Effects of Clean Water Act Regulations on Firm-Level Decisions in Agriculture

Stacy Sneeringer and Nigel Key
Economic Research Service, U.S. Department of Agriculture
Contact: ssneeringer@ers.usda.gov

Selected Paper prepared for presentation at the Agricultural & Applied Economics Association 2010 AAEA,CAES, & WAEA Joint Annual Meeting,
Denver, Colorado, July 25-27, 2010

Effects of Clean Water Act Regulations on Firm-Level Decisions in Agriculture

Stacy Sneeringer[*]
and
Nigel Key

Abstract:

U.S. environmental regulations often vary by the size of the operation, with larger operations facing more regulatory stringency. When the size distribution of firms is heavily skewed, regulation size thresholds can reduce transaction costs for regulatory agencies while bringing most production within a regulatory framework. However, size-based regulation may have unintended consequences if operations downsize, slow their growth, or enter at a smaller size in order to avoid regulation. These unintended consequences from regulation may include less pollution abatement and diminished economic efficiency. In this study we examine recently revised Clean Water Act (CWA) regulations targeting large-scale livestock operations to identify and quantify farm responses to this regulation. We find statistical evidence that farms adjust size in order to avoid regulation. Additionally farms in states with relatively higher costs of regulatory compliance experience on average 23% less growth than comparable farms in other states, net of prior state-level trends in growth. In these states, regulated farms also experience a 5.8% greater chance of exit.

PRELIMINARY AND INCOMPLETE: DO NOT CITE

JEL Codes: Q5

Keywords: livestock, Clean Water Act, growth, regulation

---

[*] Acknowledgements: 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. ssneeringer@ers.usda.gov

U.S. environmental regulations often vary by the size of the operation, with larger operations facing more regulatory pressure. Such size-based regulation may have unintended effects if operations downsize to avoid regulation or more small operations proliferate in industries with trends towards larger operations. These unintended effects may have consequences for pollution reduction and economic efficiency. Environmental regulation of livestock operations is a topic of particular recent importance. Domestically, the livestock and poultry industry produces over $100 billion dollars in cash receipts[1] and supplies 90% of the country's red meat and 97% of the country's dairy products.[2] This industry has also been found to be one of the top contributors to water pollution (EPA, 2002a) and a significant contributor of lower atmospheric air pollutants and greenhouse gases (see NRC, 2003). The water pollution is a well-known issue in many rural communities, and has recently become more widely recognized in the mainstream media through documentaries like *Food, Inc.* (2009), *Time Magazine's* cover story "The Real Cost of Cheap Food" (Walsh, 2009), and Michael Pollan's book *The Omnivore's Dilemma* (2006). This pollution has also led to more stringent Clean Water Act (CWA) legislation in 2003 (EPA, 2003), as well as possible future Clean Air Act stipulations (see GAO, 2008) and greenhouse gas emissions regulation.[3] Understanding the past effects of environmental regulation on the industry is important given this regulatory context and the potential impact of future legislation on farm structure, the

---

[1] USDA Briefing Room: Animal Production and Marketing Issues. http://www.ers.usda.gov/Briefing/AnimalProducts/. Accessed March, 2010.

[2] Statistics from 2000-2005. Jerardo (2008).

[3] In Dec. 2009 the EPA published in the *Federal Register* an "Endangerment and Cause or Contribute" statement for greenhouse gases. This stated that greenhouse gases including methane are a threat to public health; this is the first step in getting the ability to regulate such gases under the Clean Air Act. While the statement specifically pertained to automobile emissions, the livestock industry (particularly dairies) reacted with concern to this finding, believing it paved the way to regulate methane emissions from livestock operations (see, for example, *Dairy Cares* 2009).

price of food and the environment.

In this article we examine recently revised CWA regulations targeting large-scale livestock operations to identify and quantify firm decisions with respect to environmental regulation. Evolving from findings that agriculture is a significant contributor to water pollution in the U.S. (EPA, 2002a), in 2003 the Environmental Protection Agency (EPA) amended the CWA provisions related to "concentrated animal feeding operations" (CAFOs; the regulatory term for large-scale confined livestock operations). The "2003 CAFO Rule" effectively mandated all large-scale livestock operations to obtain permits and to institute land-dependent manure management plans, significantly strengthening prior 1972 regulations.

An important feature of the 2003 Rule is its size-based stipulations whereby operations over a specific number of head automatically fall under regulatory purview.[4] Thus operations face differential costs of compliance according to size, which in turn may have implications for growth, entry, and exit. Understanding the role of regulations in industry structure and growth is necessary to devise accurate predictions of regulation's environmental benefits as well as to comprehend any loss of scale efficiencies and social welfare.

Understanding how operations react to regulation also allows us to understand the compliance costs. Given that the prescribed abatement activities in agriculture are often "best management practices" rather than pollution control mechanisms like filters or scrubbers, there are substantial challenges in estimating the farm-level costs of regulation. Estimating firms' reactions to regulations can therefore provide estimates of the expected costs of regulation, which are useful in designing programs to offset

---

[4] See Appendix A for a full description of the regulatory stipulations.

regulation costs to firms.

We use individual farm-level data linked between the 1997, 2002, and 2007 U.S. Censuses of Agriculture to discern exits, entries, and growth. We first focus on operations of sizes just below the regulatory cut-off to exploit regulatory size stipulations and provide evidence of non-zero costs of compliance. We test whether these farms make up a statistically unlikely proportion of the distribution of farms and new entries after regulation, given pre-regulation population characteristics. Further tests of growth of firms with respect to the regulatory cut-off also allow us to estimate how firms with sunk costs may react to regulation differently from new farms.

While examination of farms near the regulatory size threshold can provide an indication of expected costs of regulation, they only make up a small percentage of overall production. Estimating effects of regulation on firms of size classes not near the cut-off requires cross-sectional and over-time variation in regulation. While we can compile information on state timing and adoption of facets of the updated CWA rules (i.e. "what's on the books"), we lack information on enforcement activity which could contribute to how operations react to regulation. We therefore use the heterogeneity across states and over time identified in the prior analyses to test for impacts on size classes further away from the regulatory cut-off.

We find that after the announcement of the initial 2003 CAFO Rule, 4.6%-7.6% of potentially regulated firms "avoid" it by remaining at sizes just below the regulatory cut-off. There is heterogeneity across states, with the strongest evidence for avoidance in Iowa, Minnesota, Missouri, and North Carolina. We use this avoidance as an indication of change in relative costliness of regulation, and estimate effects on entry, growth, and exit. After regulation, entry is less likely in size classes just above the regulatory cut-off in states that increase regulatory costliness compared to changes in states that do not become more stringent. Farms in states with higher expected costs of regulation see 28% less growth as measured by size, compared to pre-regulation trends in these same states and trends in states with lower regulation costs. Farms above the regulatory cut-off in the states with higher costs of regulation have a 5.8% higher likelihood of exit compared to farms of the same size in other states, net of prior trends.

Background

Livestock agriculture has increasingly moved to industrial-scale operations with thousands of animals raised in a relatively small amount of space. With the increasing spatial and farm-level disaggregation between crop and livestock production, there is less on-farm utilization of manure by livestock operations. Compared to manure, chemical fertilizers are less costly to transport and apply and have better nutrient consistency which enables facilities to adjust its nutrients to plant requirements. Livestock manure has therefore become a less valuable byproduct in many regions which creates an incentive for livestock producers to apply it to crops at rates in excess of what plants can absorb. When operators apply manure above non-agronomic rates, precipitation may then carry land-applied manure to water bodies. Additionally, liquid manure storage facilities can leak or overflow. Effects of water pollutants from livestock farms include coastal dead zones, fish kills, impaired drinking water supplies, and adverse public health outcomes (Copeland, 2006).

The EPA first attempted to address pollution problems from livestock facilities by deeming large production operations as “point sources” of pollution and regulating them under the 1976 Clean Water Act (CWA). In regulatory parlance, “point sources” are those that have an easily identifiable origin; preventing point source pollution is akin to plugging a pipe from which pollution spills. Stipulations pertaining to CAFOs required specific waste management strategies and engineering requirements so that manure storage containers would not overflow except in the event of a major storm. However, the only facilities that were required to apply for a permit were ones that had already had a documented “discharge” to a water of the U.S.; facilities that would only discharge in the event of a major storm did not need to seek permit coverage, and could avoid regulation altogether. Enforcement was devolved to the states, which also adopted their own regulations of livestock operations (GAO, 2003).

By the late 1990s the EPA concluded that the 1972 CWA rules (and subsequent amendments) did not satisfactorily prevent pollution from livestock operations. In part this was due to unregulated “nonpoint source” pollution associated with livestock. “Nonpoint sources” have a less easily identifiable pollution source that can be controlled; in terms of livestock nonpoint source pollution arises when manure is spread on land and then carried to surface water via precipitation. In the late 1990s the EPA responded to a court-order to review and update their CAFO rules (Copeland, 2006). In 2002 the first set of revised regulations were announced, and the next year these were adopted.

The “2003 CAFO Rule” attempted to address at least two of the issues with prior regulations (EPA, 2003). The first new stipulation required all livestock operations having an inventory above a specific number of head to seek coverage under a permit; this “duty to apply” meant that the regulatory authority could deem whether operations needed to adopt the stipulations required for a permit, rather than the facility itself stating that it would only discharge in the event of a major storm. For example, operations with 2,500 or more hogs each weighing 55lbs. or more automatically fell under regulatory purview based on size (EPA, 2003). The second new stipulation attempted to address nonpoint source pollution by requiring CAFOs to implement “Comprehensive Nutrient Management Plans” (CNMPs), requiring operations to land-apply manure at rates appropriate for the soil type and crops planted. For certain operations, this would mean renting or buying additional land on which to apply manure, or transporting manure off-farm. However, the low demand for manure by crop farms and the high cost of transporting manure meant that certain farms would face higher compliance costs than others.

Both industry and environmental groups found issue with the revised CAFO rules, and sued the EPA (Centner, 2008). In 2008 updated rules were adopted and adjusted for court outcomes. The 2008 rules removed the requirement that all CAFOs had to apply for permits with the regulatory authority but strengthened the stipulations regarding nutrient management (EPA, 2008a).

As the EPA began modifying its original CWA regulations of CAFOs, many states also began to revamp their environmental regulations of livestock (EPA, 2002b). Several states adopted new permitting rules for CAFOs in the late 1990s and early 2000s or strengthened their existing plans. While Federal CWA regulations aim to set a “lower bound” on the stringency of CAFO point-source regulations, there has been and continues to be wide variation between states with regards to implementation (GAO, 2003). For example, while Michigan obtained permission in 1973 from the EPA to run its permitting program, the EPA later had to sue the state to enforce the regulations, as Michigan had relied on the concept that farmers would abide by “best management practices” and did not need to seek permit coverage. Michigan adopted a permitting program in 2002 (GAO, 2006).

The impact of environmental regulation’s effects on agriculture is relatively understudied, with most analyses focusing on the association between regulatory stringency and location. In panel analysis, Sneeringer (2010; 2009) finds that North Carolina and California regulations are significantly associated the growth and regional variation in hog production and dairying 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.

The empirical literature has not addressed the effect of environmental regulations on growth, entry, exit, and livestock industry structure. In contrast, research on other industries has addressed firm responses to both domestic and international pollution laws. 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 regulation is 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.

Our first goal is therefore to model expected regulatory costs. Next, we make predictions of firm behavior given compliance cost structures. We then test our predictions. This not only allows us to understand firm decisions under regulation, but also the structure of regulatory compliance costs. Our empirical strategy first focuses on firm sizes just around the regulatory cut-off; we then examine operations of other sizes.

Model of Expected Regulatory Compliance Costs

This section presents a model of producers' scale of production decision under environmental regulation. Let $L = m$ refer to the cut-off over which firms are regulated, where L denotes number of head. Also let $\pi_1(L)$ be profits before regulation, where $\pi_1(0) = 0$, $\pi_1'(L) > 0$, and $\pi_1''(L) > 0$; the increasing profits with respect to number of livestock operations reflects increasing returns to scale found in the livestock sector (Key, McBride, and Mosheim, 2008). The post-regulation optimization decision is:

$$(1) \qquad \max_{L} \pi_2(L) = \begin{cases} \pi_1(L) & for\; L < m \\ \pi_1(L) - r(L) & for\; L \geq m \end{cases}$$

$$s.t. \quad L \leq \bar{L}$$

where $r(L)$ is the expected cost of regulation imposed if the firm is above the size threshold and $\bar{L}$ is the maximum attainable size.[5]

The expected regulatory cost $r(L)$ depends on whether or not firms comply with the regulation. They will choose to comply if the costs of compliance are less than the expected fines associated with non-compliance. Let $g(L)$ be the costs of compliance and let these cost increase with scale at an increasing rate to account for the likelihood that manure disposal will become more difficult with scale, i.e., $g'(L) > 0$ and $g''(L) > 0$. Profits with compliance are therefore: $\pi_2(L) = \pi_1(L) - g(L)$.

The other option for producers is not to comply with the regulation and face possible penalties. Let P be the probability of detection and $F(L)$ be the fine that producers must pay if detected. We model fines as a function of size, although probability of detection may also increase with size. Non-complying producers have expected profits equal to $E(\pi_2) = \pi_1(L) - PF(L)$.

A producer of size *L* who is subject to regulation therefore chooses the minimum of compliance costs and expected fine from detection:

$$(2) \qquad r(L) = \min \begin{cases} g(L) \Rightarrow comply \\ PF(L) \Rightarrow not\; comply \end{cases}$$

Note that if producers perceive probability of detection as zero due to lack of enforcement, then there will be no compliance and expected cost of regulation will be

---

[5] We assume for the current range of producer sizes that $\pi_1(L) - r(L) > 0$. Above the size *L* at which $\pi_1(L) - r(L) = 0$ it would not be profitable to operate.

zero.

Figure 1 illustrates producers' scale decision for the case where there are positive expected regulatory costs at $L = m$ such that $\pi_1(m-\varepsilon) > \pi_2(m)$(where ε is some marginal amount greater than zero). Note that, with some probability of enforcement, $r(m) > 0$ because under regulation a producer will need to use all manure at agronomic rates, rather than just the manure from the m^{th} head. Given the gap between $\pi_1(m-\varepsilon)$ and $\pi_2(m)$, there will be some size $m + x$ at which $\pi_2(m+x) = \pi_1(m)$ and $\pi_2(m+x-\varepsilon) < \pi_1(m)$, where $x > 0$. For operations between m and $m + x$, it will be optimal to reduce size to $m-\varepsilon$ or grow to size $m + x + \varepsilon$. Further, profit- maximizing new entrants would not begin at sizes between m and $m + x$, nor would firms change sizes to between m and $m + x$.

With this post-regulation profit function, producers may "avoid" regulation by shrinking or new firms may enter at a smaller size than they otherwise would have. Note that avoidance is a form of compliance, not an illegal maneuver. If the cost of complying, the probability of detection, or the fine associated with detection increases, we could expect a larger "unprofitable zone" and consequently a higher incidence of avoidance.

We proceed by testing for an "unprofitable zone" indicative of non-zero "lump sum" regulatory costs at the cut-off point. Once these have been tested for, we move to analyzing the expected regulation costs at other sizes. Our tests for avoidance at the state level provide indications of relative stringency by region.

Data

We use individual farm-level data from the U.S. Censuses of Agriculture for 1997, 2002, and 2007 to examine the size characteristics of farms before and after regulations. Access to these data is restricted to specific computer labs and requires an approval process through NASS.[6] We link farms across Censuses through the use of individual identification codes.

Because EPA regulations are animal type specific and because states adopt different regulations by animal type, we focus only on hogs. Additionally, the 2003 CAFO Rule included stipulations specifically pertaining to operations with different sizes of hogs. Thus there are different cut-off points for operations raising hogs that are 55lbs. and over as well as operations raising pigs that are under 55lbs. Hog production has become increasingly more specialized, with different stages of growth occurring at different facilities; operations are therefore characterized by the stage(s) of growth that they perform. The three major categories include "farrow-to-feeder," "farrow-to-finish," and "finish-only." Finish-only operations will have hogs that are all at least 55lbs. each, while farrow-to-feeder operations will have mostly piglets under 55lbs. Farrow-to-feeder operations will include hogs both over and under 55lbs. We therefore focus on farms growing hogs to market weight, and include in our analysis just "finish only" operations. This type of operation can be straightforwardly characterized in the 2002 and 2007 Censuses but the question is not asked in 1997. In 1997, we characterize finish hog farms as those with no breeding hogs, no sales of feeder pigs, and no litters farrowed (see Appendix B for details). We restrict analysis in all years to just operations that had any

---

[6] For more information see http://www.agcensus.usda.gov.

hog sales or removals,[7] have no breeding hogs which might indicate the presence of under 55lb. piglets, and have at least 100 hogs in inventory; see Appendix B for further data description. Entering and exiting farms are characterized by matching farms over time according to unique Census identifiers. Table 1 shows basic summary statistics for these farms over time; as is evident, the number of farms decreases while the mean and median number of hogs per farm increases.

Empirical Strategy

We first test for evidence of a expected regulatory cost at the cut-off point; this focuses on size classes directly around the regulatory cut-off. We then estimate effects on growth, entry, and exit at other sizes; this amounts to estimating expected regulatory costs that vary with size.

Testing for evidence of non-zero regulatory costs at the cut-off

We test for evidence of expected non-zero regulatory costs at the cut-off through three methods. Due to lack of information on costliness of compliance, enforcement, and relative stringency at the state level even with knowledge of what is "on the books," we begin by using the entire sample of all states to estimate effects related to the regulatory cut-off. We calculate the percentage of operations by year for each of K equal 100-head size classes ($\%N_k$).[8] The regulatory cut-off is at 2,500 head, so the size class of

---

[7] Hogs can be sold or "removed" from an operation depending on the farm's marketing strategy. Contractors are said to "remove" hogs from growers with whom they have contracts. While these growers receive some amount for the hogs, the process is known as "removal" not sales. Independent growers not in production contracts, on the other hand, are said to "sell" their hogs.

[8] For this analysis we exclude operations of size classes above 10,000 because our focus is on accurately estimating the distribution around the regulatory cut-off. Additionally, 100-head size classes above 10,000 become increasingly more likely to have no observations; this also hurts the ability to accurately estimate the distribution.

particular interest is 2,400-2,499. This analysis is partially complicated by the fact that between 1997 and 2007 a 1,200 barn size became increasing common;[9] hence farm sizes that are multiples of 1,200 become greater portions of the overall population. We later consider why this particular barn size has been adopted as a standard in the industry, but for the present analysis we must make adjustments for farm sizes that are multiples of 1,200, including the pertinent one of 2,400. To estimate whether 2,400-2,499 farms make up a statistically unlikely portion of the distribution, we drop size classes that are multiples of 1,200 as well as those that are multiples of 500 and/or 1,000 and fit an *Nth* degree polynomial function to the distribution in each year:

$$(2) \qquad \%N_k = \alpha + \sum_{m=1}^{M} \beta_k S_k^m + e_k \,.$$

Here, $\%N_k$ refers to the percentage of observations in bin k and S_k refers to the midpoint of bin. We choose the functional form by adding polynomials up to 20 degrees to maximize the adjusted R-squared with the additional stipulation that each additional polynomial increases the F-statistic by at least 0.5. We estimate this functional form for the distribution separately for each year.

We next predict the percentage of observations ($\%P_k$) in each of the size classes and estimate the standard deviation of the prediction (σ_P) using the least-squares parameters from (3). With this we compute the number of standard deviations the predicted percent is from the observed percent. The test statistic with $\%N_k$ equal to the

---

[9] A 1,200 head hog barn is often mentioned in the literature as a typical size for a modern facility. For example, a report from Iowa State University (Lammers et al., 2009) states , “Conventional confinement facilities are typical of pork industry practice in the United States and are characterized by individual gestation stalls and 1,200 head grow-finish buildings with slatted concrete floors and liquid manure systems” (p. 1).

observed percentage in size class k :

$$(3) \qquad t_k = \frac{\%N_k - \%P_k}{\sigma_P}$$

has a t-distribution with $K - (M + 1)$ degrees of freedom, where K is the number of bins (the sample size) and $M + 1$ is the number of parameters in the polynomial regression.[10]

If barn sizes that are multiples of 1,200 are standard, then we should see the percentage of farms of these sizes to be greater than what would be predicted with the above regression. To test for evidence of avoidance, we compare the test statistics for multiples of 1,200 that are not 2,400 with the test statistic for the 2,400-2,499 size class. The test statistics for size classes 1,200, 3,600, 4,800 and so forth therefore become the "lower bound" on what we accept as evidence of a statistically unlikely percentage of farms in the "just below" size class. Further, we perform this cross-sectional test for the periods before regulation (1997, 2002) and compare this to the period after regulation (2007).[11]

Using the predicted percentages from the above analysis, we calculate the percentage of farms that "avoid" regulation by being in the size class just below the regulatory cut-off ($\%A$) as:

$$(4) \qquad \%A = \%N_{k=2,400} - \%P_{k=2,400}$$

We also estimate an avoidance percentage that adjusts for the standard nature of the 1,200 size class ($\%A^{adj}$) through the following:

---

[10] See for example, Johnston (1984, p.193-198) for a derivation of (4).

[11] We do not group all periods together in our regressions because we want to allow for distribution changes across time unrelated to regulation. In order to allow for distribution changes while pooling all years we would need to interact each year's estimated distribution with an indicator for the year; hence no additional information or power would be gained from pooling.

(5) $$\%A^{adj} = \%N_{k=2,400} - \%P_{k=2,400} - \frac{1}{2}(\%N_{k=1,200} - \%P_{k=1,200} + \%N_{k=3,600} - \%P_{k=3,600})$$

Further, we calculate a “1,200-multiple-adjusted” test statistic of

(6) $$t^{adj}_{k=2,400} = t_{k=2,400} - \frac{1}{2}(t_{k=1,200} + t_{k=3,600})$$

We perform a similar type of analysis for new entries, using entries between 1997 and 2002, and between 2002 and 2007. Finally, using the percentage of firms above the regulatory cut-off of 2,500 head ($\%R$), we calculate avoidance rates:

(7) $$AV\ Rate = \frac{\%A}{\%A + \%R} \qquad \text{and} \qquad AV\ Rate^{adj} = \frac{\%A^{adj}}{\%A^{adj} + \%R}.$$

These rates provide estimates of the total number of potentially regulated firms that avoid regulation.

Computing indicators of state-level regulatory costs over time

To derive an indicator of these regulatory costs we examine the change in the number of farms near the regulatory threshold. Firms just above and below the threshold are most likely to experience distinct differences in compliance costs associated with small changes in size, and are therefore most likely to manifest observable changes in behavior in response to increased regulation. Consequently findings of firm adjustments in sizes near this regulatory cut-off can serve as an indicator of regulatory stringency that can be used to examine the effects on firms in other size classes further from the cut-off.

Estimating whether the farm size distribution changes near the regulatory threshold requires a sufficient number of farms at the State level. We therefore restrict the study to States with 100 or more finish-only operations in each Agricultural Census between 1997 and 2007. These states are Illinois, Indiana, Iowa, Kansas, Michigan, Missouri, Minnesota, Nebraska, North Carolina, Ohio, Pennsylvania, South Dakota, and

Wisconsin.

Estimating distributional and entry effects on other size classes

We use the state- and time-level heterogeneity of expected regulatory costs from the procedure described above to estimate regulation's effects on farms in other size classes. Exploiting variation across states in relative regulatory costs enables us to control for fixed characteristics of states as well as time-specific features occurring across all observations. We address entry, growth, and exit of farms, and use different analyses to address these firm decisions. Unlike exits, for entries we do not have information on what the farms "would have been" had they not entered. We therefore cannot perform farm-level analyses for effects of regulation on entries. For entries, we therefore perform effects of regulation on entry by size, and we address growth and exits in individual farm-level analyses.

We first assess how regulation may affect the overall distribution of firm entry size by calculating the percentage of entering farms by state and year in each size class ($\%N_{kst}$) and regressing this on interactions between dummy variables for each size class interacted with state regulation status (A_{st}). We then perform the following regression

$$(8)\qquad \%N_{kst} = (A_{st} \times \gamma_k)'\beta_k + \gamma_{ks} + \gamma_{kt} + e_{kst}$$

The size-bin-year fixed effects γ_{kt} will account for uniform shifts across all states during a specific time period (like a national trend toward a more skewed distribution). The bin-state fixed effects γ_{ks} will control the "average distribution" within a particular state that is constant over time. The coefficients β_k provide the change in the percentage of observations of an individual size correlated with regulation, controlling for changes post-regulation in unregulated states.

In our next set of analyses, we examine firm-level growth and exit; this requires information on each farm in at least two Census years. Growth is estimated by the change in an individual farm between one year and the next. Exit is characterized by whether the farm exits in the next time period. Our empirical strategy is akin to the now common differences-in-differences approach. We restrict our sample to all farms with observations in at least two Census years;[12] with these we calculate change across two periods (indexed p; the two periods are 1997-2002 and 2002-2007) and regress:

$$\Delta L_{isp} = \alpha + \beta(\Delta A_{sp}) + X'_{isp}\lambda + \gamma_s + \gamma_p + e_{isp}$$

Where ΔL_{ist} refers to the change in the outcome variable for farm i in state s and period p. For growth, we explore the percentage and level changes in farm size; for exit, the outcome variable refers to a dummy variable equal to one if the firm exited in the time period and zero otherwise. We also include potential farm- and time-varying confounding variables (X_{isp}) that may be correlated both with relative regulatory stringency and the outcome variable. We use levels in the beginning year of the period (i.e., 1997 or 2002) of these variables, including operator age and experience and the total number of acres on the operation; this considers these variables as "inputs" to the eventual outcome. With size change as the outcome variable, we estimate effects using ordinary least squares. With exit indicator as the outcome variable, a probit model is estimated using a maximum likelihood procedure.[13] To account for potential heteroscedasticity in error terms, we cluster them according to state and time period.

---

[12] We do not restrict ourselves to farms with observations in all three years (1997, 2002, and 2007) because of how few farms fit this criterion.

[13] Lancaster (2000) notes that probit analysis with multiple fixed effects may lead to the "incidental parameters problem," which is avoided in the linear probability model. We therefore also estimate probability of exit using a linear probability model to test for robustness according to this functional form; results are shown in Appendix D.

The state and period fixed effects are pivotal for identifying effects associated with regulation. State fixed effects will control for growth or probability of exit in the period before the regulation. Thus even if states with faster growing operations are more likely to adopt and enforce regulation, this empirical strategy will control for this. The time period fixed effects non-parametrically control for factors that affect all states in the time period.

Results

Effects of regulation on the likelihood of farms to be just under the regulatory cut-off

Figures 1A, 1B, and 1C show the overall distribution of finish-only hog farms with at least 100 hogs in inventory and with at least one sale or removal in the year for 1997, 2002, and 2007.[14] As is evident, a smaller percentage of farms occupy the smallest size classes over time as the distribution changes. Also noticeable are the increasing frequency of mass points, generally at multiples of 500 and/or 1,000. The regulatory cut-off of 2,500 head is shown; farms above this size automatically fall under "Large CAFO" status according to size. Also evident is the increasing percentage of farms in the size class directly below the regulatory cut-off.

Figures 2A, 2B, and 2C show the statistical test values for all size classes that are not multiples of 1,000 and/or 500. The multiples of 1,200 are highlighted for illustration. Negative numbers suggest that there are fewer farms in the size range than would be expected given the overall distribution. In 1997 the most statistically unlikely difference between the observed and the predicted size occurs for the size class 1,200-1,299,

---

[14] Size classes 100-199 and 200-299 are not shown for illustrative purposes. The right-most bin represents sizes of 10,000 head or more.

evidence of the “standardness” of the 1,200-head barn. By 2002, both the 1,200 and 2,400 size classes appear statistically out-of-proportion to their predictions (Fig. 2B). However, in 2007 after the 2003 CAFO Rule has been announced, the test statistic for the size category just below the regulatory cut-off becomes much larger, suggesting that a statistically unlikely percentage of farms is of this size (Fig. 2C). Table 2 provides the actual and predicted percentage of farms in three size classes that are multiples of 1,200. In all years, the test statistic suggests that the percentage of observations in each of these size classes is statistically unlikely given the rest of the distribution. The percentage of farms in the “just-below” size class becomes greater in the post-regulation period, unlike the other two multiples of 1,200. Further, the test statistic for the just-below size category rises markedly in the post-regulation period compared to the other two size classes.

To summarize, we find evidence that a portion of farms avoid the 2003 CAFO Rule by entering or remaining at a size class directly below the regulatory cut-off. This is the case even after adjusting for the fact that the “just-below” size class may be more probable due to the fact that it includes two 1,200-head barns, a barn size that is becoming more common over time.

While some avoidance is likely occurring, its magnitude is also pertinent. Table 3 shows calculation of avoidance rates, with and without adjustment for the 1,200-head standard barn size. In 2007 after the announcement of the 2003 CAFO Rule, avoidance occurs for one in 22 potentially regulated farms (an avoidance rate of 4.6%), accounting for the increased prevalence of the 1,200-head barn size. Approximately 153 more farms would be regulated if they had not remained in or entered the 2,400-2,499 size class.

Similar analyses to those above show a similar pattern for new entrants (Fig. 3A and 3B). The percentage of new entries in the 2,400-2,499 size class is also statistically unlikely (Fig. 4A and 4B).

State-Level Environmental Stringency

By performing the above analysis, we calculate the adjusted and non-adjusted test statistics by state and year (Table 4). These numbers suggest variation in the timing and stringency of state regulation pertaining to the 2,500-head regulatory cut-off. The states that have an adjusted test statistic that goes from insignificant or negative in 2002 (before the announcement of the 2003 CAFO Rule) to significant and positive in 2007 (after the announcement) include Iowa, Minnesota, Missouri, North Carolina, and Ohio. Along with Wisconsin, Ohio went from showing evidence to higher costs to evidence of lower costs between 1997 and 2002. Avoidance rates by state and year are shown in Appendix Table D1.

Effects of Regulation on Farm Entry

Fig. 5 shows the estimated effects of regulation on the size distribution of new entrants, adjusting for national distributional change and “average” distributions within the state. Regulation is correlated with a larger percentage of farms entering in size classes below the “large CAFO” regulatory cut-off, cut these correlations are not statistically significant. The only size category with a lower percentage of entrants associated with regulation is 2,500-4,999. New entrants are 3.1% less likely to be this size in regulated states after regulation. However, this effect is only significant tat the 11% level.

Farm-Level Analysis of Growth and Exit

For the farm-level analysis, we use as a measure of state-level relative compliance costs the statistical significance of the adjusted test statistic. Because we would like to compare states that exhibit similar properties in the "before regulation" period, we exclude from analysis Ohio and Wisconsin. Our "treated" states move from no changes in the statistical significance of their regulatory costs between 1997 and 2002 to higher regulatory costs between 2002 and 2007; these include Iowa, Minnesota, Missouri, and North Carolina. Our "control" states include Illinois, Indiana, Kansas, Michigan, Nebraska, Pennsylvania, and South Dakota. Tables 5 and 6 show summary statistics by treatment status over time. Summary statistics for subsets of farms (i.e., continuing farms, new entrants) are also shown, pertinent for the different types of analyses conducted according to outcome variable.

Tables 7 and 8 show results for the growth regressions. We show results not only for the overall sample, but samples according to size class at the start of the period. This is to test for different effects according to size, as predicted by the theoretical model. We also show results with and without including the potential confounders. Using the sample of all continuing farms, increased regulatory costs are associated with a 23.3% to 27.9% decline in growth. Examination by sizes associated with the different regulatory levels suggests that small farms below the regulatory cut-off exhibit declines in growth associated with regulation; this could be indicative of attempting to avoid the next largest size class. Overall, regulated farms that begin above the 2,500-head threshold do not exhibit changes in growth associated with the regulation. However, dividing large CAFOs between sizes of 2,500-4,999 and 5,000 and above shows that the largest farms exhibit declines of approximately 40% with costlier compliance. The lack of a regulation effect for farms just above the regulatory cut-off (2,500-4,999) may be indicative of both growth and decline of farms in this category. The theoretical model predicts that farms of size just above the regulatory cut-off will have an incentive to either decrease or increase in size if they wish to increase post-regulation profits. Thus some firms of this size prior to regulation may grow and others may shrink, leading to no overall effect.[15]

Examination of level changes echoes many of the results found for percentage changes (Table 8). The overall effect is statistically insignificant, but we find statistically significant negative effects for both sizes below 2,500 and sizes above 5,000. The largest effects in terms of number of head occur for the largest operations. Additionally, results are largely robust with respect to inclusion of the farm- and time- varying covariates.

Table 9 shows effects of relatively higher regulatory costs on probability of exit. When considering farms of all size classes, there is no statistically significant effect of regulation on exit. Dividing by size suggests that this overall effect masks different effects at different sizes. However, after controlling for covariates, there is a weakly significant (at the 10% level) higher probability of exit for farms in the "large CAFO" category. The magnitude of this effect is approximately 5%. Interestingly, regulation is also correlated a 5% decreased likelihood of exit for farms in the "medium CAFO" size category. This may be indicative that regulation creates more favorable market outcomes for unregulated farms compared to regulated ones.[16]

---

[15] As a robustness check, we exclude North Carolina and Indiana separately from the treatment and control groups, respectively. North Carolina had a moratorium limiting new hog operations and the growth of existing hog operations in effect between 1997 and the present. Because this feature is fixed for the state over the time period, it should be captured in the state fixed effect; nevertheless, we perform the robustness check, we results largely the same as those shown. Indiana had a state-level regulatory cut-off of 600 head, suggesting that this state's reaction to the 2003 CAFO Rule may have been different from other states. Again, results remain largely unchanged.

[16] Appendix Table D3 shows results from the linear probability model. These are largely similar to those found in the probit model.

Discussion and Conclusion

We find evidence that increased costliness of environmental regulation has an impact on the size, growth, and continuation of farms. A statistically unlikely percentage of farms exist in the size category directly below where they would be designated as "Large CAFOs". This suggests that some farms avoid regulation by adjusting size. This indicator of higher regulatory compliance costs is correlated with slower growth, even for farms that do not fall into the highest regulation category. Higher regulatory costs are also correlated with a higher rate of exit for firms in the "large CAFO" category.

These findings are pertinent for a variety of policy questions. In its estimates of the costs and benefits of the 2003 CAFO Rule, the EPA does not consider the changing distribution of farm sizes or the effects that the regulation may have on growth. State-level policy makers considering the stringency of their environmental regulations of livestock production may consider such effects as they weigh the benefits of such regulation against the costs. Finally, these findings may inform private and public programs to help farms institute the more sustainable measures called for in regulation.

References

Becker R, Henderson V. 2000. "Effects of air quality regulations on polluting industries." *Journal of Political Economy* 108(2): 379-421.

Berman E, Bui LT. 2001. "Environmental regulation and labor demand: Evidence from the South Coast Air Basin." *Journal of Public Economics* 79(2): 265-295.

Centner TJ. 2008. "Courts and the EPA interpret NPDES general permit requirements for CAFOs." *Environmental Law* Sept. 22. ISSN: 0046-2276.

Copeland C. 2006. Animal waste and water quality: EPA regulation of concentrated animal feedin operations (CAFOs). CRS Report for Congress Order Code RL31851.

Czebiniak R. 2003. State regulation of animal feeding operations: Seven state summaries. Washington, DC: Environmental Law Institute. http://www.elistore.org/reports_detail.asp?ID=10786&topic=Federal_and_State_Relations.

Dairy Cares. 2009. "Comments on EPA's Proposed Endangerment and Cause or Contribute Findings for Greenhouse Gases Under Section 202(a) of the Clean Air Act." Sent via email to HGH-Endangerment-Docket@epa.gov. June 23. http://www.dairycares.com/pdf%20files/DocketID.EPA.HQ.OAR.2009.0171.pdf

Food, Inc. 2008. DVD. Directed by Robert Kenner. Los Angeles, CA: Participant Media.

Isik M. 2004. "Environmental regulation and the spatial structure of the U.S. dairy sector." *American Journal of Agricultural Economics* 86(Feb.): 949-962.

Jerardo A. 2008. "What share of U.S. consumed food is imported?" *Amber Waves* 6(1): 36-37.

Key N, McBride W, Mosheim R. 2008. "Decomposition of Total Factor Productivity Change in the U.S. Hog Industry." *Journal of Agricultural and Applied Economics*. 40(1): 137-149

Lancaster T. 2000. "The incidental parameter problem since 1948," *Journal of Econometrics* 95: 391-413.

Lammers PJ, Honeyman MS, Harmon JD, Kliebenstein JB, Helmers MJ. 2009. "Construction resrouce use of different types and scales of swine production facilities." Iowa State University Animal Industry Report 2009. A.S. Leaflet R R2471. http://www.ans.iastate.edu/report/air/2009pdf/R2471.pdf.

Metcalfe, M. 2000. "State Legislation Regulating Animal Manure Management." *Review* *of Agricultural Economics* 22:519-532.

Miller D. 2006. "North Carolina Focus on Fine-Tuning." *National Hog Farmer* May 15. http://www.nationalhogfarmer.com/mag/farming_north_caroling_focus/index.html.

National Research Council. 2003. *Air emissions from animal feeding operations: Current knowledge, future needs*. Washington, DC: The National Academies Press.

Pollan M. 2006. *The Omnivore's Dilemma*. New York: Penguin Press.

Roe B, Irwin EG, Sharp JS. 2002. "Pigs in Space: Modeling the Spatial Structure of Hog Production in Traditional and Nontraditional Production Regions." *American Journal of Agricultural Economics* 84:259-278.

Ribaudo M, Gollehon N, Aillery M, Kaplan J, Johansson R, Agapoff J, Christensen L, Breneman V, Peters M. 2003. Manure management for water quality: Costs to animal feeding operations of applying manure nutrients to land. U.S. Dept. of Agriculture, Economic Research Service, Resource Economics Division. Agricultural Economic Report 824. http://www.ers.usda.gov/Publications/AER824/.

Sneeringer S. 2010. "Effects of Environmental Regulation and Urban Encroachment on Dairy Structure in California." Working Paper, Wellesley College.

Sneeringer S. 2009. "Effects of Environmental Regulation on Economic Activity and Pollution in Commercial Agriculture." *The B.E. Journal of Economic Analysis and Policy*. 9(1) (Contributions), Article 31. http://www.bepress.com/bejeap/vol9/iss1/art31.

U.S. Environmental Protection Agency. 2002a. *National Water Quality Inventory, 2000 Report.* Office of Wetlands, Oceans, and Watersheds, Publication EPA-841-R-02-001, Washington DC, September.

----. 2002b. State compendium: Programs and regulatory activities related to animal feeding operations. Office of Wastewater Management. Prepared by Tetra Tech, Inc., Fairfax, VA. http://www.epa.gov/npdes/pubs/statecom.pdf

---. 2003. The producers' compliance guide for CAFOs. Revised Clean Water Act regulations for concentrated animal feeding operations (CAFOs). Washington, DC.

---. 2008a. Concentrated animal feeding operations final rulemaking – fact sheet. Office of Wastewater Management. http://cfpub.epa.gov/npdes/afo/cafofinalrule.cfm.

---. 2008b. *Animal feeding operations. State and territory links*. Webpage. http://cfpub.epa.gov/npdes/linkresult.cfm?program_id=7&link_category=2&view=link.

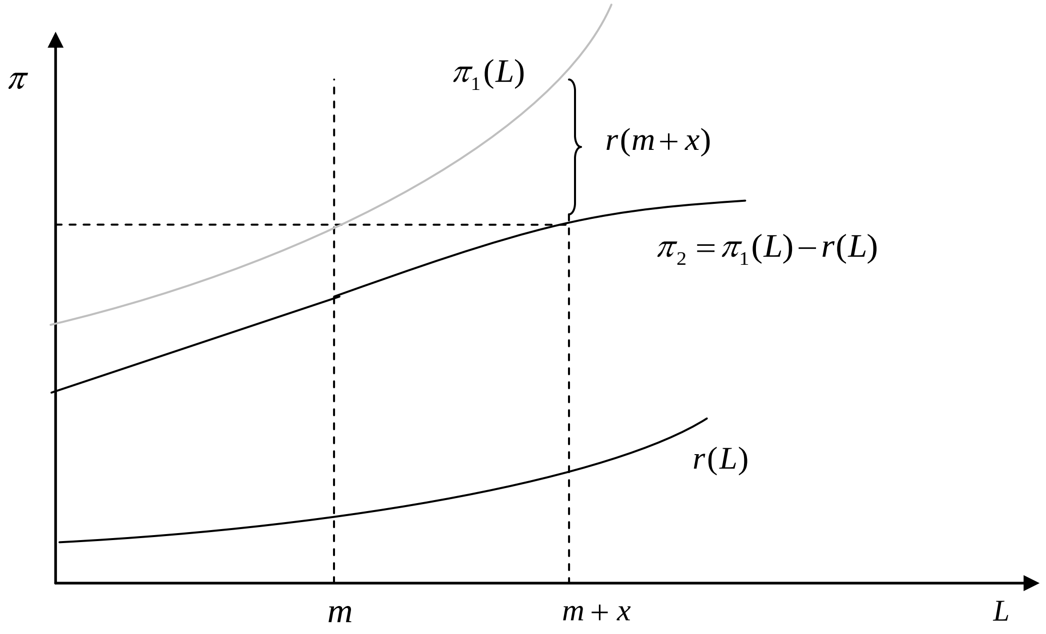
---. 2009. “Endangerment and Cause or Contribute Findings for Greenhouse Gases Under Section 202(a) of the Clean Air Act; Final Rule.” Federal Register 74(239) Dec.: 66496-66546.

U.S. General Accounting Office. 2008. EPA needs more information and a clearly defined strategy to protect air and water quality from pollutants of concern. US GAO Report to Congress 08-944.

---. 2003. Livestock agriculture: Increased EPA oversight will improve environmental program for concentrated animal feeding operations. USGAO Report to the Ranking Member, Committee on Agriculture, Nutrition and Forestry, U.S. Senate. GAO-03-285. http://www.gao.gov/cgi-bin/getrpt?GAO-030285.

Walsh B. 2009. “The Real Cost of Cheap Food.” *Time Magazine* 174(8): pp. 30-37.

Schematic 1: Profit functions and expected regulatory costs as a function of size



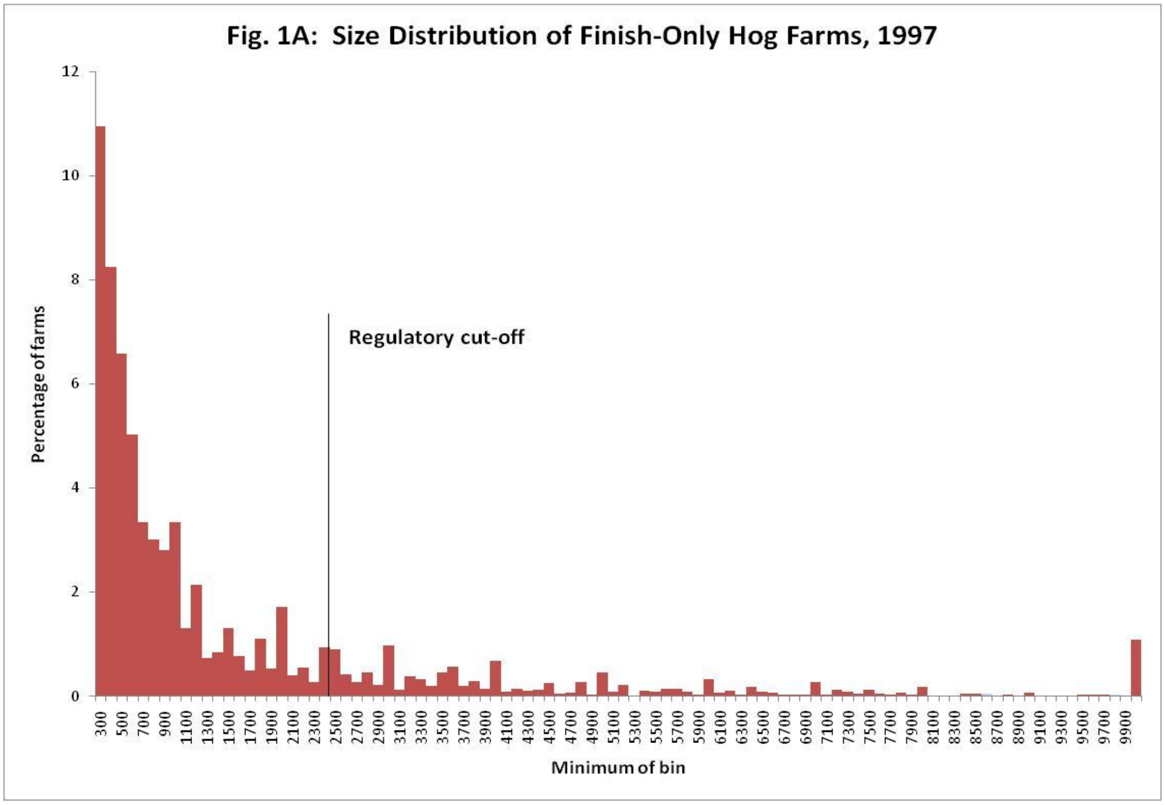


Fig. 1A: Size Distribution of Finish-Only Hog Farms, 1997

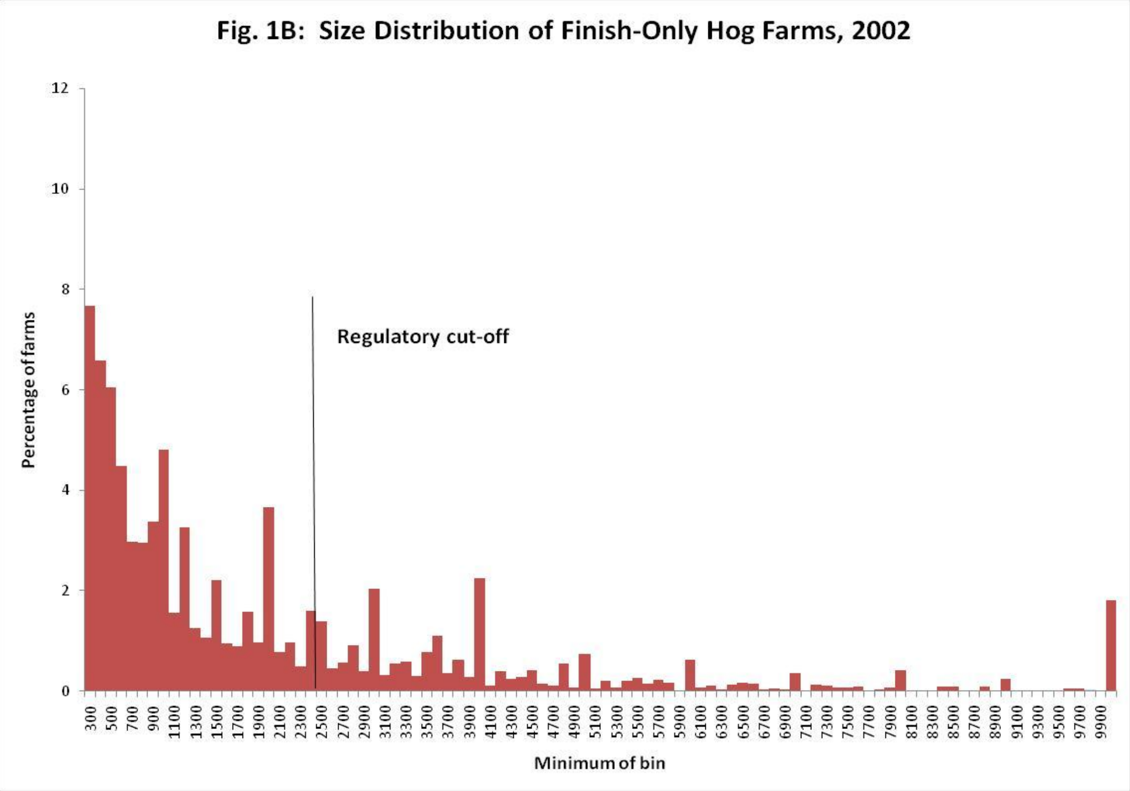


Fig. 1B: Size Distribution of Finish-Only Hog Farms, 2002

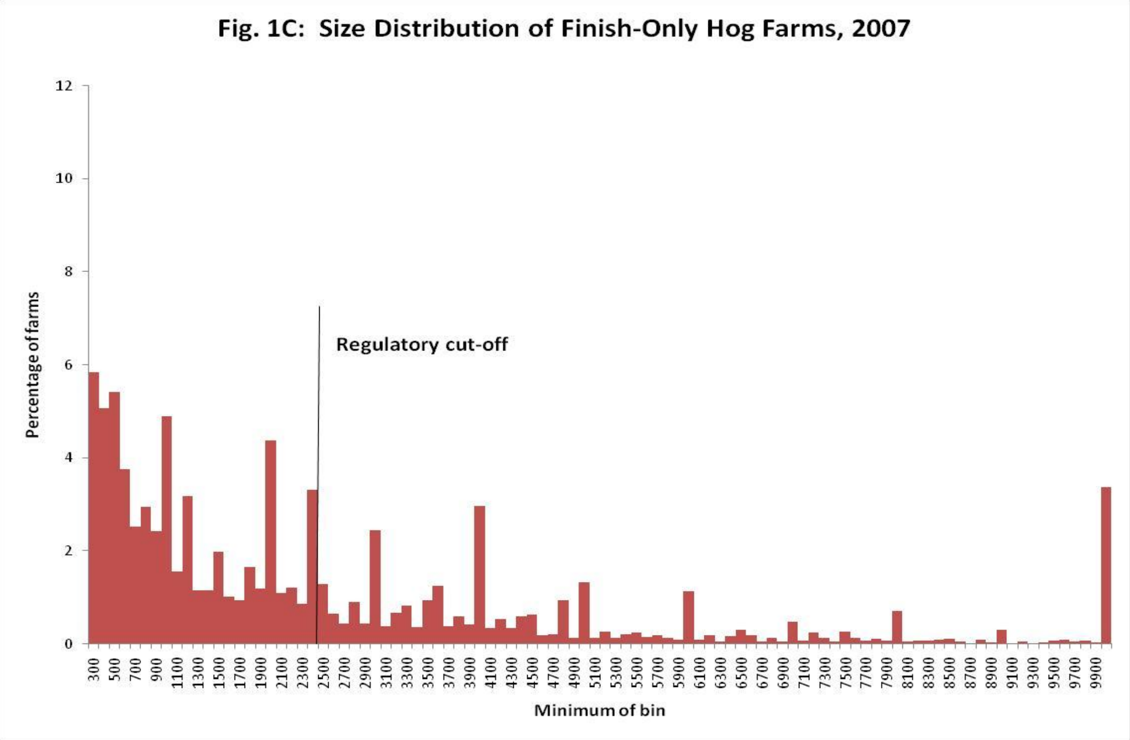


Fig. 1C: Size Distribution of Finish-Only Hog Farms, 2007

Notes for Fig. 1: Percentages are of total number of finish-only hog farms; see Appendix B for description of farms. Size classes 100-199 and 200-299 are excluded from figures for illustrative purposes. Right-most bin represents percentage of farms of 10,000 or more.

Fig. 2A: Test statistic by Farm Size, 1997
(Pre-2003 CAFO Rule)

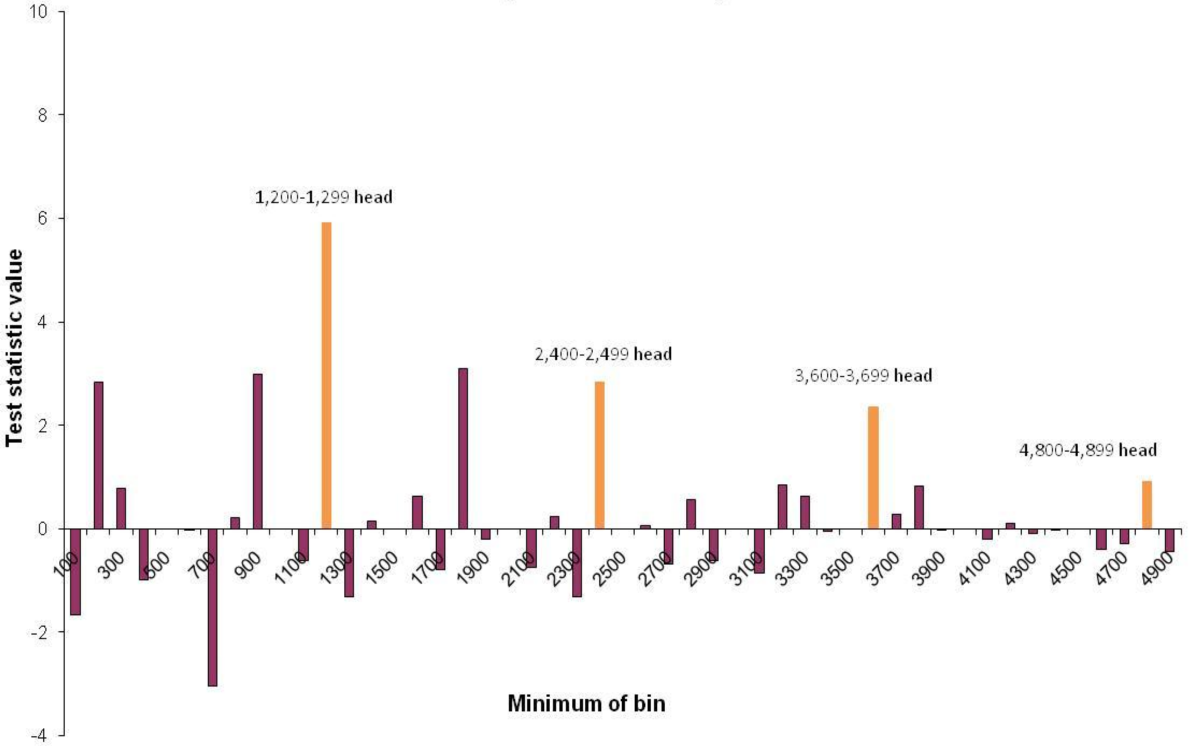


Fig. 2B: Test statistic by Farm Size, 2002
(Pre-2003 CAFO Rule)

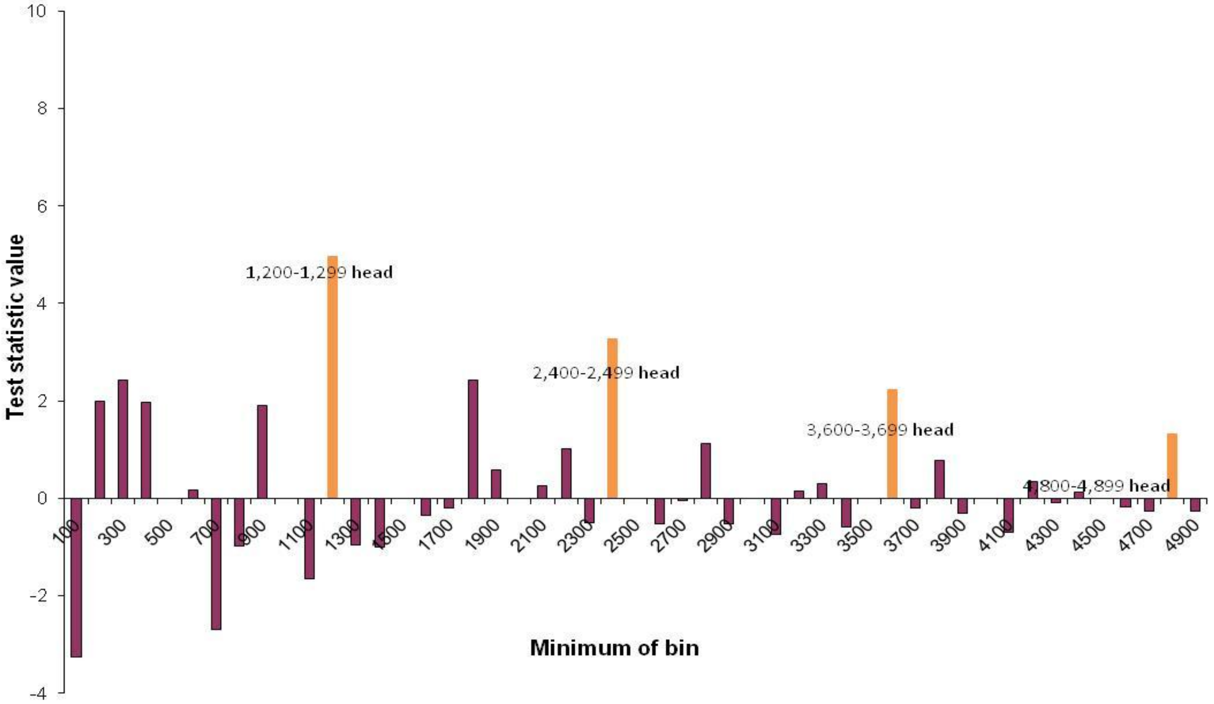
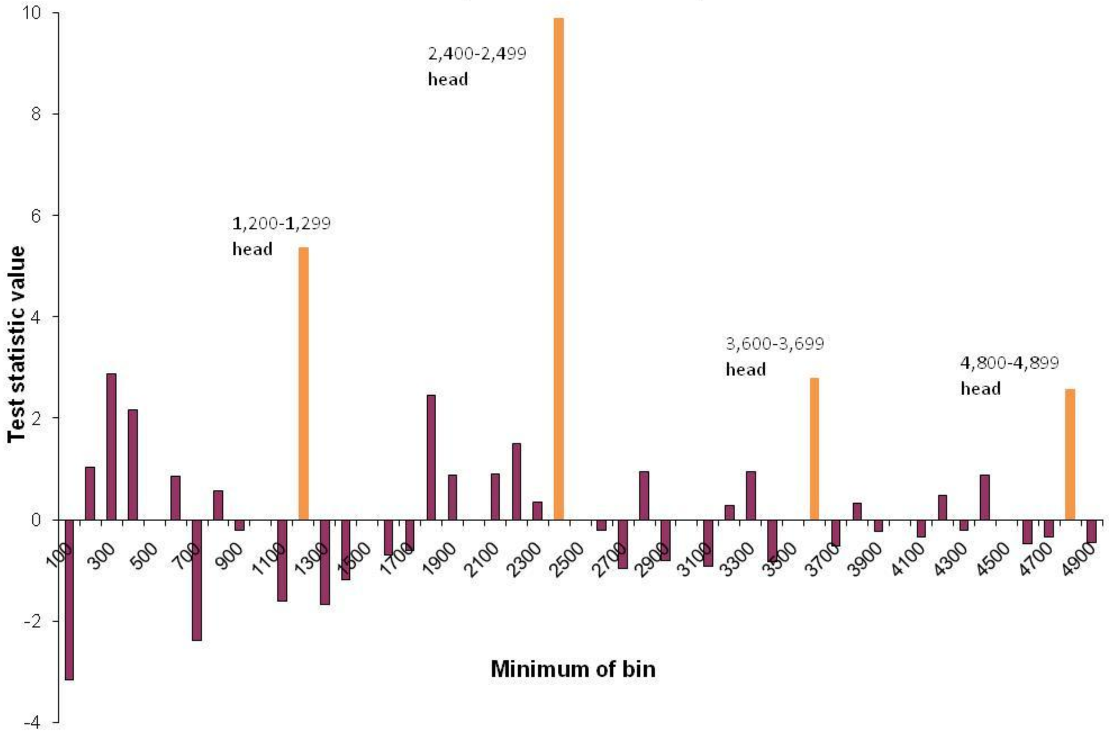


Fig. 2C: Test statistic by Farm Size, 2007
(Post-2003 CAFO Rule)



Notes: See text for description of test statistic.

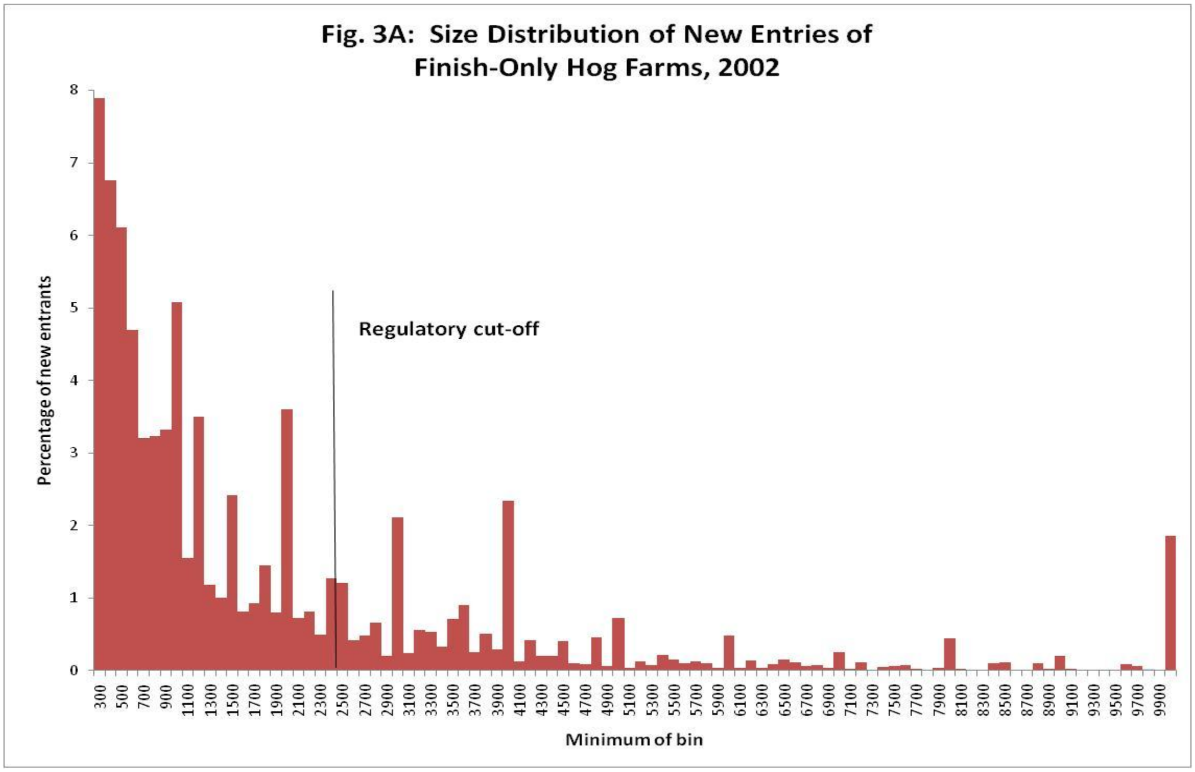


Fig. 3A: Size Distribution of New Entries of Finish-Only Hog Farms, 2002

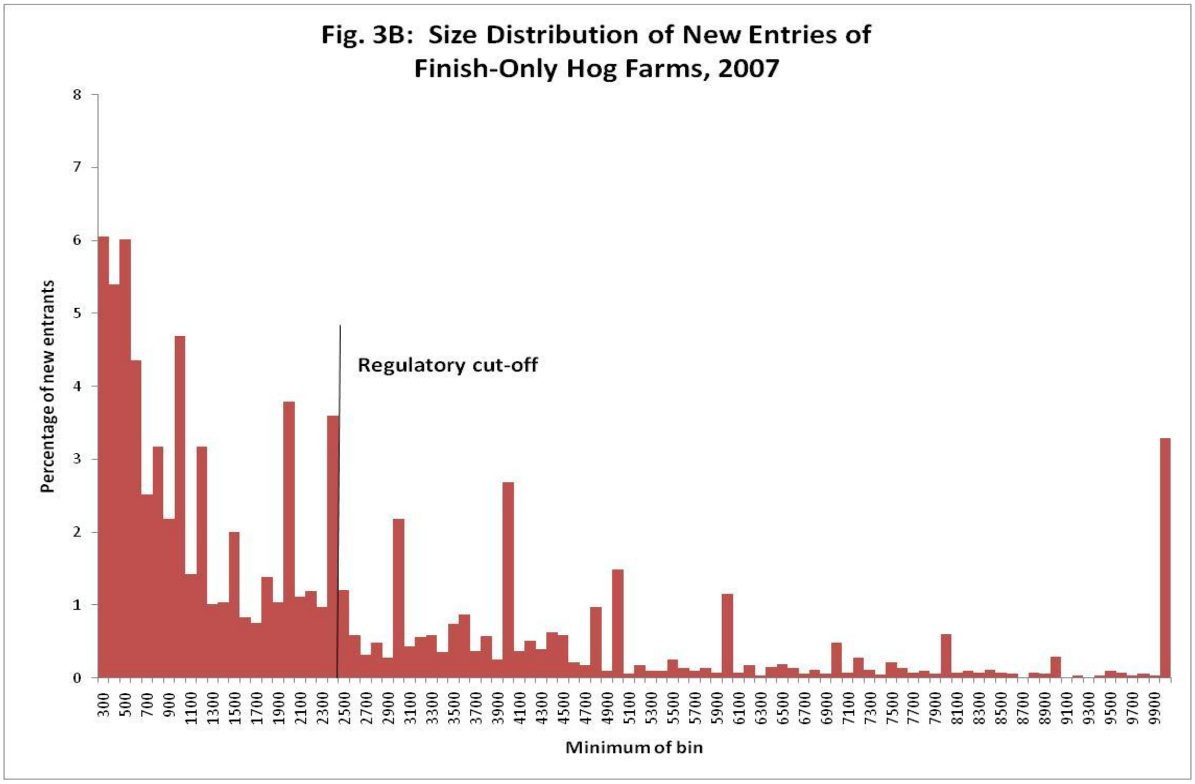


Fig. 3B: Size Distribution of New Entries of Finish-Only Hog Farms, 2007

Notes for Fig. 3: Percentages are of total number of finish-only hog farms; see Appendix B for description of farms. Size classes 100-199 and 200-299 are excluded from figures for illustrative purposes. Right-most bin represents percentage of farms of 10,000 or more.

Fig. 4A: Test statistic for New Entrants by Farm Size, 2002
(Pre-2003 CAFO Rule)

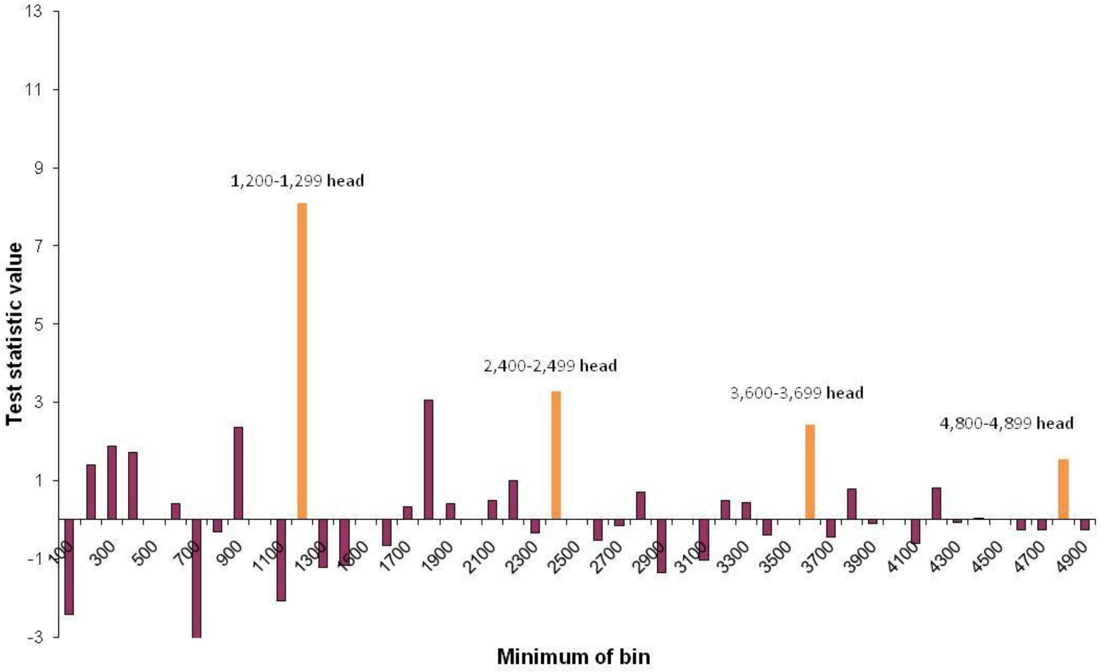
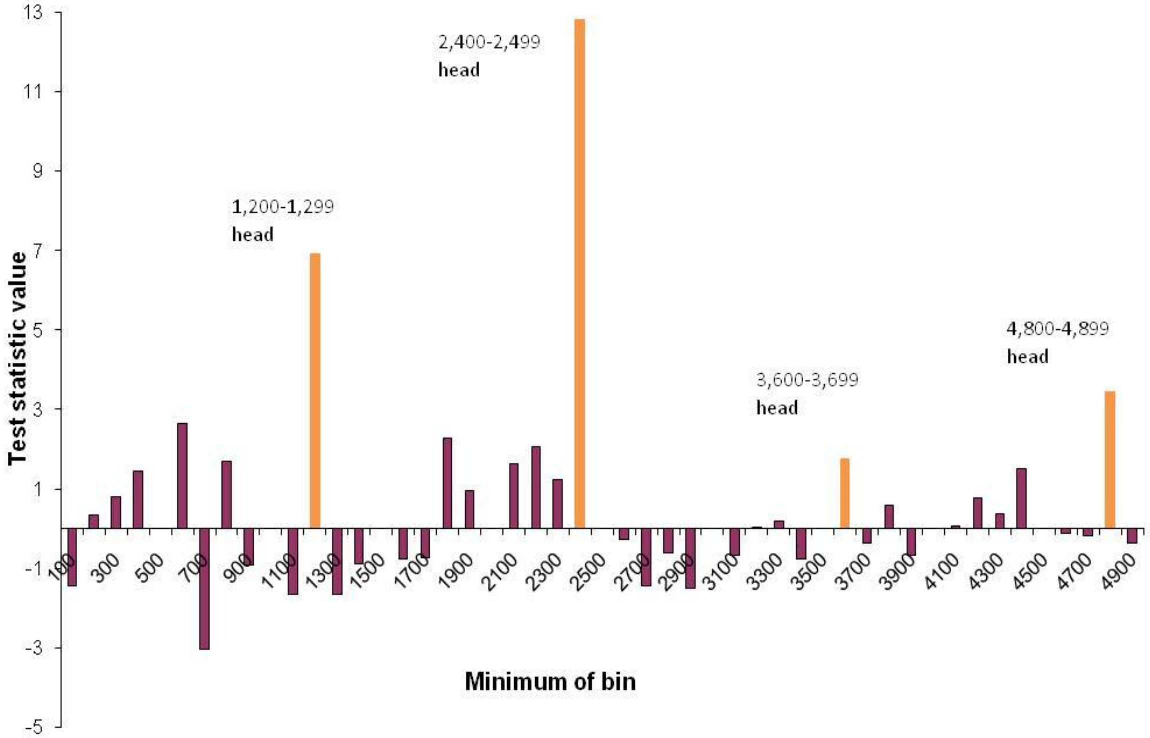


Fig. 4B: Test statistic for New Entrants by Farm Size, 2007
(Post-2003 CAFO Rule)



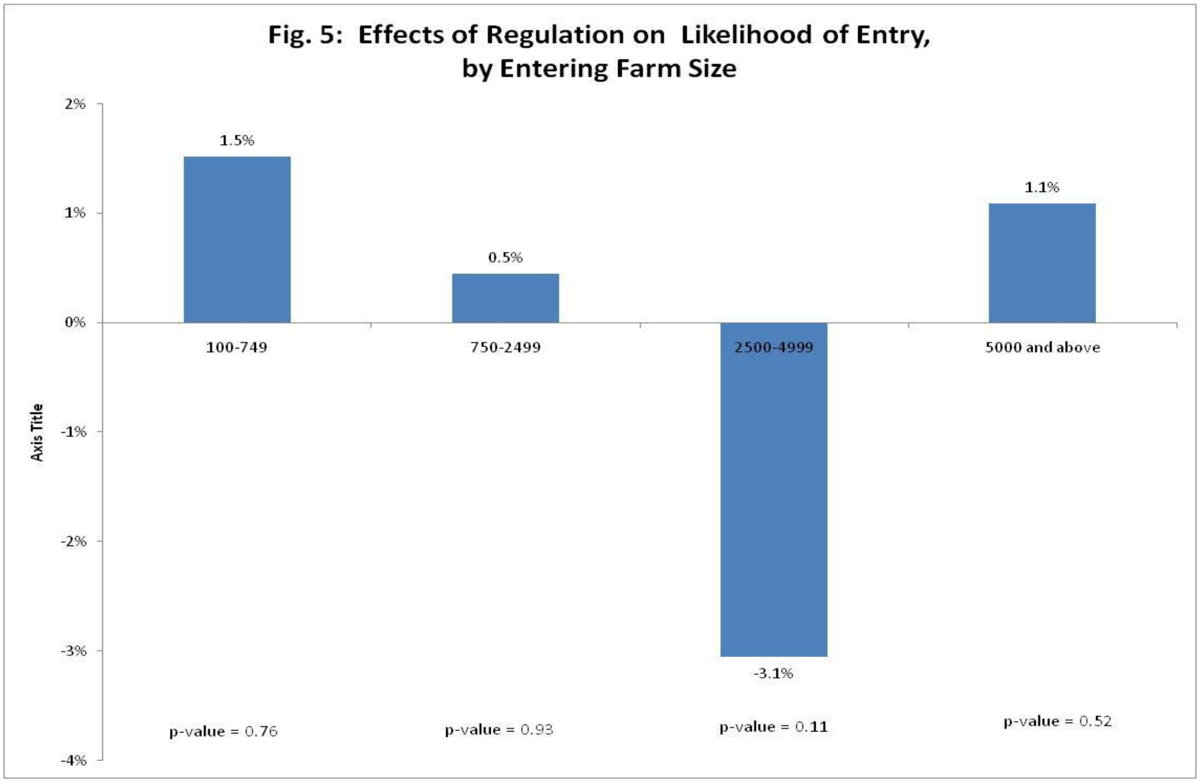


Fig. 5: Effects of Regulation on Likelihood of Entry, by Entering Farm Size
Axis Title
2%
1%
0%
-1%
-2%
-3%
-4%
1.5%
0.5%
-3.1%
1.1%
100-749
750-2499
2500-4999
5000 and above
p-value = 0.76
p-value = 0.93
p-value = 0.11
p-value = 0.52

Table 1: Summary Statistics for Finish-Only Hog Farms

	Year		
	1997	2002	2007
Unweighted number of farms	13,549	10,159	9,386
Weighted number of farms	14,649	11,020	10,232
Mean number of hogs in inventory	1,186	1,906	2,640
Median number of hogs in inventory	480	950	1,350
Mean number of sales or removals	2,667	4,543	5,901
Median number of sales or removals	800	2,011	3,000
Mean size of new entrants	--	1,821	2,621
Median size of new entrants	--	850	1,155
Mean size of exiting farms	953	1,586	--
Median size of exiting farms	400	600	--

Notes: Means and medians are weighted for non-response. See Appendix B for characterization of farms.

Table 2: Predicted and Actual Percentage of Finish-only Hog Farms of Sizes that are Multiples of 1,200; 1997, 2002, and 2007

		Year		
Farm size (head)		**1997**	**2002**	**2007**
1,200-1,299				
	Actual % of farms	2.1	3.3	3.2
	Predicted % of farms	1.1	1.8	1.8
	Std. dev. of prediction	0.2	0.3	0.3
	(Actual-Predicted)/Std. dev.	5.9	5.0	5.4
2,400-2,499				
	Actual % of farms	0.9	1.6	3.3
	Predicted % of farms	0.5	0.6	0.7
	Std. dev. of prediction	0.2	0.3	0.3
	(Actual-Predicted)/Std. dev.	2.8	3.3	9.9
3,600-3,699				
	Actual % of farms	0.6	1.1	1.3
	Predicted % of farms	0.2	0.4	0.5
	Std. dev. of prediction	0.2	0.3	0.3
	(Actual-Predicted)/Std. dev.	2.3	2.2	2.8

Notes: Farms are defined in Appendix B. See text for method of generating predictions.

Table 3: Percentage of Finish-Only Hog Farms that "Avoid" Regulation Through Size Just Below Regulatory Cut-off

	Year		
	1997	**2002**	**2007**
Avoiders, not adjusting for 1,200 standard:			
% of overall number of farms	0.5%	1.0%	2.6%
Number of farms	69	107	262
Avoiders, adjusting for 1,200 standard:			
% of overall number of farms	-0.2%	-0.1%	1.5%
Number of farms	-33	-11	153
Farms with sizes over regulatory cut-off (non-avoiders)			
% of overall number of farms	12.2%	23.0%	31.1%
Number of farms	1,794	2,537	3,179
Avoidance rate			
Not adjusting for 1,200 standard	3.7%	4.0%	7.6%
Adjusting for 1,200 standard	-1.9%	-0.4%	4.6%
Statistical significance of avoidance (Test statistic value)			
Not adjusting for 1,200 standard	2.8	3.3	9.9
Adjusting for 1,200 standard	-1.3	-0.3	5.8

Notes: Avoidance rate = (# Avoiders) / (#Avoider + #Non-Avoiders). See Appendix B for definition of farms. "% of overall farms" refers to the percentage of the total number of finish-only hog farms as defined in the notes to Table 1. See text for description of test statistic.

Table 4: Test Statistic by State, With and Without Adjusted for 1,200 Barn Size; 1997, 2002, and 2007

	Not Adjusted for 1,200 Barn Size			Adjusted for 1,200 Barn Size		
	Year			Year		
State	1997	2002	2007	1997	2002	2007
Illinois	1.5	0.4	3.0	1.3	-0.1	0.5
Indiana	-0.2	-0.5	0.9	-0.6	-2.0	-0.4
Iowa	0.8	1.8	9.2	-0.8	-0.4	5.6
Kansas	-0.1	1.7	2.1	-1.0	1.3	0.1
Michigan	0.5	2.3	2.0	0.3	1.8	0.9
Minnesota	2.0	3.0	8.2	1.1	1.2	5.2
Missouri	0.5	1.6	5.1	-1.2	1.8	5.0
Nebraska	0.1	0.5	0.9	-0.9	-0.3	0.1
North Carolina	5.7	6.7	7.2	1.2	0.6	2.2
Ohio	1.0	3.6	4.5	2.5	1.4	4.2
Pennsylvania	-0.2	-0.8	-0.5	-0.4	-0.8	-0.3
South Dakota	0.5	-0.5	2.4	-2.4	-1.8	1.4
Wisconsin	1.3	1.4	0.3	2.2	1.5	-0.4

Table 5: Farm-Level Averages Before and After Announcement of 2003 CAFO Rule

	States indicating lower expected regulatory costs (IL, IN, KS, MI NE, PA, SD)		
	1997	**2002**	**2007**
All operations			
N	4,215	2,959	2,639
Operator age	47	49	51
Operator experience	20	23	26
Number of acres	661	794	854
Number of hogs	683	1,227	1,801
New entrants			
N		1,984	1,427
Percentage new entrants		67%	54%
Operator age		49	50
Operator experience		23	25
Number of acres		806	800
Number of hogs		1,266	1,830

	States indicating higher expected regulatory costs (IA, MO, MN, NC)		
	1997	**2002**	**2007**
All operations			
N	7,571	6,161	5,810
Operator age	46	48	50
Operator experience	18	21	24
Number of acres	470	576	602
Number of hogs	1,404	2,040	2,542
New entrants			
N		3,724	2,726
Percentage new entrants		60%	47%
Operator age		47	49
Operator experience		21	23
Number of acres		586	564
Number of hogs		1,855	2,335

Table 6: Farm-Level Averages Before and After Announcement of 2003 CAFO Rule

	States indicating lower expected regulatory costs (IL, IN, KS, MI NE, PA, SD)		
	Before	**After**	**Difference**
Continuing operations			
N	1,047	1,315	268
Operator age	45	48	3
Operator experience	20	22	3
Number of acres	654	875	221
Change in number of hogs	173	304	131
Percentage change in hogs	46.7%	32.7%	-14.0%
Exits plus continuing operations			
N	4,660	3,257	-1,403
Operator age	47	49	2
Operator experience	20	23	3
Number of acres	661	794	133
Exit rate	77.5%	59.6%	-17.9%

	States indicating higher expected regulatory costs (IA, MO, MN, NC)		
	Before	**After**	**Difference**
Continuing operations			
N	2,539	3,253	714
Operator age	44	47	3
Operator experience	17	21	4
Number of acres	492	607	115
Change in number of hogs	371	478	107
Percentage change in hogs	73.0%	36.9%	-36.1%
Exits plus continuing operations			
N	8,085	6,634	-1,451
Operator age	46	48	2
Operator experience	18	21	3
Number of acres	470	576	106
Exit rate	68.6%	51.0%	-17.6%

Table 7: Regression Results for Effects of Regulation on Percentage Growth

Dependent Variable: Percent change in number of hogs between t and t+1

	Size class					
		Possible Small CAFOs	Possible Medium CAFOs	Large CAFOs		
Independent Variable	**All**	**100-749**	**750-2499**	**2500 and above**	**2500-4999**	**5000 and above**
Regulation = 1	-0.233**	-0.529***	-0.114**	-0.0374	0.00364	-0.440***
	(0.102)	(0.141)	(0.0508)	(0.0573)	(0.0659)	(0.0805)
Time period fixed effects included?	**Y**	**Y**	**Y**	**Y**	**Y**	**Y**
State fixed effects included?	**Y**	**Y**	**Y**	**Y**	**Y**	**Y**
Observations	8,154	2,768	3,086	2,300	1,584	716

	Size class					
		Possible Small CAFOs	Possible Medium CAFOs	Large CAFOs		
Independent Variable	**All**	**100-749**	**750-2499**	**2500 and above**	**2500-4999**	**5000 and above**
Regulation = 1	-0.279**	-0.609***	-0.102**	0.00110	0.0357	-0.397***
	(0.104)	(0.160)	(0.0432)	(0.0628)	(0.0675)	(0.0689)
Operator age	-0.00611*	-0.0209***	0.000518	-0.00263*	-0.00399**	0.00108
	(0.00304)	(0.00692)	(0.00629)	(0.00143)	(0.00184)	(0.00307)
Years operations has been in existence	-0.00375	-0.00256	-0.00627	-0.00172	-0.00217	-0.00158
	(0.00268)	(0.0117)	(0.00698)	(0.00113)	(0.00128)	(0.00211)
Total acres at the operation	1.85e-05	7.56e-05	4.40e-05**	1.44e-05	-8.22e-06	4.27e-05**
	(2.79e-05)	(8.02e-05)	(2.01e-05)	(1.04e-05)	(1.41e-05)	(2.01e-05)
Time period fixed effects included?	**Y**	**Y**	**Y**	**Y**	**Y**	**Y**
State fixed effects included?	**Y**	**Y**	**Y**	**Y**	**Y**	**Y**
Observations	7,723	2,595	2,956	2,172	1,503	669

Notes: Observations are weighted according to the non-response adjustment weight in the beginning year of the period. Standard errors are clustered according to the state-period. Results of 12 regressions shown.

Table 8: Regression Results for Effects of Regulation on Growth

Dependent Variable: Change in number of hogs between t and t+1

	Size class					
		Possible Small CAFOs	Possible Medium CAFOs	Large CAFOs		
Independent Variable	**All**	**100-749**	**750-2499**	**2500 and above**	**2500-4999**	**5000 and above**
Regulation = 1	-22.42	-169.7***	-89.67	-185.9	56.53	-2,438***
	(52.90)	(36.25)	(55.95)	(258.0)	(214.5)	(524.9)
Time period fixed effects included?	**Y**	**Y**	**Y**	**Y**	**Y**	**Y**
State fixed effects included?	**Y**	**Y**	**Y**	**Y**	**Y**	**Y**
Observations	8,154	2,768	3,086	2,300	1,584	716

	Size class					
		Possible Small CAFOs	Possible Medium CAFOs	Large CAFOs		
Independent Variable	**All**	**100-749**	**750-2499**	**2500 and above**	**2500-4999**	**5000 and above**
Regulation = 1	-0.636	-167.2***	-95.19**	-8.921	132.6	-1,886**
	(50.59)	(34.26)	(44.85)	(267.6)	(217.3)	(686.6)
Operator age	7.299	-4.060*	3.648	17.93	-12.30*	75.17
	(11.38)	(2.335)	(8.782)	(24.05)	(6.239)	(82.30)
Years operations has been in existence	-16.42	-1.033	-12.01	-34.47	-9.149*	-77.78
	(12.25)	(4.121)	(10.10)	(26.96)	(4.996)	(73.06)
Total acres at the operation	0.113	0.0441	0.0629*	0.289	-0.0109	0.619
	(0.0693)	(0.0414)	(0.0353)	(0.180)	(0.0466)	(0.417)
Time period fixed effects included?	**Y**	**Y**	**Y**	**Y**	**Y**	**Y**
State fixed effects included?	**Y**	**Y**	**Y**	**Y**	**Y**	**Y**
Observations	7,723	2,595	2,956	2,172	1,503	669

Notes: Observations are weighted according to the non-response adjustment weight in the beginning year of the period. Standard errors are clustered according to the state-period. Results of 12 regressions shown.

Table 9: Regression Results for Effects of Regulation on Exit

Dependent Variable: Exit between t and t+1

	Size class					
		Possible Small CAFOs	Possible Medium CAFOs	Large CAFOs		
Independent Variable	**All**	**100-749**	**750-2499**	**2500 and above**	**2500-4999**	**5000 and above**
Regulation = 1	0.0159	0.0365**	-0.0402**	0.0493	0.0581	0.103
	(0.0178)	(0.0182)	(0.0204)	(0.0354)	(0.0498)	(0.101)
Time period fixed effects included?	**Y**	**Y**	**Y**	**Y**	**Y**	**Y**
State fixed effects included?	**Y**	**Y**	**Y**	**Y**	**Y**	**Y**
Observations	22,636	12,283	6,407	3,946	2,566	1,380

	Size class					
		Possible Small CAFOs	Possible Medium CAFOs	Large CAFOs		
Independent Variable	**All**	**100-749**	**750-2499**	**2500 and above**	**2500-4999**	**5000 and above**
Regulation = 1	0.00678	0.0311	-0.0509**	0.0576*	0.0792*	0.0673
	(0.0192)	(0.0192)	(0.0219)	(0.0334)	(0.0472)	(0.108)
Operator age	0.00534***	0.00338***	0.00595***	0.00598***	0.00495***	0.00611***
	(0.000440)	(0.000635)	(0.00111)	(0.00133)	(0.00123)	(0.00165)
Years operations has been in existence	-0.00139**	-0.000620	-0.00228**	-0.00552***	-0.00453***	-0.00577***
	(0.000574)	(0.000750)	(0.000918)	(0.000969)	(0.000856)	(0.00129)
Total acres at the operation	-4.86e-05***	-3.08e-05***	-2.17e-05*	-2.29e-05*	-2.08e-05	-3.36e-05**
	(1.03e-05)	(1.13e-05)	(1.14e-05)	(1.23e-05)	(1.65e-05)	(1.63e-05)
Time period fixed effects included?	**Y**	**Y**	**Y**	**Y**	**Y**	**Y**
State fixed effects included?	**Y**	**Y**	**Y**	**Y**	**Y**	**Y**
Observations	20,527	10,947	5,924	3,656	2,396	1,260

Notes: Observations are weighted according to the non-response adjustment weight in the beginning year of the period. Standard errors are clustered according to the state-period. Results of 12 regressions shown.

Appendix A: Clean Water Act Regulation Pertaining to Hog Operations

In the 1972 Clean Water Act (CWA), certain types of livestock operations of certain sizes with histories of discharging pollutants to federal waters were deemed "point sources" of pollution. To fall under the original regulation's purview, the operation first had to meet the following two stipulations:

- *Animals have been, are, or will be stabled or confined and fed or maintained for a total of 45 days or more in any 12-month period.*

- *Crops, vegetation, forage growth, or post-harvest residues are not sustained in the normal growing season over any portion of the lot or facility.*

[italicized portion directly quoted from GAO (2008), p. 61-62.]

If a livestock operation displayed these two characteristics, it was deemed "animal feeding operations" (AFOs). Only certain AFOs were regulated under the original CWA. AFOs were first characterized by number of animal units, where an "animal unit" represents approximately 1,000 pounds of live weight. If an AFO had 1,000 or more animal units, it was automatically deemed a "concentrated animal feeding operation" (CAFO). If an operation had between 300 and 999 animal units, it could also be deemed a CAFO if it satisfied one of the following two "discharge requirements":

- *Discharged pollutants into federally regulated waters through a manmade ditch, flushing system, or similar manmade device.*

- *Discharged pollutants directly into federally regulated waters that originate outside of and pass over, across, or through the facility or otherwise come into contact with animals confined in the operation.*

[italicized portion directly quoted from GAO (2008), p. 61-62.]

AFOs with 300-999 animal units could also be deemed CAFOs through discretion of the regulatory authority. Finally, operations with fewer than 300 could be deemed CAFOs on a case-by-case basis.

For hog, 1,000 animal units referred to 2,500 or more swine each weighing over 55 pounds. The medium size class covered 750-2,499 head each over 55 pounds.

The 2003 CAFO Rule did not change the size class for hogs, but did add explicit rules for swine operations with hogs under 55 pounds.

Once deemed a CAFO, an operation needed to obtain a National Pollution Discharge Elimination System (NPDES) permit. To obtain this permit, a facility had to satisfying certain requirements with regards to manure storage. Many of these stipulations remained largely unchanged with the 2003 CAFO Rule. The two main changes for hog operations with swine above 55 pounds are described in the text.

Appendix B: Further Data Description

Farm Selection

The regulatory cut-off points of the 2003 CAFO Rule pertain to the number of hogs of a certain weight at an individual farm (see Appendix A). In order to accurately reflect the operations that would fall into the regulatory framework, we focus only on operations that are likely to have most hogs over the specific weight defined in the regulations. Since the Census of Agriculture does not contain information on the number of hogs of specific weights in inventory, we need to characterize such farms in another manner. Specifically, we focus on farms that are most likely to have head each weighing 55lbs. or more. The type of operation where this is most likely to be the case is "finish only."

While farms are asked their type of operation in 2002 and 2007, we can straightforwardly characterize finish-only operations in these years. Because the 1997 Census does not include a question on type of farm, we must devise a method to characterize likely finish-only farms in that year. Finish-only operations specialize in the last phase of hog growth, feeding hogs of 50lbs. and over to market weight around 250lbs. They are therefore unlikely to have many hogs in inventory used for breeding. Examining the percentage of the total inventory that is breeding hogs for the different types of operations (Appendix Table B1) confirms this statement. In 2002 and 2007, less than 4% of inventory at self-described "finish only" operations was in breeding hogs. Further, more than 94% of these operations had no breeding hogs. To characterize finish-only operations in 1997 we first eliminate farms with any breeding hogs in inventory; examination of other levels of breeding hog inventory suggest that nothing is gained by setting the limit at a higher percentage than zero. As is evident in Appendix Table B1, nursery operations are also likely to have few breeding hogs. For 1997 we therefore also eliminate farms that had any litters farrowed or with any sales or removals of feeder pigs (information not gathered in the 2002 and 2007 Censuses).

Approximately 50% of the total number of finish-only hog farms have between 1 and 99 hogs in inventory. We exclude these farms from analysis for the following reasons. First, coverage is less complete for these smallest of hog farms; while the 2002 and 2007 Censuses include coverage adjustment factors, the 1997 Census does not. In order to be consistent over time, we therefore exclude these farms. Second, our focus is on the reactions of farms to regulation; these smallest of farms are unlikely to experience changes related to regulation. Third, farms with fewer than 100 head in inventory are unlikely to contribute a substantial portion to overall production.

To summarize, included farms are defined in the following manner:

- 2007: Self-reported "finish only" operations with no breeding hogs, at least one sale or removal during 2007, and at least 100 hogs in inventory on Dec. 31, 2007
- 2002: Self-reported "finish only" operations with no breeding hogs, at least one sale or removal during 2002, and at least 100 hogs in inventory on Dec. 31, 2002
- 1997: Operations with no breeding hogs, no sales/removals of feeder pigs, no litters farrowed, at least one sale or removal during 1997, and at least 100 hogs in inventory on Dec. 31, 1997

Appendix Table B1: Percentage of Inventory in Breeding Hogs, by Hog Production Type of Farm

	Year					
	2002			2007		
Type of operation	% of total inventory that are breeding hogs	% of farms that have zero breeding hogs	% of farms that have less than 10% breeding hogs	% of total inventory that are breeding hogs	% of farms that have zero breeding hogs	% of farms that have less than 10% breeding hogs
Farrow to wean	46%	14%	18%	50%	11%	14%
Farrow to finish	19%	22%	35%	22%	26%	37%
Finish only	2%	95%	96%	4%	94%	94%
Farrow to feeder	36%	19%	24%	40%	19%	23%
Nursery	4%	91%	93%	5%	90%	91%
Other	14%	73%	75%	18%	71%	73%

Note: This is for all farms that have at least one hog sale or removal in the year and at least one hog in inventory on Dec. 31 of the year.

Appendix C: The Problem of Characterizing State Regulation of Livestock Operations

The EPA largely devolved the enforcement of the 1972 CWA to the states. Therefore, states could enact whatever level of stringency and oversight they deemed appropriate. Further, states could adopt additional stipulations for livestock operations that were more stringent that those in the CWA. An overview in 2002 reveals heterogeneity in state regulations (EPA, 2002).

In addition to what is listed in state level regulations, there is also heterogeneity in enforcement. A 1998 overview of application of state regulations reveals marked lack of enforcement of CAFO regulations in many states (NRDC, 1998). In addition to poor state-level enforcement, the GAO has written reports critiquing the EPA's oversight of states' application of CAFO regulations (2003, 2008).

In order to characterize the expected regulatory costs associated with state-level enforcement of CWA regulations, we estimate which states in which years have a statistically unlikely percentage of farms of size just below the regulatory cut-off of 2,500 head. As described in Appendix A, the federal CWA regulations of 1972 instituted a size class stipulation. The 2003 CAFO Rule announced a "duty to apply" While we are specifically interested

While one might expect that the announcement of the 2003 CAFO Rule would lead to a uniform application of the federal regulation across states, subsequent lawsuits contesting the 2003 Rule led to different timing of adoption across states.

Appendix D: Further Result Tables

Appendix Table D1: Avoidance Rate by State, Adjusted and Not Adjusted for 1,200 Barn Size; 1997, 2002, and 2007

	Not Adjusted for 1,200 Barn Size			Adjusted for 1,200 Barn Size		
	Year			Year		
State	**1997**	**2002**	**2007**	**1997**	**2002**	**2007**
Illinois	9.5%	1.0%	4.9%	7.9%	-0.3%	0.8%
Indiana	-2.0%	-1.3%	2.2%	-8.1%	-5.9%	-1.1%
Iowa	3.0%	3.8%	8.9%	-3.4%	-1.0%	5.6%
Kansas	-1.1%	9.0%	7.5%	-9.8%	7.1%	0.5%
Michigan	4.6%	9.6%	3.8%	3.4%	7.7%	1.8%
Minnesota	9.4%	5.9%	9.5%	5.3%	2.3%	6.2%
Missouri	1.6%	6.9%	15.3%	-4.5%	7.5%	15.2%
Nebraska	1.3%	4.3%	4.3%	-11.6%	-3.4%	0.4%
North Carolina	4.6%	5.3%	4.9%	1.0%	0.5%	1.5%
Ohio	8.8%	18.5%	19.1%	19.9%	8.1%	18.0%
Pennsylvania	-1.5%	-3.4%	-1.8%	-3.0%	-3.4%	-1.2%
South Dakota	6.8%	-2.5%	11.9%	-47.7%	-9.8%	7.5%
Wisconsin	15.1%	15.4%	4.0%	22.9%	17.1%	-5.4%

Appendix Table D2: Predicted and Actual Percentage of New Entries of Finish-only Hog Farms of Sizes that are Multiples of 1,200; 2002 and 2007

Farm size (head)		Year 2002	 2007
1,200-1,299			
	Actual % of farms	3.5	3.2
	Predicted % of farms	1.7	1.6
	Std. dev. of prediction	0.2	0.2
	(Actual-Predicted)/Std.Dev.	8.1	6.9
2,400-2,499			
	Actual % of farms	1.3	3.6
	Predicted % of farms	0.6	0.7
	Std. dev. of prediction	0.2	0.2
	(Actual-Predicted)/Std.Dev.	3.3	12.8
3,600-3,699			
	Actual % of farms	0.9	0.9
	Predicted % of farms	0.4	0.5
	Std. dev. of prediction	0.2	0.2
	(Actual-Predicted)/Std.Dev.	2.4	1.8

Notes: Farms are defined in Appendix B. See text for method of generating predictions.

Appendix Table D3: Regression Results for Effects of Regulation on Exit, Linear Probability Model

Dependent Variable: Exit between t and t+1

	Size class					
		Possible Small CAFOs	**Possible Medium CAFOs**	**Large CAFOs**		
Independent Variable	**All**	**100-749**	**750-2499**	**2500 and above**	**2500-4999**	**5000 and above**
Regulation = 1	0.00202	0.0337	-0.0402*	0.0520	0.0627	0.0781
	(0.0165)	(0.0205)	(0.0200)	(0.0349)	(0.0511)	(0.0771)
Time period fixed effects included?	**Y**	**Y**	**Y**	**Y**	**Y**	**Y**
State fixed effects included?	**Y**	**Y**	**Y**	**Y**	**Y**	**Y**
Observations	22,636	12,283	6,407	3,946	2,566	1,380

	Size class					
		Possible Small CAFOs	**Possible Medium CAFOs**	**Large CAFOs**		
Independent Variable	**All**	**100-749**	**750-2499**	**2500 and above**	**2500-4999**	**5000 and above**
Regulation = 1	-0.00506	0.0276	-0.0499**	0.0588*	0.0841*	0.0404
	(0.0171)	(0.0202)	(0.0215)	(0.0329)	(0.0487)	(0.0824)
Operator age	0.00499***	0.00325***	0.00577***	0.00590***	0.00496***	0.00579***
	(0.000468)	(0.000653)	(0.00105)	(0.00131)	(0.00122)	(0.00153)
Years operations has been in existence	-0.00140**	-0.000641	-0.00221**	-0.00544***	-0.00456***	-0.00545***
	(0.000527)	(0.000691)	(0.000886)	(0.000961)	(0.000850)	(0.00123)
Total acres at the operation	-4.15e-05***	-2.69e-05***	-2.10e-05*	-2.19e-05*	-2.04e-05	-3.08e-05**
	(9.95e-06)	(9.14e-06)	(1.11e-05)	(1.11e-05)	(1.54e-05)	(1.46e-05)
Time period fixed effects included?	**Y**	**Y**	**Y**	**Y**	**Y**	**Y**
State fixed effects included?	**Y**	**Y**	**Y**	**Y**	**Y**	**Y**
Observations	20,527	10,947	5,924	3,656	2,396	1,260

Notes: Observations are weighted according to the non-response adjustment weight in the beginning year of the period. Standard errors are clustered according to the state-period. Results of 12 regressions shown.

Appendix References

National Resource Defense Council. 1998. America's animal factories: How states fail to prevent pollution from livestock waste. Online publication. http://www.nrdc.org/water/pollution/factor/aafinx.asp.

U.S. Environmental Protection Agency. 2002. State compendium: Programs and regulatory activities related to animal feeding operations. Office of Wastewater Management. Prepared by Tetra Tech, Inc., Fairfax, VA. http://www.epa.gov/npdes/pubs/statecom.pdf

U.S. General Accounting Office. 2003. Livestock agriculture: Increased EPA oversight will improve environmental program for concentrated animal feeding operations. US GAO Report to the Ranking Member, Committee on Agriculture, Nutrition, and Forestry, U.S. Senate. GAO-03-285.

U.S. General Accounting Office. 2008. EPA needs more information and a clearly defined strategy to protect air and water quality from pollutants of concern. US GAO Report to Congress 08-944. http://www.gao.gov/new.items/d08944.pdf