(4.993)	(13.63)	(46.92)	(15.81)	(0.0104)	(9,931)	(0.00390)	(0.00481)	(2.868)
Total confined animal units	0.000720***	0.00137***	0.00349***	0.000440**	-2.20e-07	0.519***	-1.17e-07	4.15e-07**	6.05e-05
	(0.000182)	(0.000347)	(0.000797)	(0.000214)	(1.96e-07)	(0.186)	(1.48e-07)	(2.10e-07)	(6.29e-05)
Controls for dominant animal type?	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Large CAFO = yes	148.3***	281.4***	625.9***	182.4***	-0.00580	89,695***	0.0382***	-0.0321***	32.40***
	(4.871)	(13.38)	(46.76)	(15.68)	(0.0103)	(9,611)	(0.00391)	(0.00482)	(2.902)
Total manure excreted	0.000175***	0.000333***	0.000857***	0.000202***	-1.02e-08	0.114***	-8.73e-09	4.74e-08*	1.97e-05**
	(3.69e-05)	(8.11e-05)	(0.000168)	(6.34e-05)	(2.62e-08)	(0.0303)	(1.76e-08)	(2.47e-08)	(8.42e-06)
Controls for dominant animal type?	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Large CAFO = yes	158.9***	327.6***	700.5***	227.5***	0.00518	98,771***	0.0584***	-0.0154***	36.88***
	(4.821)	(13.71)	(48.02)	(16.12)	(0.0107)	(11,188)	(0.00388)	(0.00479)	(2.939)
Total nitrogen recovered	4.80e-06***	1.07e-05***	2.26e-05***	5.56e-06***	2.88e-09	0.00279***	4.27e-10	7.96e-09***	4.29e-07
	(1.41e-06)	(2.56e-06)	(5.35e-06)	(1.73e-06)	(2.02e-09)	(0.00106)	(1.47e-09)	(2.31e-09)	(5.83e-07)
Controls for dominant animal type?	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes

(continued)

Table 4 (continued) – Model III

	Outcome variable								
	Manure applied acres	Fertilizer applied acres	Total crop and pasture acreage	Total land rented from others	Land rented/ Total crop and pasture acreage	Total nitrogen uptake	Percentage of land to which manure is applied	Percentage of land to which fertilizer applied	Nitrogen uptake per acre
Large CAFO = yes	155.9***	279.4***	444.1***	116.2***	-0.0500	78,442***	0.0537***	-0.00850	17.82**
	(25.25)	(46.25)	(85.06)	(39.89)	(0.0303)	(12,694)	(0.00586)	(0.0141)	(8.474)
Total confined animal units	0.000734***	0.00116**	0.00209**	-0.000256	-5.89e-07	0.536*	-7.28e-08	4.09e-07	4.59e-05
	(0.000264)	(0.000512)	(0.000916)	(0.000342)	(5.59e-07)	(0.279)	(1.87e-07)	(2.74e-07)	(7.70e-05)
Controls for dominant animal type?	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Controls for state?	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Large CAFO = yes	156.8***	284.2***	452.8***	123.0***	-0.0457	77,888***	0.0568***	-0.00255	18.04**
	(25.49)	(47.16)	(86.02)	(38.67)	(0.0304)	(11,869)	(0.00600)	(0.0144)	(8.790)
Total manure excreted	0.000182***	0.000306**	0.000577***	7.78e-05	-7.06e-08	0.112**	1.10e-08	6.89e-08*	1.52e-05
	(5.87e-05)	(0.000118)	(0.000189)	(5.42e-05)	(6.55e-08)	(0.0444)	(2.42e-08)	(3.65e-08)	(1.08e-05)
Controls for dominant animal type?	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Controls for state?	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Large CAFO = yes	164.6***	326.2***	624.1***	199.5***	-0.0216	89,513***	0.0743***	0.00335	25.38**
	(26.26)	(52.60)	(114.8)	(39.14)	(0.0268)	(13,774)	(0.00681)	(0.0153)	(10.79)
Total nitrogen recovered	4.52e-06**	8.96e-06**	2.02e-05***	3.85e-06*	6.65e-10	0.00310*	-0	5.89e-09**	5.14e-07
	(1.85e-06)	(3.49e-06)	(7.21e-06)	(2.05e-06)	(2.61e-09)	(0.00175)	(1.71e-09)	(2.63e-09)	(8.38e-07)
Controls for dominant animal type?	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Controls for state?	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Observations in common support of…									
Total confined animal units	80,124	80,124	80,124	80,124	80,124	80,124	80,124	80,124	80,124
Total manure excreted	104,613	104,613	104,613	104,613	104,613	104,613	104,613	104,613	104,613
Total nitrogen recovered	148,254	148,254	148,254	148,254	148,254	148,254	148,254	148,254	148,254

Note: Results of 81 regressions shown. Model I includes controls only for large CAFO status and the match variable. Model II adds controls for the dominant animal type at the operation. Model III includes fixed effects for states. In all regressions standard errors are clustered at the level of the state. When a match variable (like total confined animal units) is controlled for, the sample only includes observations in the common support of that match variable.

Table 5: Propensity Score Matching Results

	Outcome variable								
	Manure applied acres	**Fertilizer applied acres**	**Total crop and pasture acreage**	**Total land rented from others**	**Land rented/ Total crop and pasture acreage**	**Total nitrogen uptake**	**Percentage of land to which manure is applied**	**Percentage of land to which fertilizer applied**	**Nitrogen uptake per acre**
Match variable: Total confined animal units									
Large CAFO = yes	36.975***	-10.102	60.809	-74.898***	-0.081***	31823***	0.006	-0.101***	7.899***
	(5.74)	(17.86)	(47.71)	(19.48)	(0.020)	(11774.90)	(0.005)	(0.01)	(3.25)
Match variable: Total manure excreted									
Large CAFO = yes	26.089***	-35.002***	-395.583***	-244.145***	-0.108***	33344***	-0.006	-0.113***	12.039***
	(4.33)	(16.56)	(116.11)	(56.60)	(0.02)	(11354.92)	(0.00)	(0.01)	(3.23)
Match Variable: Total nitrogen recovered									
Large CAFO = yes	92.249***	293.401***	568.106***	191.937***	0.0505***	89146***	-0.0055	0.065**	44.747***
	(4.81)	(14.24)	(60.60)	(16.86)	(0.01)	(8625.25)	(0.004)	(0.004)	(4.36)

Appendix Table 1: Summary Statistics of Large CAFOs versus other AFOs, Common Supports of Match Variables

	Common support in…					
	Total confined animal units		Total manure excreted		Total nitrogen recovered	
	Other AFOs	Large CAFOs	Other AFOs	Large CAFOs	Other AFOs	Large CAFOs
Total number of confined animal units	862	2,779	652	2,683	449	2,817
	(7,191)	(18,856)	(6,197)	(16,089)	(5,121)	(19,377)
Total manure excreted	9,047	35,506	7,034	34,724	4,837	34,783
	(58,960)	(161,944)	(50,838)	(140,234)	(42,055)	(165,776)
Total nitrogen recovered	83,640	192,136	62,862	181,750	43,357	203,131
	(763,024)	(1,989,681)	(657,366)	(1,680,848)	(543,101)	(2,045,278)
Acreage to which manure is applied	100	224	85	224	62	218
	(0,161)	(0,471)	(0,147)	(0,471)	(0,127)	(0,448)
Acreage to which fertilizer is applied	369	590	328	590	272	590
	(0,675)	(1,329)	(0,653)	(1,329)	(0,587)	(1,309)
Total crop and pasture acreage	677	1,090	627	1,091	493	1,081
	(4,703)	(4,127)	(4,148)	(4,128)	(2,116)	(4,206)
Acres of land rented from others	337	439	306	439	250	444
	(2,298)	(1,425)	(2,026)	(1,425)	(1,689)	(1,444)
Total nitrogen uptake (lbs)	74,551	156,823	65,257	156,896	54,963	156,127
	(306,557)	(1,161,411)	(279,005)	(1,161,686)	(250,667)	(1,190,895)
Percent of acreage to which manure is applied	0.27	0.30	0.26	0.30	0.22	0.30
	(0.32)	(0.36)	(0.31)	(0.36)	(0.30)	(0.36)
Percent of acreage to which fertilizer is applied	0.55	0.48	0.54	0.48	0.51	0.49
	(0.43)	(0.45)	(0.43)	(0.45)	(0.44)	(0.45)
Average nitrogen uptake per acre (lbs)	116	145	112	145	108	146
	(209)	(274)	(210)	(274)	(204)	(281)
Percentage of land rented from others	0.54	0.39	0.50	0.39	0.47	0.39
	(10.84)	(0.89)	(9.38)	(0.89)	(7.87)	(0.90)

Note: Standard deviations shown in parentheses.

Appendix Table 2: Types of Animals at Large CAFOs and Other AFOs, Common Supports of Match Variables

	Common support in…					
	Total confined animal units		Total manure excreted		Total nitrogen recovered	
	Other AFOs	Large CAFOs	Other AFOs	Large CAFOs	Other AFOs	Large CAFOs
Percentage of operations with dominant animal type						
Confined pasture types	0.11	0.00	0.13	0.00	0.27	0.00
	(0.32)	(0.05)	(0.33)	(0.05)	(0.44)	(0.05)
Pasture	0.06	0.01	0.10	0.01	0.11	0.01
	(0.24)	(0.10)	(0.30)	(0.10)	(0.31)	(0.10)
Fattened cattle and veal	0.10	0.11	0.07	0.11	0.08	0.12
	(0.30)	(0.32)	(0.26)	(0.32)	(0.28)	(0.32)
Dairy	0.43	0.20	0.47	0.20	0.34	0.17
	(0.49)	(0.40)	(0.50)	(0.40)	(0.47)	(0.38)
Hogs	0.11	0.35	0.08	0.35	0.09	0.37
	(0.32)	(0.48)	(0.28)	(0.48)	(0.29)	(0.48)
Chicken, ducks, and turkeys	0.19	0.33	0.14	0.33	0.11	0.33
	(0.39)	(0.47)	(0.35)	(0.47)	(0.31)	(0.47)
Percentage of operations with animal types present						
Confined pasture types	0.27	0.21	0.26	0.21	0.38	0.22
	(0.44)	(0.40)	(0.44)	(0.41)	(0.49)	(0.41)
Pasture	0.56	0.40	0.62	0.40	0.51	0.38
	(0.50)	(0.49)	(0.49)	(0.49)	(0.50)	(0.48)
Fattened cattle and veal	0.23	0.17	0.22	0.17	0.22	0.18
	(0.42)	(0.37)	(0.41)	(0.37)	(0.41)	(0.38)
Dairy	0.45	0.22	0.50	0.22	0.38	0.19
	(0.50)	(0.41)	(0.50)	(0.41)	(0.48)	(0.39)
Hogs	0.17	0.38	0.14	0.38	0.15	0.40
	(0.37)	(0.49)	(0.35)	(0.49)	(0.36)	(0.49)
Chicken, ducks, and turkeys	0.24	0.36	0.21	0.36	0.19	0.36
	(0.43)	(0.48)	(0.41)	(0.48)	(0.39)	(0.48)

Note: Standard deviations shown in parentheses.