Effects of Increased Environmental Regulation of Manure Management at Livestock Operations:

A Differences-in-Differences Approach

Stacy Sneeringer
Economic Research Service
ssneeringer@ers.usda.gov

Nigel Key
Economic Research Service
nkey@ers.usda.gov

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Background

The U.S. Environmental Protection Agency (EPA) judges agriculture to be one of the most significant contributors to impairments of rivers, streams, and lakes (EPA, 2002). Nitrogen and phosphorus are applied to agricultural land in the form of commercial fertilizer and manure, but can be carried to local waterways via precipitation if the amount applied exceeds the land's absorptive capacity. An overabundance of nutrients can hurt fisheries and regional economies dependent on them, and can also generate algae blooms, discourage biodiversity, and lower recreational value.

Despite these concerns, agriculture has been largely unregulated with respect to water quality. The exception to this has been Clean Water Act (CWA) legislation enacted in 2003 and updated in 2008 and 2011, which was intended to reduce water pollution arising from manure at large-scale livestock operations. The updated regulations require large-scale livestock operators (but no other agricultural operations) to apply nutrients at agronomic rates such that soils and plants absorb them before the nutrients enter nearby waterways. A regulatory challenge arises when limits are placed on nutrient application rates because it is difficult or impossible for regulators to monitor compliance.

The goal of this research is to shed light on the efficacy of the CWA legislation by examining whether the manure management practices of regulated operations differ from similar non-regulated operations. We use a differences-in-differences approach to non-parametrically control for features of individual farms, state-level regulatory regimes, and national trends.

Method 1: Differences-in-Differences

Let $Y_{T,1}$, $Y_{T,2}$, and $Y_{T,3}$ be outcomes related to manure management practices for large (regulated) CAFOs in 1997, 2002, and 2007, respectively. The percentage change in large CAFOs' outcomes in the pre-regulatory period (1997-2002) is

$$D_{T,Pre} = \frac{(Y_{T,2} - Y_{T,1})}{(Y_{T,2} + Y_{T,1})/2}.$$

In the post-regulatory period (2002-2007), this percentage change is

$$D_{T,Post} = \frac{(Y_{T,3} - Y_{T,2})}{(Y_{T,3} + Y_{T,2})/2}.$$

The difference between the two periods (1997-2002 and 2002-2007), $D_{T,Post} - D_{T,Pre}$, provides us with the first difference in trends. It accounts for the fact that operations have a 'baseline' change in their outcomes in the pre-regulatory period, and then the regulation causes a change in this trend.

A potential problem with this estimator is that a number of things could have changed in the post-regulatory period (2002-2007), and so we cannot isolate the effect of the regulation. To address this we can look at a similar difference for non-regulated operations (those operations that confine animals but are not considered 'large CAFOs'). The difference between the two periods for these operations is $D_{C,Post} - D_{C,Pre}$.

The difference in the differences provides the estimated trend attributable to the regulation:

$$\left(D_{T,Post} - D_{T,Pre}\right) - \left(D_{C,Post} - D_{C,Pre}\right).$$

In a regression framework, we estimate the following difference-in-differences equation:

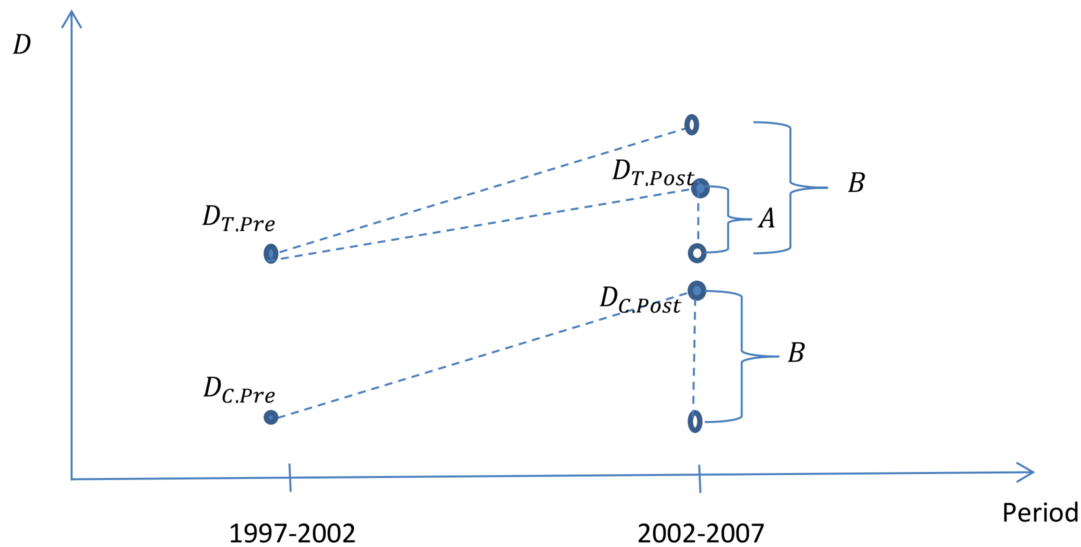
$$D_{i,p} = \alpha + \beta_1\left(Large\ CAFO_i \times Post_p\right) + \beta_2(Large\ CAFO_i) + \beta_3(Post_p) + \lambda_i + e_{i,p}$$

Where i indexes the individual operation and p indexes period. $Large\ CAFO$ and $Post$ are indicator variables for large CAFO status and whether or not period is after the regulation. λ_i is a set of operation-level fixed effects (a vector of dummy variables, one for each operation).

The coefficient of interest is β_1, which shows the effect of being a large CAFO in the post-regulatory period, controlling for fixed features of individual operations, factors affecting all livestock farms in a period, and pre-regulatory trends.

A primary identifying assumption in differences-in-differences estimation is that trends for the treatment and control groups are the same; this method of examining percent changes allows us to avoid this assumption and directly account for potential differences in trends.

Figure 1. Illustration of Differences-in-Differences Strategy



- $A = D_{T,Post} - D_{T,Pre}$
  - A is the change in the trend in the post period for “treated” observations (large CAFOs).
- $B = D_{C,Post} - D_{C,Pre}$
  - B is the change in the trend in the post period for “control” observations (other confined livestock operations that are not large CAFOs).
- The difference in differences estimate is $A - B$.

Data

The 2003 CWA rules apply only to concentrated livestock operations, as determined by the species and number of animals in confinement at the operation. We use individual farm-level data from the 1997, 2002, and 2007 U.S. Censuses of Agriculture and involved procedures from the Natural Resource Conservation Service to predict the regulatory status of an operation as well as to estimate the amount of manure and nutrients produced and the nutrient assimilative capacity of the crops planted (see Kellogg, Lander, Moffitt, and Gollehon, 2000; Kellogg, Moffitt, and Gollehon, 2012).

We restrict the sample to operations that stay within a regulatory class (either large CAFOs or not large CAFOs) for the entire period 1997 to 2007.

How do large CAFOs compare to other animal feeding operations?

Table 1: Mean Differences in Outcomes, 1997-2002 and 2002-2007, by CAFO Status

	Non-CAFOs			**CAFOs**			
% change in	**Percent change: 1997-2002**	**Percent change: 2002-2007**	**Difference in percent changes (2002-2007) - (1997-2002)**	**Percent change: 1997-2002**	**Percent change: 2002-2007**	**Difference in percent changes (2002-2007) - (1997-2002)**	**Difference in Differences: CAFOs - Non-Cafos**
Total nitrogen recovered	0.230	0.016	-0.216	0.678	0.150	-0.553	-0.337***
	(0.562)	(0.474)	(0.820)	(0.806)	(0.412)	(0.970)	(0.025)
Total phosphorus recovered	0.210	0.011	-0.200	0.611	0.149	-0.486	-0.286***
	(0.547)	(0.486)	(0.822)	(0.743)	(0.415)	(0.916)	(0.024)
Total nitrogen uptake	0.115	-0.012	-0.132	0.269	0.094	-0.189	-0.057*
	(0.665)	(0.669)	(1.086)	(0.731)	(0.683)	(1.132)	(0.031)
Total phosphorus uptake	-0.025	-0.021	0.003	0.159	0.099	-0.067	-0.069***
	(0.648)	(0.643)	(1.048)	(0.713)	(0.674)	(1.109)	(0.030)
Excess nitrogen	0.019	0.005	-0.015	0.175	0.060	-0.120	-0.105***
	(0.258)	(0.242)	(0.376)	(0.554)	(0.341)	(0.678)	(0.018)
Excess phosphorus	0.048	0.017	-0.041	0.274	0.063	-0.222	-0.180***
	(0.371)	(0.415)	(0.545)	(0.630)	(0.465)	(0.784)	(0.022)

How to read these numbers: A value of "0.230" means that total nitrogen recovered increased by 23.0% between 1997 and 2002.
***, **, and * refer to significance at the 1%, 5%, and 10% levels, respectively.

- On average, confined livestock operations had a smaller upward trend in nutrient production between 2002 and 2007 than between 1997 and 2002.
- This change in trend was larger for large CAFOs versus non-large-CAFOs.

Fig. 2: Percentage change in total nitrogen recovered, 1997-2002 and 2002-2007, by large CAFO status

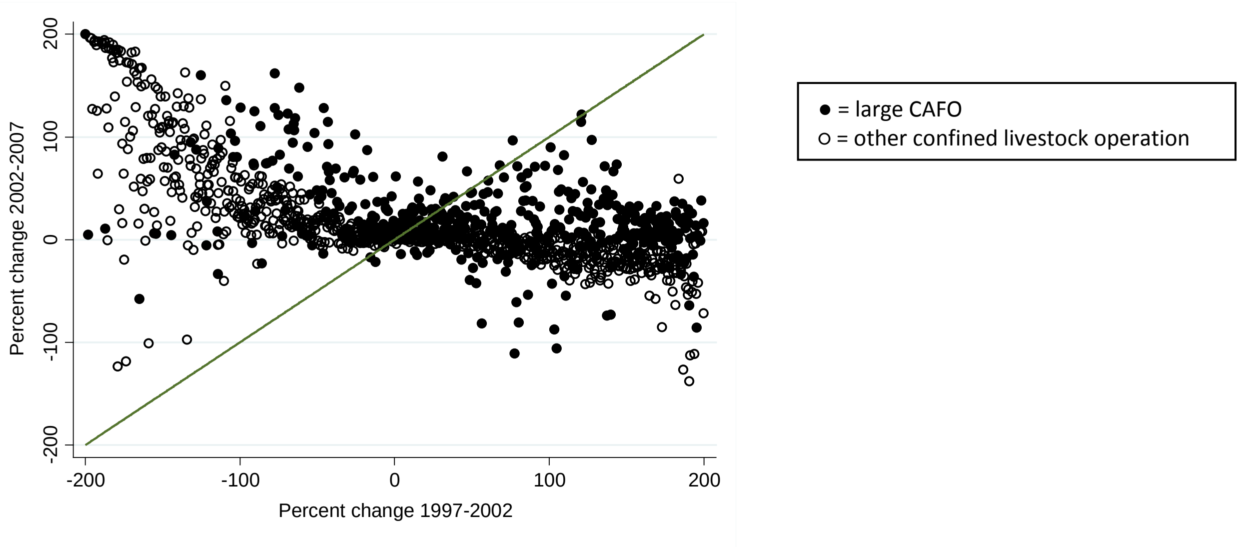


Fig. 3: Percentage change in nitrogen uptake, 1997-2002 and 2002-2007, by large CAFO status

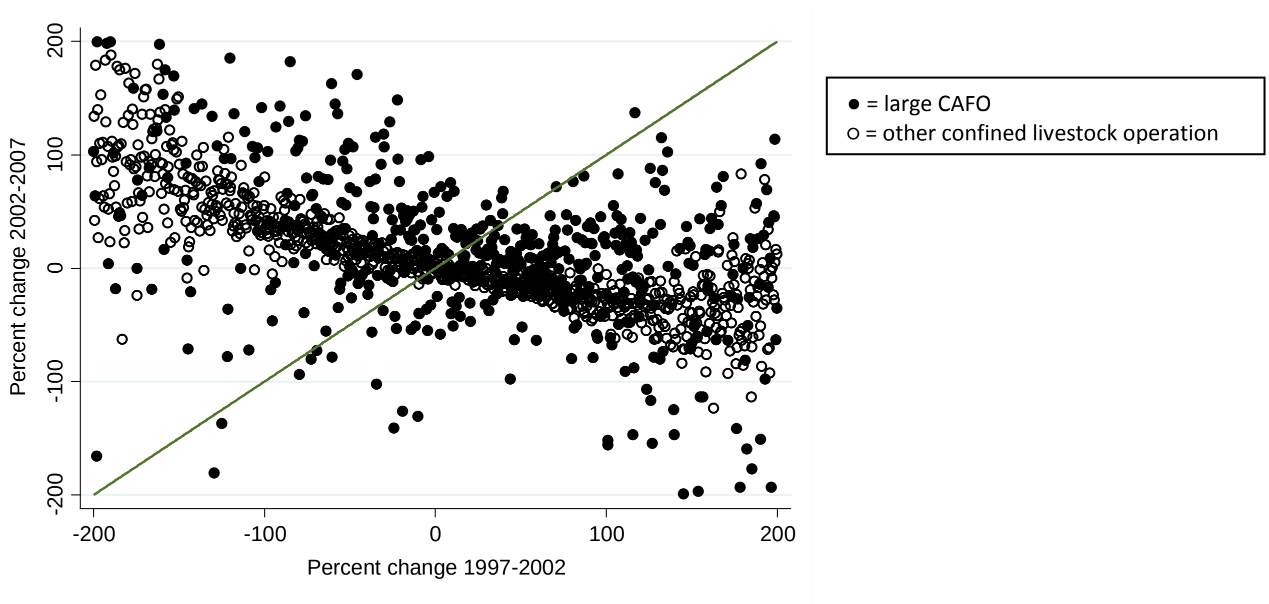
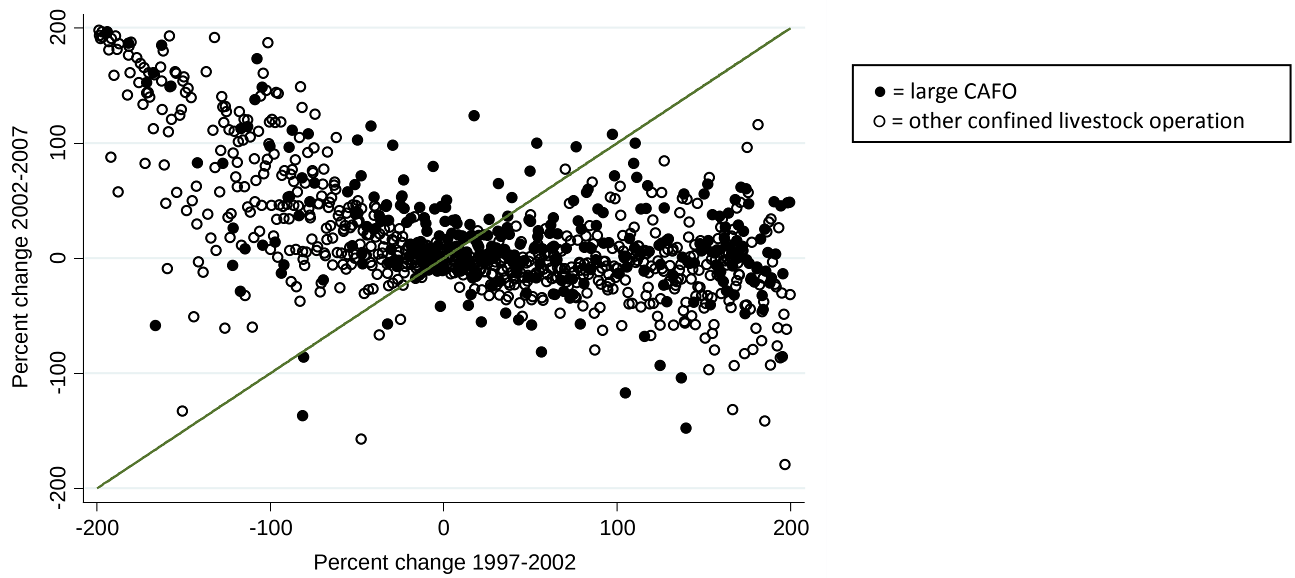


Fig. 4: Percentage change in excess nitrogen, 1997-2002 and 2002-2007, by large CAFO status



- The graphs show for individual operations the percentage change in 2002-2007 according to the percentage change in 1997-2002.
- Operations above the 45-degree line had a larger percentage change in 2002-2007 than in 1997-2002. Operations below the 45-degree line had a smaller percentage change in 2002-2007 than in 1997-2002.
- The figures suggest that operations that are not large CAFOs are more likely to have a bigger increase in the post-regulatory period (2002-2007) than the pre-regulatory period (1997-2002), while large CAFOs are more likely to have smaller increases or declines in the post-regulatory period than the pre-period.

Regression Results

Table 1: Regression Results for Differences-in-Differences Model

	Dependent variable					
	Percent change in…					
Independent variable	**Total nitrogen recovered**	**Total phosphorus recovered**	**Total nitrogen uptake**	**Total phosphorus uptake**	**Excess nitrogen**	**Excess phosphorus**
Large CAFO in Post-Regulatory Period (=1)	-0.328***	-0.278***	-0.0518	-0.0668**	-0.104***	-0.186***
	(0.0325)	(0.0297)	(0.0323)	(0.0319)	(0.0201)	(0.0262)
Large CAFO (=1)	0.535***	0.484***	0.144***	0.170***	0.170***	0.271***
	(0.0322)	(0.0294)	(0.0222)	(0.0210)	(0.0192)	(0.0256)
Post-Regulatory Period (=1)	-0.215***	-0.199***	-0.129***	0.00342	-0.0141***	-0.0325***
	(0.00941)	(0.00882)	(0.0105)	(0.0105)	(0.00239)	(0.00427)
Individual fixed effects included?	Yes	Yes	Yes	Yes	Yes	Yes
Number of observations	87,919	87,919	85,607	85,607	83,908	74,057

Standard errors are clustered at the level of the individual operation and are shown in parentheses. Sample includes just operations that confine livestock. Results of 6 regressions shown. ***, **, and * refer to significance at the 1%, 5%, and 10% levels, respectively.

Discussion

- Large CAFOs reduce their excess nitrogen and excess phosphorus by 10 and 19% (respectively) between 2002 and 2007, factoring out their predicted changes based on 1997 to 2002 trends, and controlling for changes affecting all confined animal feeding operations in the post-regulatory period.
- This reduction in excess is the result of changes in nutrients produced, rather than increasing nutrient uptake. This may be because CAFOs added fewer animals in the post-regulatory period than their non-CAFO counterparts.

Future Extensions

- Examine other outcome variables such as expenditures on fertilizer and fertilizer-applied acreage.
- Test how results differ across regions with different concentrations of livestock relative to land available for spreading manure.
- Examine whether the large CAFO responses are stronger in states having greater regulatory stringency.

References

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