Effects of Size-Based Environmental Regulations: Evidence of Regulatory Avoidance

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United States environmental regulations often vary by operation size, with larger facilities facing more regulatory stringency. However, such legislative structure may have unintended consequences if operations downsize, slow their growth, or enter at a smaller scale in order to avoid regulation. In this study we use a regression-discontinuity framework and exploit the size threshold of federal and state rules targeting large-scale livestock operations to examine whether facilities adjust size to avoid regulation. We find statistical evidence of avoidance, primarily by operations entering at sizes just below the threshold.

Key words: environmental regulation, livestock, regression discontinuity, structure.

JEL codes: Q5.

United States environmental regulations often vary by operation size, with facilities larger than some threshold facing more stringent requirements. Such size-based rules may have unintended effects if existing operations downsize to avoid mandates or if greater numbers of new operations enter below the threshold. These unintended effects may have consequences for pollution abatement and economic efficiency. In industries with scale economies, size reductions may result in higher product prices and lower consumer welfare. Consequently, understanding the role of regulations in industry structure is necessary for evaluating their economic and environmental benefits.

Livestock production is an important economic activity having substantial environmental implications. Domestically, the livestock and poultry industries produce over $100 billion in cash receipts[1] and supply 90% of the country's red meat and 97% of its dairy products.[2] While economically important, livestock production has been found to be a significant contributor to water pollution as well as to atmospheric (air) pollution, e.g., through greenhouse gases (see Environmental Protection Agency [EPA] 2002a; National Research Council 2003). Livestock-related pollution is a well-known issue in many rural communities and has recently become more widely recognized in the mainstream media through the documentary *Food, Inc.* (2008), *Time* magazine's cover story "The Real Cost of Cheap Food" (Walsh 2009), and Michael Pollan's (2006) book *The Omnivore's Dilemma*. Efforts to address livestock-related pollution led to more stringent legislation under the Clean Water Act (CWA) in 2003 (EPA 2003) and may yield future stipulations and regulations of greenhouse gas emissions under the Clean Air Act (see General Accounting Office [GAO] 2008).[3] Understanding the past effects of environmental regulations on the livestock sector is important given this regulatory context and the potential impact of future legislation on farm structure, the price of food, and environmental quality.

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

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

[3] The EPA (2009) published *Endangerment and Cause or Contribute Findings for Greenhouse Gases*. This document in the Federal Register declared that greenhouse gases, including methane, were 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

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This article examines whether some livestock producers have altered their operation size to avoid costs associated with increasingly stringent size-based regulations. In the late 1990s the EPA began discussions to amend the original 1976 CWA provisions related to "concentrated animal feeding operations" (CAFOs), the regulatory term for large-scale confined livestock operations. The federal discussions culminated in the 2003 CAFO Rule, which significantly strengthened prior regulations. An important and unchanging feature of the CWA CAFO Rule is its size-based stipulation: operations with an inventory above a threshold number of head automatically fall under regulatory purview.[4] The objective of this study is to examine whether operators adjust their facility size to avoid regulations by producing right below the threshold, and whether they increase avoidance in the context of increasingly stringent requirements for those over the threshold. Findings provide information about whether this type of size-based regulation avoidance is a significant problem in the current regulatory framework and provide insights into the design of future regulations.

Our empirical approach uses methods from the regression discontinuity (RD) literature. We build on the assumption that barring regulatory avoidance, the operation size distribution would vary smoothly across the threshold. Thus a discontinuity in the distribution of operations at the threshold provides evidence of a response to regulation. This strategy relies on the sharp variation in regulation status by size. Because the CWA size threshold is constant over our period of study (1997–2007), we are able to examine whether avoidance rates changed in response to a changing regulatory landscape. We test for discontinuities in multiple subgroups to confirm whether this pattern is widespread, examine whether several observable characteristics vary discontinuously at the threshold, and consider a number of alternative explanations.

To avoid concerns that any distributional anomalies are the result of survey design and not regulations, we use individual operation-level data from the 1997, 2002, and 2007 U.S. Censuses of Agriculture. Based on the specifics of the regulation, we focus on "finish-only" hog farms in this study. To examine whether the past capital investments contribute to farm decision making with respect to regulation, we perform similar tests for continuing and entering operations. We also explore whether livestock "integrators" play a role in regulation avoidance by comparing avoidance rates for contract versus independent producers. Finally, we compare avoidance rates in thirteen major pork-producing states to examine the extent of geographic heterogeneity.

Our results indicate that four years after the 2003 CAFO Rule, 7.7% of potentially regulated operations near the threshold "avoided" by remaining just below the cutoff. We find statistically significant evidence for avoidance for both continuing operations and new entrants, with avoidance being more prevalent for new operations. Operations with production contracts are more likely to circumvent than independent operators. Results indicate a substantial heterogeneity in regulatory circumvention across states, with the strongest evidence for growth in avoidance rates between 2002 and 2007 in Iowa, Minnesota, Missouri, North Carolina, and Ohio.

Size-Based Environmental Regulation of Livestock Operations

Confined livestock production has increasingly moved to very large scale operations on which thousands of animals are raised on a relatively small amount of land. These large livestock operations often produce manure nutrients far exceeding what is required by the crops grown on-farm (Gollehon et al. 2001). However, transporting manure off-farm is expensive, and the willingness to pay for manure by crop farms is often very low because of the relatively higher costs of applying manure and because chemical fertilizers have better nutrient consistency than manure. Hence, manure has little value in many regions, creating an incentive for some livestock producers to apply it to crops at rates in excess of what plants can absorb. When operators apply manure above agronomic rates, precipitation may carry nutrients and pathogens into streams, lakes, and other water bodies. Additionally, liquid manure storage facilities can leak or overflow. Water pollutants from livestock farms have contributed to coastal dead zones, fish kills,

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, e.g., *Dairy Cares* 2009).

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

impaired drinking water supplies, and adverse public health outcomes (Copeland 2006).

The EPA first attempted to address pollution problems from livestock facilities by declaring large production operations over 1,000 "animal units" in inventory as point sources of pollution and regulating them under the 1976 CWA.[5] An animal unit is a metric to normalize across animal types and is the equivalent to 2.5 market hogs, 0.7 dairy cows, or 100 chickens. Stipulations pertaining to these "large CAFOs" involved specific waste management strategies and engineering requirements to prevent manure storage facilities from overflowing except in the event of a major storm. However, the only operations that were required to apply for a permit were ones that had already had a documented discharge to any waters of the United States; facilities that would only discharge in the event of a major storm did not need to seek permit coverage, and could avoid regulation altogether. After state authorities submitted plans detailing how they would implement the federal requirements, the EPA devolved enforcement to them; states then frequently codified these plans into state legislation. Hence many states' rules include the federal threshold (EPA 2002b; National Association of State Departments of Agriculture 2001; Environmental Law Institute 2003).

After lengthy deliberations, in 2003 the EPA updated the CWA CAFO regulations. While the definition of a large CAFO remained substantively unchanged, two new stipulations substantially increased stringency of the CWA regulations for large operations (EPA 2003). The first required all such operations to obtain discharge permits.[6] This "duty to apply" meant that a facility could not avoid regulation by simply stating that it would discharge only in the event of a major storm. For the case of hog producers, this meant that operations with 2,500 or more hogs weighing 55 lbs. in confined inventory for 45 days or more during the year automatically fell under regulatory purview (EPA 2003). The second new stipulation attempted to reduce nonpoint runoff from livestock operations through comprehensive nutrient management plans (CNMPs), which required operations to land-apply manure at rates appropriate for the soil type and crops planted. For certain operations, this would require renting or buying additional land on which to apply manure, or transporting manure off-farm.[7]

Likely in anticipation of satisfying the eventually updated federal rules, several states adopted new legislation for CAFOs in the late 1990s and early 2000s or strengthened their existing plans (EPA 2002b). Like the updated federal rules, most state updates also included the same federal threshold. Despite these similarities, there has been and continues to be wide state-level variation in implementation and enforcement (GAO 2003).

Despite the concern expressed over regulation's purported negative impacts, little empirical research has examined the effect that it may have on growth and the structure of the industry. 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. This makes it difficult to compare similar operations 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 in use on some operations, it is difficult to ascertain the costs associated with regulation *ex post*.

Partly because of these complexities, there have been few empirical evaluations of the impact of environmental regulation's effects on livestock production decisions, with most analyses focusing on the association between regulatory stringency and location. In panel analyses, Sneeringer (2009, 2010) finds that in North Carolina and California regulations are significantly associated with the growth and regional variation in hog and dairy production, respectively, in those states.

[5] 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.

[6] The only "large CAFOs" that would be exempt would be those that had "no potential to discharge." The EPA (2003) guidance document suggests that this would occur only in "limited circumstances, such as where the CAFO is so far from waters of the United States that any runoff from the land application areas could never reach them" (p. 18). The operation would need to apply to the permitting authority to obtain "no potential to discharge" status.

[7] 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 2008).

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.

There is no empirical study of which we are aware that examines the effect of environmental regulations on livestock operation size or industry structure, apart from effects on operation location. 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 variation and county variation in Clean Air Act 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 postponing of firm investment decisions until uncertainty about specific regulations is resolved.

Operation Size in the Hog Industry

The livestock industry has witnessed rapid changes over the past several decades, with implications for the distribution of farm size (Key and McBride 2007). The industry has moved to larger operations to capture economies of scale enabled by technological advances and new management and housing methods. In addition, production contracts between individual farms and integrators have proliferated, particularly in certain regions. Production contracts in the livestock sector are agreements in which integrators (the contractors) provide animals, feed, and technical expertise to producers (the contractees) in exchange for raising the animals to market weight. In 2001, 88% of the value of production in the poultry and egg industry and 61% in the hog sector occurred under these contracts (MacDonald et al. 2004).

These structural changes could have implications for how livestock operations respond to size-based regulations. Production contracts generally dictate many facets of production, including barn size. Increasing industry dominance by a small number of integrators means that these contractors' preferred farm sizes may become more common, suggesting an increasing prevalence of mass points in the farm size distribution. Because contracts in the hog industry are often long term (only 17% of contracts in 2001 were for less than a year; MacDonald et al. 2004), existing contract producers may have less ability to adjust farm size in response to market conditions or new regulations.

Regulations impose costs on producers by requiring permitting and compliance measures. The permitting process is costly in that it requires preparation of plans and may also add delays in starting production. Individual livestock producers are price takers, and therefore any additional costs related to regulation reduce profits in the short run. Despite the general trend toward larger operations, there is a suggestion in the popular press that some operations are entering at smaller sizes that enable them to avoid regulation. For example, Iowa's 2003 stipulations mandate construction requirements for hog operations with 2,500 head or more. A reporter in the state noted in 2009:

> In recent years . . . for each confinement building requiring a construction permit, almost three others have been built below the 2,500-market-hogs-per-year threshold that triggers the requirement. "At least some of those are attempts to avoid regulations," said [an environmental specialist with the state's Department of Natural Resources]. "It's definitely a loophole in the law." (Love 2009)

Another reporter from the state noted that after an operation was denied a permit for a 4,800-head facility, the operator decided instead to build a 2,400-head facility because no permit would be required for the smaller project (Strandberg 2004). This anecdotal evidence suggests that some farm operators consider regulation when choosing size.

While the originally proposed updates to the CAFO Rule suggested holding contractors at least partially responsible for environmental damages at contractee operations (National Pollutant Discharge Elimination System 2001), the current federal statutes rest environmental liability on those owning the operation (generally, the producers). Thus contractors do not have a liability reason for requiring farms to be of a certain size due to regulations. However, the matter of integrator liability has been hotly debated in a number of states and has been the subject of a number of lawsuits (Hipp and Francis 2005); hence contractors may react to this legal climate by requiring contractees to operate at sizes below the regulatory threshold. Additionally, integrators have an incentive to keep their contractees' production costs low in order to minimize the fees they must pay them. In the long term, if contract producers face higher costs due to regulation, they will demand higher fees from integrators in order to remain in business. Thus integrator and producer incentives are aligned, and the regulatory costs faced should have similar effects on farm size decisions for contract and independent producers.

Optimal Operation Size Given Capital Adjustment and Regulatory Costs

We develop a model that contrasts how existing and newly entering producers choose operation size (inventory) and capital (e.g., barns) taking into account the costs of regulation and a regulatory size threshold. Without regulations, an entering operation chooses livestock inventory L and capital K to maximize profits:

$$(1) \qquad \max_{L,K} \pi(L,K).$$

Let $\pi(L,K)$ be concave in L and K so that there is a unique L^* and K^* that solves equation (1).

Now consider an existing operation A that has already invested capital in the amount $K_A = K^*$ that cannot be adjusted. Consider what happens when a size-based regulation is introduced. Assume that the regulation imposes a fixed regulatory cost on operations with an inventory above the regulatory threshold c, where $r > 0$.[8] Also assume that the size threshold c is below the optimal unregulated size L^*. With the regulation, the objective function for the existing operation is:

$$(2) \qquad \max_{L_A} \begin{cases} \pi(L_A, K^*) - \mathrm{r} & \text{if } L_A > c \\ \pi(L_A, K^*) & \text{if } L_A \le c \end{cases}.$$

Since r is fixed, the maximum profit that can be earned at a size above the threshold is obtained at the optimal unregulated size L^*. Maximum profits above the threshold are therefore $(L^*, K^*) - r$. At a size below (or equal to) the threshold, profits are maximized at c.[9] Hence, the profit change for an existing operation from avoiding the regulation by shifting inventory size from to is:

$$(3) \qquad \Delta\pi_A = \pi(c, K^*) - [\pi(L^*, K^*) - r].$$

The optimal size for an existing operation under a size-based regulation is therefore:

$$(4) \qquad L_A^* = \begin{cases} L^* & \text{if } \Delta\pi_A \le 0 \\ c & \text{if } \Delta\pi_A > 0 \end{cases}.$$

That is, an existing operation will avoid regulations by shrinking in size from L^* to c if costs of the regulations exceed the lost profits from operating at a smaller scale.

With regulations, profits for existing farms are always lower than without regulations, even when a farm is avoiding the regulations. Profits are lower when the farm avoids the regulation because avoidance requires operating below the optimal size, L^*.

Now consider an entering operation B that is subject to the same size-based regulations. The entering operation's objective function is:

$$(5) \qquad \max_{L_B, K_B} \begin{cases} \pi(L_B, K_B) - \mathrm{r} & \text{if } L_B > c \\ \pi(L_B, K_B) & \text{if } L_B \le c \end{cases}.$$

If $L_B > c$, so that the operation does not avoid regulations, then it will maximize its profits by investing the unregulated optimal amount K^* and choosing the optimal size L^*. In this case, operation B earns a profit, $\pi(L^*, K^*) - r$, which is the same as that of the existing operation A that operates above the threshold.

Unlike the existing operation, the entering operation B has the option of avoiding the regulations by investing just enough capital K^c to maximize profits at the regulatory cutoff c. In this case, the operation earns $\pi(c, K^c)$. Hence, the profit change for an entering operation from avoiding the regulation by entering at inventory size c instead of L^* is:

$$(6) \qquad \Delta\pi_B = \pi(c, K^*) - [\pi(L^*, K^*) - r].$$

[8] Without loss of generality regulatory costs could be modeled as increasing in L such that $r(L) > 0$ and $r'(L) > 0$.

[9] Because $\pi(L,K)$ is concave, profits are increasing in L_A below size L^*. The threshold is below L^* so profits are maximized at the largest possible size below or equal to the threshold, which is c.

The optimal size for an existing operation under a size-based regulation is therefore:

$$(7) \qquad L_B^* = \begin{cases} L^* & \text{if } \Delta\pi_B \le 0 \\ c & \text{if } \Delta\pi_B > 0 \end{cases}.$$

At any regulatory cost, it will always be more profitable (or less costly) for an entering firm to avoid the regulation than for an existing firm to avoid the regulation. That is:

$$(8) \qquad \Delta\pi_B - \Delta\pi_A = \pi(c, K^c) - \pi(c, K^*) > 0.$$

Profits at the size threshold are always higher for the entering firm because it is able to invest an optimal level of capital to produce at the threshold. In contrast, the existing firm must produce with a suboptimal level of capital K^* for the inventory c. Since it is generally less costly for entering operations to avoid regulations, we would expect a higher rate of avoidance among these operations compared with existing operations.

Using this model, we can make predictions about what we expect to see in terms of operation size choices before and after regulation. First, we expect to see some existing facilities avoiding regulation by reducing their size to be under the threshold. Second, we expect some new operations to avoid regulation by entering under the threshold. Third, we expect to see more avoidance among new entrants than among continuers because it is less costly for prospective entrants to adjust their capital (barns, equipment, and so forth) before starting production.

Empirical Strategy

The goal is to estimate the magnitude and statistical significance of anomalies in the distribution of operation sizes near the regulatory threshold of the CAFO Rule. This regulatory delineation has existed at the federal level since the original rules in the 1970s and has therefore been in effect throughout the period that we examine (1997 to 2007). Further, we limit our sample to states that have adopted the threshold (see below). Evidence of statistical anomalies around the regulatory threshold demonstrates one method that operations adjust size according to regulation. We employ methods found in the regression discontinuity (RD) design literature to test for such statistical anomalies.

We proceed in the following manner. First, we provide a brief overview of RD designs that we use later in the paper when considering alternative explanations for our findings besides regulatory avoidance. Second, we describe a test that is an accessory to RD analysis but serves as the basis for our analysis. This test assesses whether there is a statistically significant discontinuity in the probability distribution of operation sizes at the regulatory threshold. The size of the discontinuity provides an estimate of the extent of avoidance. Finally, we consider longitudinal aspects of the data, describe our test for potential effects of observable covariates, discuss how state-level regulations factor into analyses, and specify the samples used.

Basic RD design

In the RD design, a discrete jump in the probability of treatment over the values of an observable variable is exploited to estimate the effects of that treatment on some outcome.[10] Consider a deterministic and discontinuous rule in which treatment is assigned on the basis of some continuous measure such that those with a value above a threshold receive treatment while those below do not. The basic RD approach is to compare those just above the threshold with those just below. Because this sorting around the threshold is as good as random, those just above serve as a reasonable counterfactual to those just below. Thus comparing outcomes across these two groups allows one to plausibly estimate the causal effect of the treatment on the outcome.

The empirical method is to estimate a regression of the outcome on both the indicator variable for treatment and a flexible function of the continuous measure. Conditioning on the continuous variable, there is no additional variation in the indicator variable; therefore, this indicator variable cannot be correlated with any other factor that does not also jump at the cutoff. Observable and unobservable factors are arguably very similar for those just above and just below, so the difference in the outcome variable at the cutoff provides a causal estimate of the effect of the treatment on the outcome. Note that the pertinent variation used to identify causal effects is cross-sectional;

[10] For thorough descriptions of RD theory and implementation in economics, see Lee and Lemieux (2009) and Imbens and Lemieux (2008).

other periods of time may be useful for robustness checks, but longitudinal variation should provide no further information.

To apply the RD design to outcomes related to regulation (which we do later in the article when considering alternative explanations), let S_i be the size of operation and let c be the regulatory threshold over which operations are regulated. Regulation status (D_i) is a deterministic and discontinuous function of size: $D_i = 1(S_i \geq c)$. A basic parametric RD model is:

$$(9) \qquad Y_i = \alpha + f(S_i) + \lambda D_i + D_i g(S_i) + e_i$$

where Y_i is an outcome for operation of size S, $f(S_i)$ and $g(S_i)$ are smooth functions of size below and above c (respectively), and e_i is an unobserved error component. The parameter λ measures the discrete change in the expectation of Y_i that occurs at c. Discrete jumps in Y_i at the regulatory cutoff are arguably attributable to the regulation under the assumption that other determinants of Y_i vary smoothly across c.

Notably, the estimate of λ will depend on appropriately fitting the smooth functions ($f(\cdot)$ and $g(\cdot)$) above and below the threshold. While the parametric version of the RD model in equation (9) is useful for explicative purposes, nonparametric methods are generally thought to more flexibly fit the smooth functions. We therefore make use of such methods when we later apply the standard RD method.

Testing for sorting around the threshold

The identification of a regulation's effect on some outcome (Y_i) via the RD design relies on operations not deliberately choosing their size based on the threshold. However, if operations were to sort on the basis of the threshold, this condition would be violated and would provide evidence of regulatory avoidance. McCrary (2008) develops a method to formally test for discontinuous jumps in the probability distribution of the determining variable. The logic (and method) is much the same as for the RD case described in equation (9). The pertinent identifying assumption is that factors in an operator's size decision vary continuously across the threshold. For example, there are unlikely to be major scale efficiency disadvantages to being sized $c - \varepsilon$ compared with $c + \varepsilon$, where c is the cutoff. Thus, using the RD framework, observed and unobserved factors that vary continuously across the threshold are plausibly controlled for.[11]

To estimate whether there is a statistically significant break in the probability density of farm size at the regulatory cutoff, we follow McCrary's two-step procedure. In the first step we create a histogram of the number of operations in each of J equally sized bins of width b, where X_j and N_j refer to the midpoint and the (normalized[12]) number of observations in bin j, respectively; the number of observations in bin j is found by summing the number of observations over i with a size S_i such that $X_j - \frac{b}{2} \leq S_i < X_j + \frac{b}{2}$. We start with a bin width of 100 but compute several robustness checks using alternate bin sizes. The minima and maxima of the bins are set so that no one bin includes observations on both sides of the regulatory cutoff.

In the second step, we use a smooth function to estimate the discontinuity at c, where N_j serves as the outcome, while X_j represents the covariates. D now refers to whether a bin's midpoint is greater than or equal to the cutoff: $D_j = 1(X_j \geq c)$. A parametric version of this relationship would take the form:

$$(10) \qquad N_j = \alpha + h(X_j) + \gamma D_j + D_j k(X_j) + v_j.$$

The coefficient γ would provide an estimate of the discontinuity at c, and the standard error of this coefficient provides a test of statistical significance.

Instead of imposing a functional form as in equation (7), McCrary recommends nonparametric methods to allow for the most flexibility in estimating the predicted density approaching the threshold from the left and the right.[13] Using McCrary's notation, let $\hat{f}^{-1}$ and $\hat{f}^{+}$ be the estimated values of the density approaching c from the left and the right, respectively. The discontinuity test statistic is the log difference in these values:

$$(11) \qquad \hat{\theta} = ln\hat{f}^{+} - ln\hat{f}^{-}.$$

[11] In robustness checks in the paper we examine whether observable factors such as productivity vary discontinuously at the threshold. If they do, this provides an alternate reason why (aside from regulation) operations may bunch right below the threshold.

[12] For this test, normalization refers to adjusting the number of observations such that the area of the histogram equals one. Thus if Q_j is the actual count of observations in bin j, b is the bin size, and n is the total number of observations, $N_j = Q_j/nb$.

[13] Since we perform this test for multiple subgroups and years, the shape of each distribution differs. Thus using nonparametric methods also allows us to avoid having to test and support multiple functional forms specific to each subgroup and year.

McCrary also describes a procedure to compute a standard error for this difference, denoted $\hat{\sigma}_\theta$.[14] Dividing $\hat{\theta}$ by $\hat{\sigma}_\theta$ generates a t-statistic with standard critical values and properties.[15] To estimate $\hat{f}^-$ and $\hat{f}^+$ we use local linear regressions with a triangle kernel and a bandwidth of 1,000; we also estimate multiple robustness checks with alternate bandwidths.[16] We report the actual size of discontinuity (estimated using the nonnormalized bin count), as well as the t-statistic generated from $\hat{\theta}$ and $\hat{\sigma}_\theta$.

Using longitudinal aspects of the data

We use the sharp variation in regulatory status across size in each time period to identify effects of the threshold. While we examine multiple years and note that federal and state regulations become more stringent over time, we do not rely on time-based variation for identification. As the threshold is unchanging over time there is no temporal variation in this regulatory stipulation. What is changing over time is regulation stringency, implementation, and enforcement, at both the state and federal levels. Additionally, anticipation of changes in these factors may evolve over time. Thus it is important to note that our strategy does not allow us to separate many of these effects from each other.

While the regression discontinuity design rests on cross-sectional variation in regulation status, we can make use of the fact that we have multiple time periods for additional testing. First, we can test for a discontinuity in each year to evaluate whether avoidance becomes more (or less) prevalent over time. While we expect that a discontinuity would become more prevalent after the announcement of the 2003 CAFO Rule with its more stringent policies, it is possible that operations anticipated future regulatory changes and therefore adjusted before 2003 or that abiding by the original CWA regulations was costly enough to spur size adjustment (particularly given heterogeneity in state enforcement and stringency).

Second, we can evaluate whether there is a discontinuous break in distributional *change* over time at the regulatory cutoff. For this strategy, allow N_{jt} to be the number of observations in bin j and time t. We perform a regression discontinuity test using $N_{jt+1} - N_{jt}$ as the outcome variable and X_j as covariates.[17] This allows us to examine whether the growth rate in different sizes changed differently with respect to the regulatory cutoff. A parametric version of this test would be:

$$(12)\qquad N_{j,t+1} - N_{j,t} = \alpha + h(X_j) + \gamma D_j + D_j k(X_j) + w_{j,t}.$$

Here, D_j retains its prior definition. By differencing each size group, we can allow growth rates to differ across the distribution but control for features of a size class that are fixed over time. For example, if some size class was associated with unusually high or low productivity, we might expect that size class to contain a larger percentage of the overall distribution in the cross-section. If this unusual productivity was unchanging over time, then differencing will allow us to control for this feature. Again we present the parametric description for explanatory purposes (equation (9)), but in application we estimate the discontinuity using local linear regression, and bootstrap the standard errors.[18]

Effect of covariates

As the RD literature makes clear, if other factors aside from regulation vary smoothly across the threshold, then controlling for additional covariates will likely have little effect on the estimated discontinuity. This includes fixed and time effects in the case of longitudinal or pooled data.[19] However, we test for the impact of other covariates in the following manner. We examine whether several observable outcomes that also may be associated with an operator's size decision show discontinuities at the regulatory threshold. For example, if operations of

[14] Allowing h to be the bandwidth, $\hat{\sigma}_\theta = \sqrt{\frac{1}{nh}\cdot\frac{24}{5}\left(\frac{1}{\hat{f}^+}+\frac{1}{\hat{f}^-}\right)}$.

[15] See McCrary (2008) for proofs and simulations showing the properties of the test statistic.

[16] McCrary (2008) outlines why this method is preferable to performing kernel density estimates on either side of the threshold; specifically, the RD design is fundamentally concerned with a prediction at a boundary, and kernel density estimates are widely accepted to be biased at boundaries (p. 701).

[17] Note that X_j is a midpoint of a bin and therefore does not vary over time.

[18] The RD methods described here would not be useful in examining other types of outcomes that would *not* be expected to "jump" at the regulatory boundary. For example, the change in a continuing operation's size would likely smoothly vary across the boundary even as operations avoid regulation. This is because operations that are size $c + \varepsilon$ would have an incentive to reduce their size by ε, while operations that are $c - \varepsilon$ would want to increase size by only ε. Likewise, operations sized $c + 2\varepsilon$ would want to shrink by 2ε, and operations sized $c - 2\varepsilon$ would want to grow by more than 2ε. Plotting these changes would provide a linear and smooth relationship across the threshold.

[19] See Lee and Lemeiux (2009) for discussion.

size $c - \varepsilon$ had much higher productivity than those at size c, we may expect operations to bunch at $c - \varepsilon$ due to the productivity gain. We would then expect to see a discontinuity in productivity by size at c. We therefore employ RD methods to estimate whether there is a discontinuity at the regulatory threshold in several observable variables. For this, we use the RD approach described in equation (9); the outcome variables we consider are productivity (calculated as total value of product divided by total expenditures), total value of product, and total expenditures.

Effects of state-level regulations

As described in the background section, implementation and enforcement of the federal rules were devolved to individual states after EPA approved states' plans for rule abidance. This procedure often yields conformity in state rules. Examination of state-level statutes in effect between 1997 and 2007 (our time period of interest) suggests that most states adopted the same threshold as the federal in their regulation of livestock operations (e.g., see Environmental Law Institute 2003; EPA 2002b; National Association of State Departments of Agriculture 2001). We limit our main sample to those states with the federal regulatory threshold throughout the 1997 to 2007 period. In Appendix C we provide narratives of the regulatory changes between 1997 and 2007 for the hog production states included in the sample; in the Results section we discuss how some of these state-level regulatory changes interact with our state-level results.

The threshold remains constant for the states in our sample over our period of study. However, regulatory requirements for operations above the threshold and enforcement activity vary across states over time. In this article, we do not attempt a detailed account of required practices and enforcement activity by state over time. Thus our findings of discontinuities should be interpreted as avoidance of size-based regulation, not avoidance of some specific mandated management practice. Despite this, we provide some anecdotal evidence to contextualize some of our individual state findings with regard to state adoption of stipulations. Further, our testing of multiple states allows us to confirm the similarity in the structure of states' laws and also to test whether one individual state drives results.

Table 1A. Summary Statistics for Finish-Only Hog Farms

	Year		
	1997	2002	2007
Main Sample			
Unweighted number of operations	10,187	7,764	7,236
Weighted number of operations	11,093	8,474	7,954
Hogs in inventory:			
Mean	912	1,693	2,428
Standard deviation	2,262	4,123	6,292
25% quantile	229	380	500
Median	429	850	1,200
75% quantile	916	2,000	2,700
Mode	200	500	2,000
Entire U.S.			
Unweighted number of operations	13,550	10,160	9,386
Weighted number of operations	14,650	11,021	10,232
Hogs in inventory:			
Mean	1,186	1,906	2,640
Standard deviation	2,491	3,953	6,169
25% quantile	236	400	500
Median	480	950	1,350
75% quantile	1,100	2,300	3,050
Mode	200	500	2,000

Note: All statistics refer to finish-only operations over 100 head. Thus, the percentage of U.S. sales and removals covered by the sample refers to the number of sales and removals at finish-only operations over 100 head in the sample divided by the number of sales and removals at finish-only operations over 100 head in the United States. See Appendix B for further characterization of operations. Means and medians are weighted for nonresponse. The weight is provided by NASS to expand to a sample representative of the population.

Data

We use individual operation-level data from the 1997, 2002, and 2007 U.S. Censuses of Agriculture to examine the size of operations before and after regulations. Access to these data is restricted to specific computer labs and requires an approval process through the National Agricultural Statistics Service (NASS).[20] We use a NASS-provided weight to adjust for nonresponse in all analyses. The NASS weight allows data users to expand from the number of respondents to the universe of farms.[21]

Because EPA regulations are specific to animal type, we focus only on one animal type, specifically hog operations. The 2003

[20] For more information, see http://www.agcensus.usda.gov.
[21] While the Census of Agriculture is mandatory, there is still nonresponse, particularly among very small operations.

Table 1B. Summary Statistics for Finish-Only Hog Farms

	Entire U.S.		Sample	
	Year		Year	
	2002, %	2007, %	2002, %	2007, %
% of operations that are independent producers	51	44	57	49
of independent operations that are continuing	32	45	32	46
of independent operations that are new entrants	68	55	68	54
% of operations that are contract producers	51	53	45	48
of contract producers that are continuing	42	54	37	51
of contract producers that are new entrants	58	46	63	49
% of operations that are continuing	37	50	34	48
of continuing operations that are independent producers	45	40	54	46
of continuing operations that are contract producers	58	58	49	51
% of operations that are new entrants	63	50	66	52
of new entrants that are independent producers	55	49	59	52
% of new entrants that are contract producers	46	48	42	46
Contract operations: Number of head				
Mean	2,372	2,977	1,928	2,549
Median	1,450	2,000	1,080	1,763
Independent operations: Number of head				
Mean	1,280	2,065	1,326	2,132
Median	600	860	625	950
New entrants: Number of head				
Mean	1,821	2,621	1,723	2,479
Median	850	1,155	800	1,050
Continuing operations: Number of head				
Mean	2,053	2,658	1,634	2,374
Median	1,055	1,614	900	1,320

Note: All statistics refer to finish-only operations over 100 head. Means and medians are weighted for nonresponse. See Appendix B for characterization of operations. Size given for continuing operations are sizes in the end year.

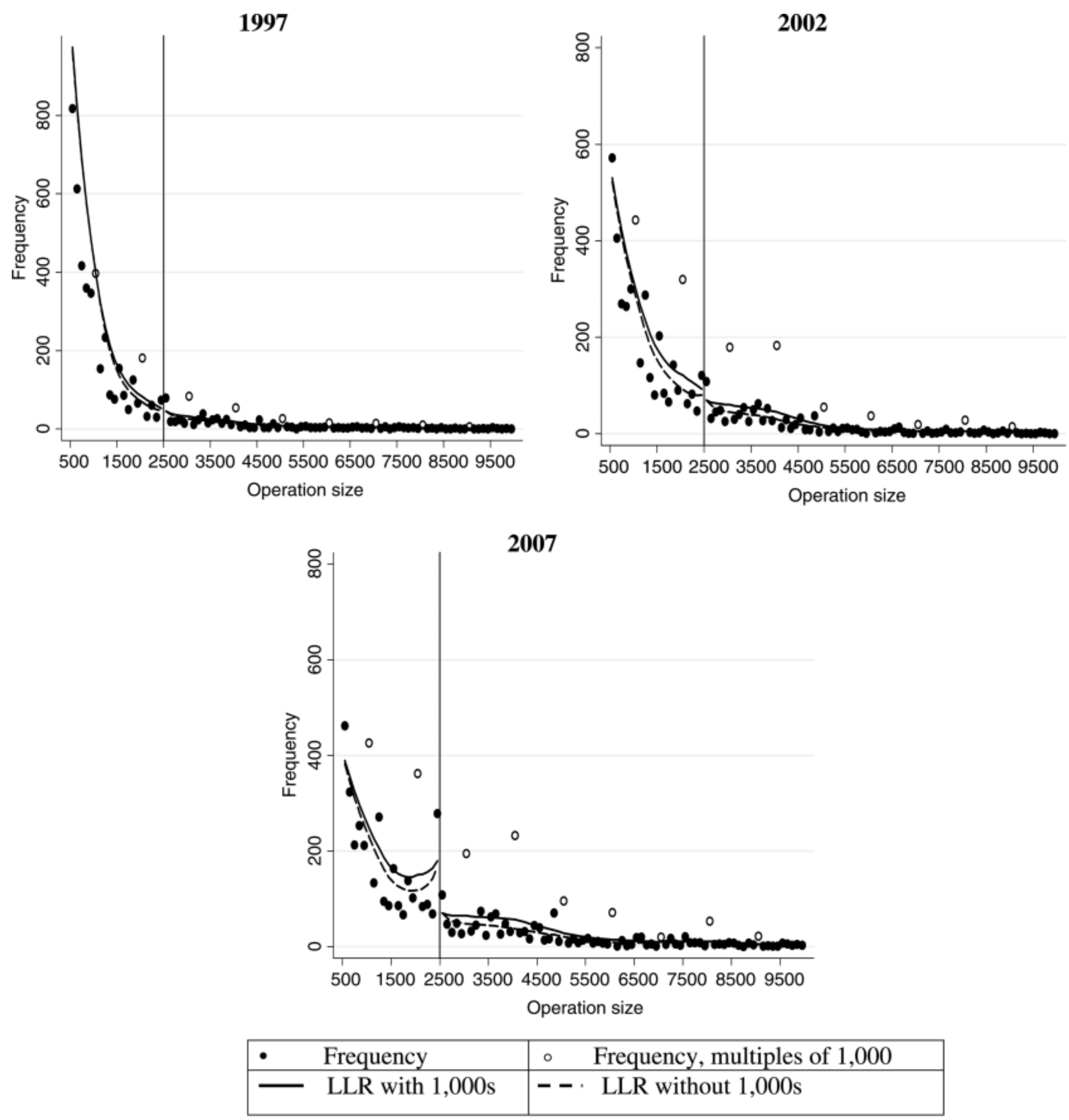
CAFO Rule included stipulations pertaining to operations with different weights of hogs. In particular, there are different regulatory size thresholds for operations raising hogs weighing at least 55 lbs. versus less than 55 lbs. These weights correspond to particular types of hog operations. There are three major categories of hog production facilities distinguished by the stage of growth occurring there: "farrow-to-feeder," "farrow-to-finish," and "finish-only." Finish-only operations will have hogs that are all at least 55 lbs. each, while farrow-to-feeder operations will have mostly piglets under 55 lbs. Farrow-to-feeder operations will include hogs both over and under 55 lbs. To observe a uniform regulatory size threshold, we therefore focus only on finish-only operations.[22]

We restrict the analysis in all years to operations that had positive hog sales or removals,[23] had no breeding hogs that might indicate the presence of piglets under 55 lbs., and had at least 100 hogs in inventory on December 31(see Appendix B for further data description). Continuing farms and new entrants are identified by matching operations over time according to unique Census identifiers. Information on contract production exists in only the 2002 and 2007 Censuses; hence, continuing operations' contract status is characterized in the end year.

We limit our sample to specific states for two main reasons. First, we test for distributional discontinuities at the state level, meaning that a state needs to have a significant number

[22] This type of operation can be easily discerned in the 2002 and 2007 Censuses as operators were asked their operation type; however, this information was not directly gathered in 1997. For that year, 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).

[23] 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.



Note: LLR = local linear regression. The vertical line at 2,500 head represents the regulatory threshold.

Figure 1. Distribution of operation sizes: 1997, 2002, and 2007

of operations such that a distribution can be adequately characterized. We therefore restrict the study to states with 100 or more finish-only operations in each Agricultural Census between 1997 and 2007. This limits us to thirteen states. Second, states need to have the federal regulatory threshold in place (as part of state law) throughout the period in question. The nine states that satisfy these two requirements are Illinois, Iowa, Kansas, Missouri, Minnesota, Nebraska, Ohio, South Dakota, and Wisconsin. These nine states characterize our "main sample" and cover approximately three-quarters of all finish-only hog farms in the United States. Four other states with significant hog production but without the federal regulatory threshold in place throughout the period were Indiana, Michigan, North Carolina, and Pennsylvania.[24] We perform individual tests for these states, describing them in the context

[24] See Appendix C for a description of included states' regulatory histories.

of their specific state regulations, but do not include them in the main sample.

We divide our main sample across several lines in order to examine how regulation interacts with other factors. To consider the importance of essentially irreversible capital investments in the avoidance decision, we perform the same analyses for the cross sections of all farms, continuing operations, and new entrants. To explore the effect of contract relationships, we also compare contract farms and independent farms and disaggregate these into continuing and new operations. Finally, we repeat the analyses for each state distribution to test for regional heterogeneity of compliance costs.

Tables 1A and 1B provide summary statistics for our main sample of nine states and examine its comparability to the U.S. population. Our sample covers more than three-quarters of all U.S. operations in each year. The various statistics characterizing the distributions suggest strong similarities between our main sample and the U.S. population. Over time the number of farms decreases, while the mean and median number of hogs in inventory per facility increases. Table 1B shows that around half of the sample consists of independent operations in 2002 and 2007. New entrants make up a smaller share of the sample in 2007 compared with 2002. Contract operations are larger in size than independent operations. There are similar shares of independent and contract producers among the new entrants and continuing operations.

Results

Figure 1 shows the distribution of operations in 1997, 2002, and 2007. For expository purposes only the sizes between 500 and 10,000 are shown.[25] Each dot represents the number of observations in that size class. The smooth lines show the results of the local linear regressions. The vertical line at 2,500 denotes the regulatory threshold.

As is evident, a smaller percentage of farms occupy the smallest size classes over time as the distribution changes. Also noticeable is the increasing frequency of mass points at multiples of 1,000 (hollow circles), which appear as outliers from the distributions, particularly in 2002 and 2007.

Table 2. Size of Discontinuity and Test Statistics Using All Finish-Only Hog Farms with 100 or More Head

	1997	2002	2007
Entire sample	−1.71	−18.49	−114.14
	0.25	*2.11*	*9.93*
New entrants		−13.94	−73.25
		2.07	*8.39*
Continuing operations		−4.55	−40.89
		0.81	*5.45*
Contract producers—all		−19.15	−88.30
		3.01	*9.38*
Contract producers—new entrants		−14.28	−54.98
		2.95	*7.63*
Contract producers—continuing operations		−4.88	−33.32
		1.18	*5.48*
Independent producers—all		4.25	−22.86
		0.69	*3.54*
Independent producers—new entrants		1.02	−18.07
		0.21	*3.69*
Independent producers—continuing operations		3.22	−4.79
		0.82	*1.13*

Note: Shown are estimates of size of and direction of the discontinuity and t-value of the test statistic (in italics). Sample includes finish-only hog operations with 100 or more hogs in the nine states listed in the text. The sizes of the discontinuities are estimated using local linear regression with a bin size of 100 and a bandwidth of 1,000. The discontinuity is measured as the estimate from the right of the cutoff minus the estimate from the left of the cutoff. The t-values are estimated by calculating theta (θ; as described in the text and by McCrary [2008]) and its standard error and then dividing θ by its standard error and taking the absolute value. The magnitudes of the t-values correspond to standard critical values for samples with 100 or more observations.

The increasing magnitude over time of a discontinuity at the regulatory threshold is evident. Table 2 provides the magnitude of the estimated discontinuities for different samples in each year along with t-statistics measuring statistical significance. In 1997, there is a small, statistically insignificant discontinuity. By 2007 this has become a strongly significant discontinuity of 114 operations.[26]

[25] While we show the operations between only sizes 500 and 10,000, we perform the statistical analyses (shown in tables 2–4 for the entire distribution above 100 head. Robustness checks including operations with at least one hog yield strongly similar results (compare Appendix table A1 to table 2).

[26] This discontinuity of 114 operations is noted as a negative number in table 2 because it is calculated by subtracting the estimate at the left of the cutoff from that at the left. If a parametric test were to be done as in equation (10), this would correspond to an estimate of γ.

Table 3. Avoidance Rates

	Year		
	1997, %	2002, %	2007, %
Avoidance rate as % of all potentially regulated operations			
Entire sample	0.22	**1.15**	**5.03**
New entrants		**1.35**	**6.57**
Continuing operations		0.78	**3.54**
Contract producers—all		**1.96**	**6.64**
Contract producers—new entrants		**2.37**	**9.20**
Contract producers—continuing operations		1.29	**4.55**
Independent producers—all		0.68	**2.66**
Independent producers—new entrants		0.25	**3.84**
Independent producers—continuing operations		1.45	1.24
Avoidance rate as % of potentially regulated operations of size 2,500–5,000 head			
Entire sample	0.31	**1.58**	**7.68**
New entrants		**1.92**	**10.51**
Continuing operations		1.03	**5.18**
Contract producers—all		**2.58**	**9.90**
Contract producers—new entrants		**3.16**	**14.32**
Contract producers—continuing operations		1.68	**6.55**
Independent producers—all		0.95	**4.08**
Independent producers—new entrants		0.37	**6.06**
Independent producers—continuing operations		1.88	1.82

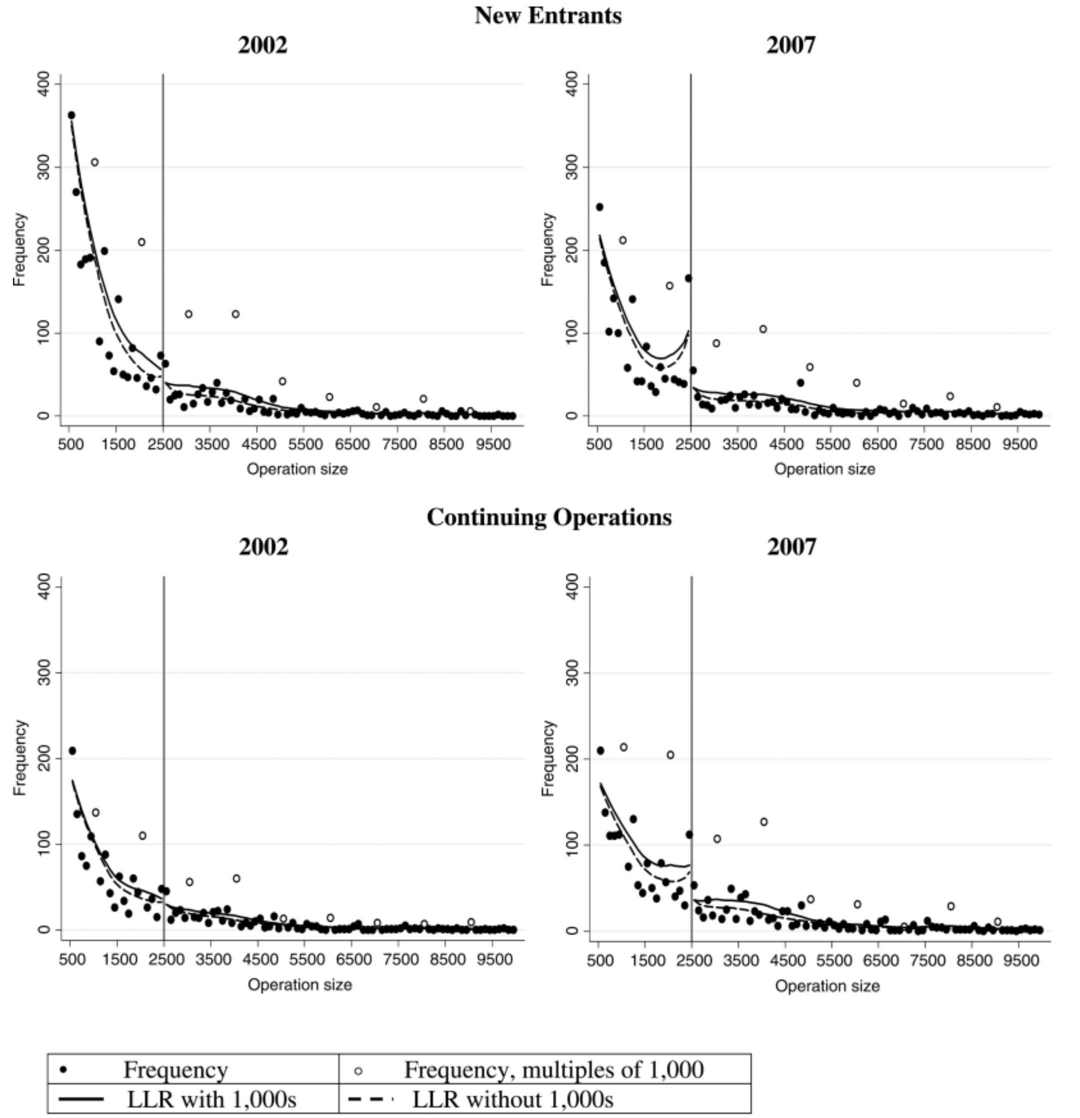
Note: Avoidance rate is calculated as: Avoiders/(Avoiders + Nonavoiders). Percentages in bold are statistically significant at the 5% level (see table 2).

Table 3 places the magnitude of the discontinuity in relationship to the rest of the distribution by showing two avoidance rates. The first avoidance rate is the number of avoiders divided by the number of all potentially regulated operations; for example, in 2007 there were 2,155 operations at or above 2,500 head, so the avoidance rate was $114/(114 + 2155) = 5.0\%$. However, this assumes that had they not avoided regulation, these operations would have been *any* size above 2,500 head. It is more likely that these operations would have chosen a size closer to the regulatory threshold; we therefore present a second avoidance rate which is a percentage of potentially regulated operations sized 2,500 to 5,000 head. Thus in 2007 this more realistic avoidance rate was 7.7%.[27]

The 1,000-head mass points have been highlighted to examine whether they affect the estimate of the discontinuity. These mass points appear as outliers and likely shift the smoothed functions upward. If the multiples of 1,000 *below* the threshold are the same distance away from the rest of the distribution as the multiples of 1,000 *above* the threshold, then the smooth function on both sides of the regulatory threshold may be shifted up by the same amount. This would not influence the estimated size of the discontinuity. However, the discontinuity estimate could be affected if the multiples of 1,000 *below* the regulatory threshold are more extreme outliers than those *above*. This would pull upward the smooth function below the regulatory threshold more than above it, leading to an overestimated discontinuity. We therefore estimate the local linear regressions without the multiples of 1,000 (shown as the dotted lines); the corresponding discontinuity estimates and statistical significance can be found in Appendix table D2. These estimates are largely similar to those in table 2; the only consistent difference is that the discontinuities in 2002 are largely not statistically significant at standard levels.[28]

[27] There were 1,373 operations between 2,500 and 5,000 head in 2007.

[28] As a series of robustness checks, we estimate the local linear regressions for the 2007 main sample using a variety of bin sizes and bandwidths (Appendix table D3). The resulting estimated discontinuities are always significant but change in size; larger bin sizes and smaller bandwidths generally provide larger estimates of the discontinuity. McCrary (2008) also provides a method of calculating a "default" bin size and bandwidth, although he suggests that visual inspection of how well the smooth function fits the observations should play a predominant role in choosing these parameters. McCrary's default bin size is calculated as $\hat{b} = 2\hat{\sigma}n^{-1/2}$, where $\hat{\sigma}$ is the sample standard deviation of operation size. In our main sample, this yields a bin size of 122. His bandwidth selection procedure is more involved (see p. 705) and yields a value of 20,012. Using this bin size and bandwidth results in a similar estimate of θ (−0.987) compared with using a bin size of 100 and bandwidth of 1,000 (as in the main text; the estimate of θ −0.965). However, McCrary's method yields a much smaller standard error of θ (0.023 versus



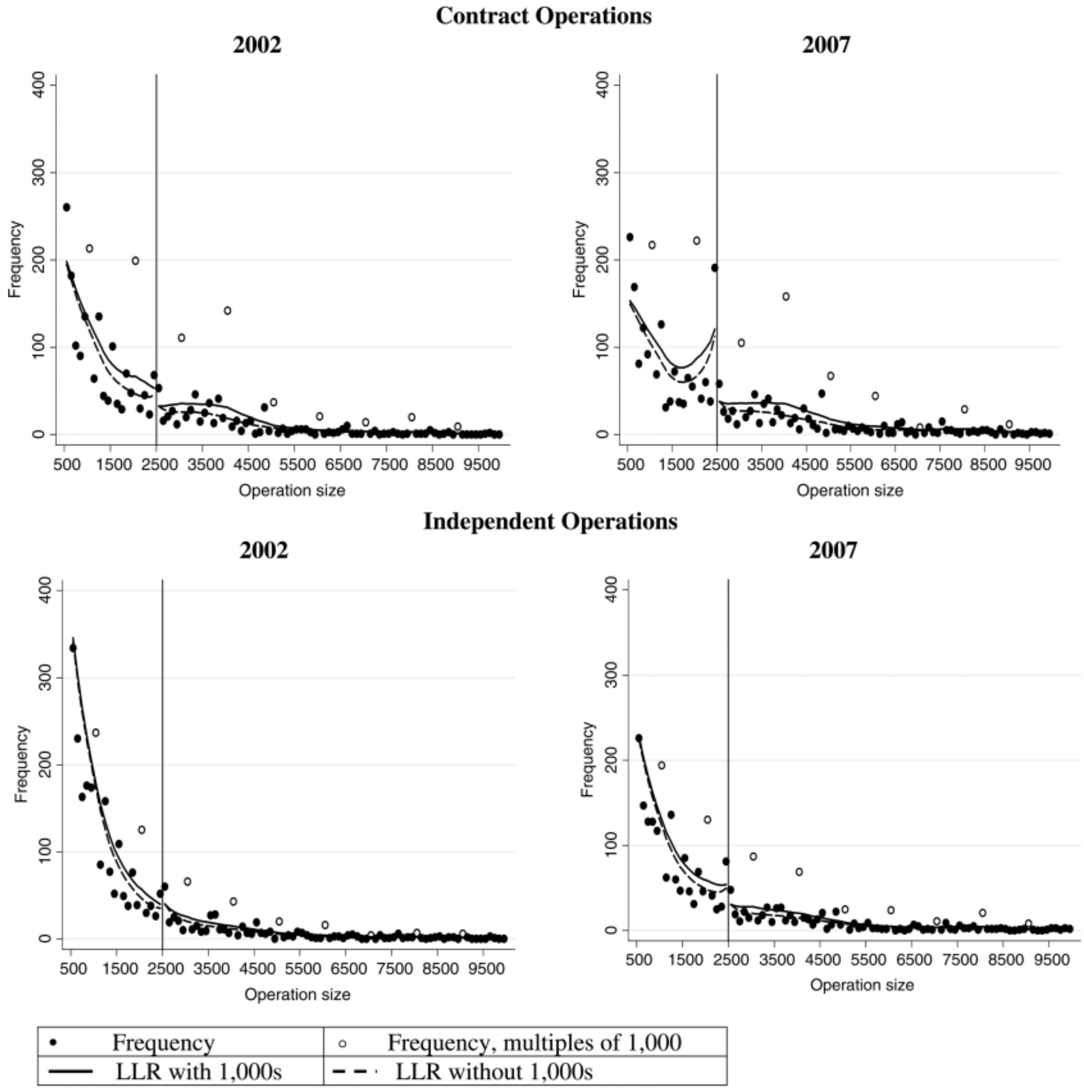
Note: LLR = local linear regression. The vertical line at 2,500 head represents the regulatory threshold.

Figure 2. Distribution of new entrants versus continuing operations: 2002 and 2007

Avoidance is more pronounced for new entrants than for continuing operations. Figure 2 shows distributions in 2002 and 2007 for new entrants and continuing operations; the accompanying discontinuity size estimates, *t*-statistics, and avoidance rates appear in tables 2 and 3. As a percentage of potentially regulated operations with 2,500 to 5,000 head, new entrants exhibit a 10.5% avoidance rate, while that for continuing operations is only 5.2%.

Figure 3 reveals that avoidance is more common among contract than independent operations, although it exists in both groups. Estimates of discontinuity sizes and avoidance rates are shown in tables 2 and 3. In 2007, contract producers exhibited an avoidance rate of 9.9% of operations near the threshold (2,500 to 5,000 head), while independent producers' comparable rate is less than half of this, at 4.1%. New contract producers have the highest avoidance rate, at 14.3%, while continuing

0.097 using our values). Thus choosing bin size and bandwidth by McCrary's proposed "default" method yields even stronger results than the one presented in the text.



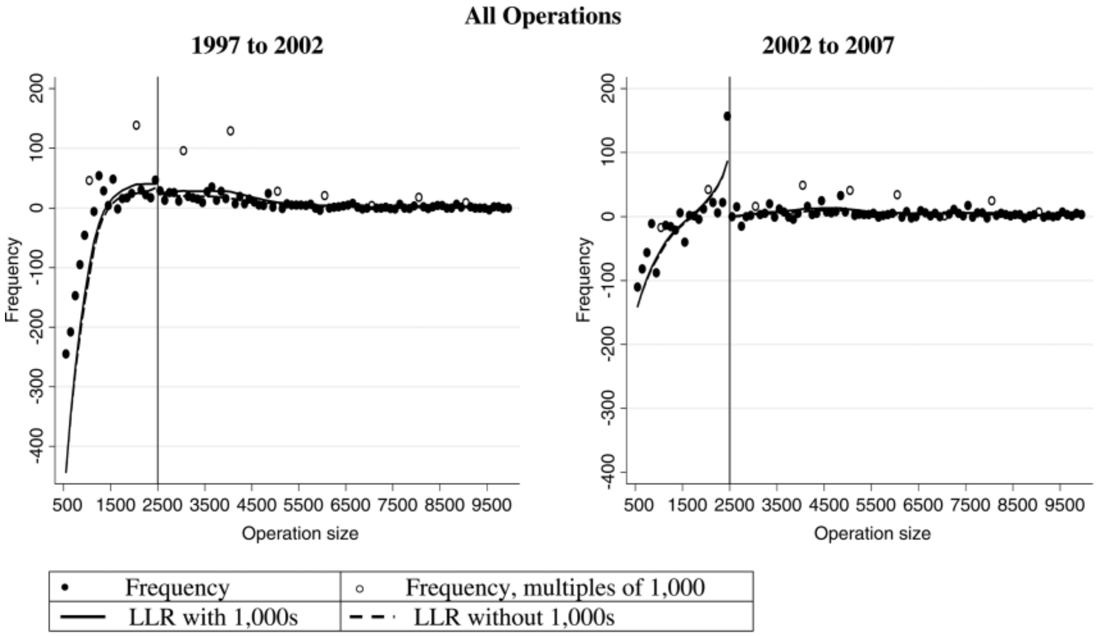
Note: LLR = local linear regression. The vertical line at 2,500 head represents the regulatory threshold.

Figure 3. Distribution of contract versus independent operations: 2002 and 2007

independent operations do not exhibit avoidance statistically different from zero.

Turning to the distribution of changes over time, figure 4 shows that while distributional change by size is fairly smooth between 1997 and 2002, it shows a discontinuity at the regulatory threshold between 2002 and 2007, with the number of farms in the size bins just below the threshold increasing and the number in the bins above the threshold staying about the same. This distributional change is most noticeable for contract operations and new entrants (figure 5). The statistical significance of these estimates is not as strong as in the cross sections (table 4).

Table 5 provides the estimate of the discontinuity, the *t*-statistic, and the two avoidance rates for each of the nine states included in the main sample, as well as the four additional major hog-producing states. Results suggest substantial variation in the timing and stringency of state regulation pertaining to the 2,500-head regulatory cutoff. Of the nine states in the main sample, Iowa and Missouri displayed statistically insignificant discontinuities in 2002 (before the announcement of the 2003



Note: LLR = local linear regression. The vertical line at 2,500 head represents the regulatory threshold.

Figure 4. Distribution of changes in distribution

CAFO Rule) but significant ones in 2007 (after the announcement). Ohio shows statistically significant avoidance in 2002 as well as 2007, while Minnesota's discontinuity is significant (at the 10% level) in all three years but grows between 2002 and 2007. For these states, avoidance rates in 2007 ranged between 4.6% and 22.9% (for farms with 2,500 to 5000 head).

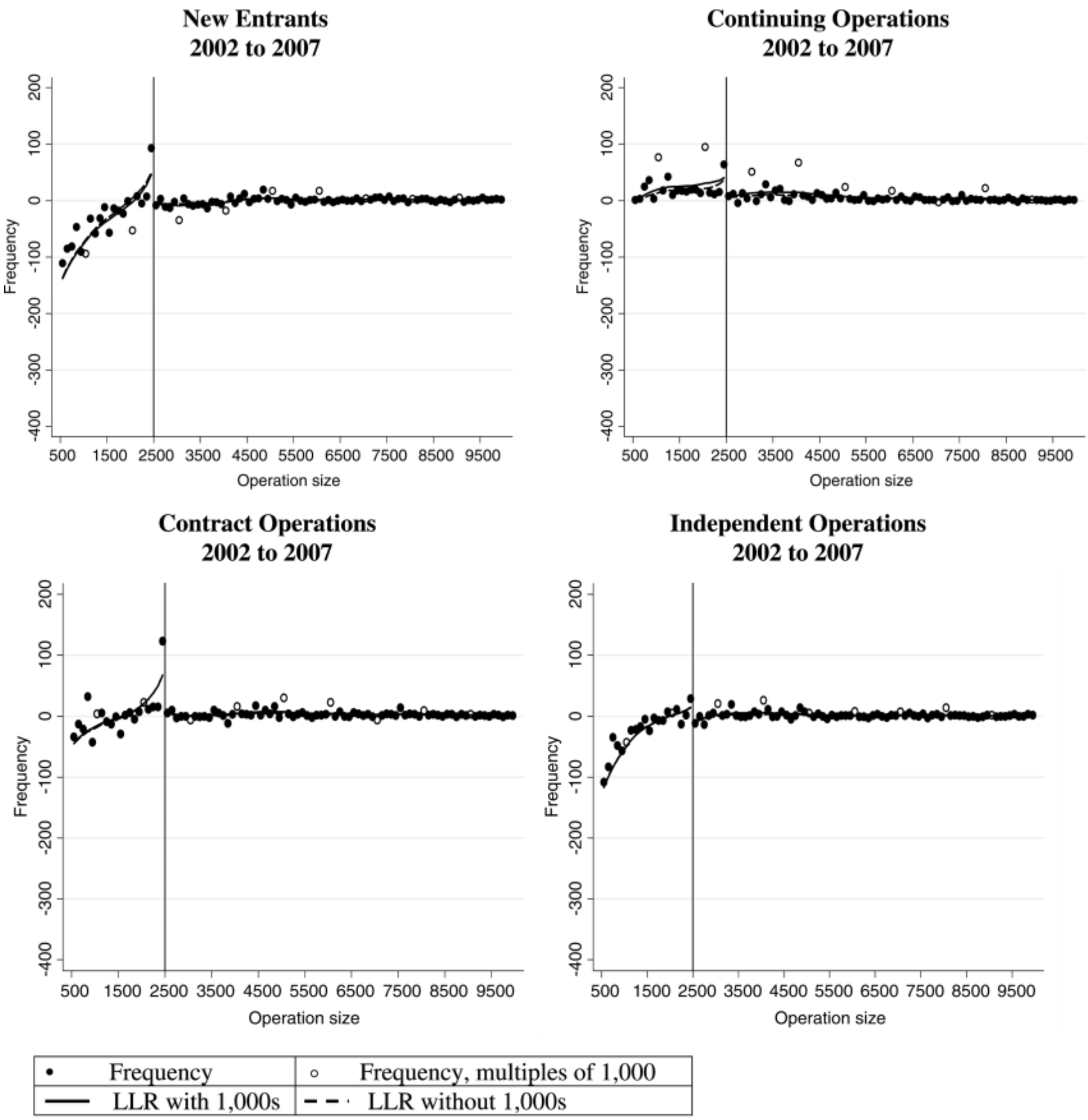
While space does not allow a full description of the state-level statistics in the context of each state's regulatory history, a couple of anecdotes help to contextualize the statistics and serve as falsification tests. Minnesota, which shows statistically significant avoidance in all three years, enacted relatively early legislation in 1998 requiring operations of sizes greater than the federal threshold to obtain permits; the state updated these regulations in 2000. A 2008 GAO report found that Minnesota did not have to modify its state rules after the release of the federal 2003 CAFO Rules because its own requirements were already more stringent. This legislative history may explain Minnesota's consistently significant avoidance.

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 had not instituted any size-based environmental regulations and adopted a permitting program only after a lawsuit in 2002; a 2003 report stated that Michigan had not issued any individual permits at that time (GAO 2003). As late as 2007, the Michigan Department of Environmental Quality stated that its permit did not provide the same level of stringency as that required under federal law (Michigan Department of Environmental Quality Water Bureau 2007). This legislative history may explain Michigan's lack of any statistically significant avoidance between 1997 and 2007.[29]

Alternative Explanations

The prior analyses show that there is increased "bunching" over time at sizes just below the regulatory threshold. The question is whether this bunching could be caused by some other factor besides regulation avoidance. Examination of multiple subgroups shows that the

[29] See Appendix C for a brief legislative background of each of the thirteen states.

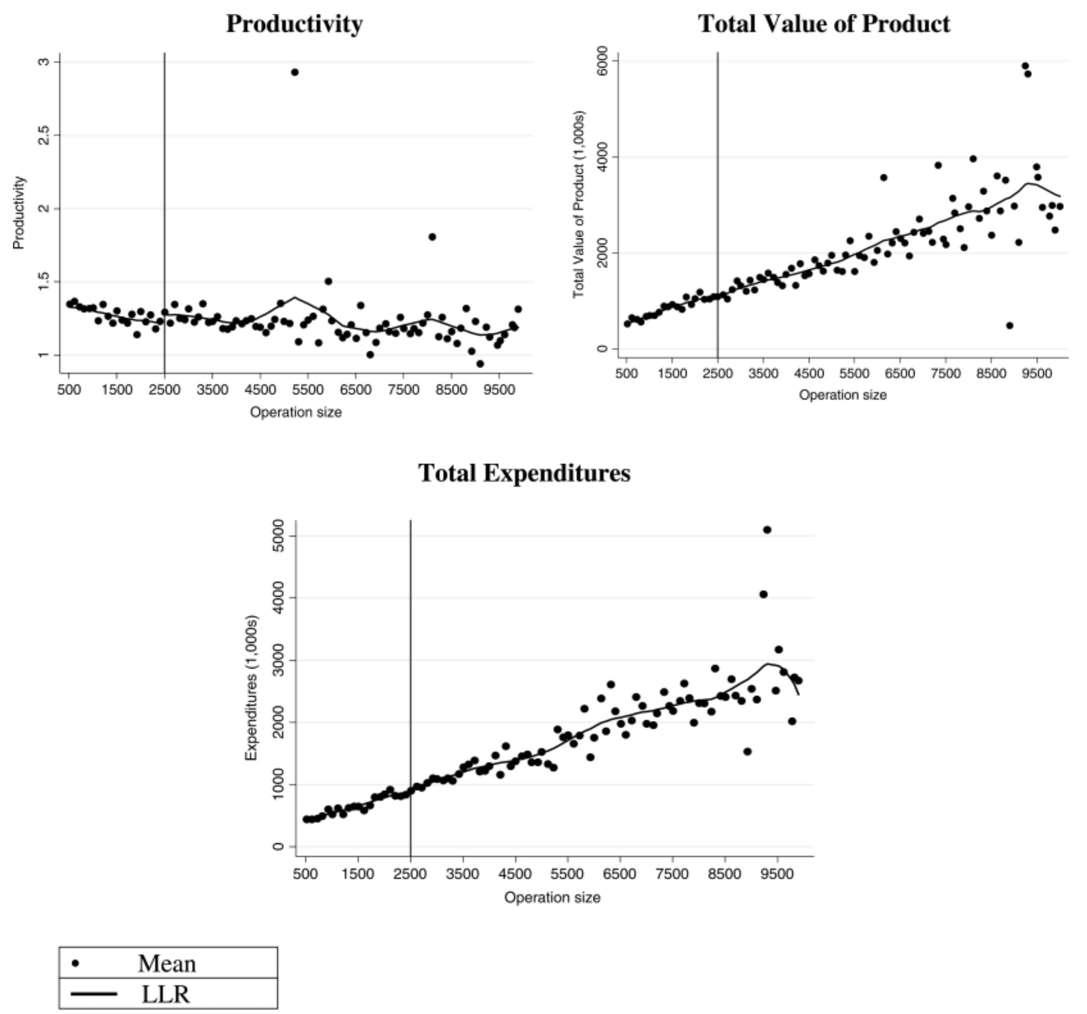


Note: LLR = local linear regression. The vertical line at 2,500 head represents the regulatory threshold.

Figure 5. Distribution of changes in distribution: new entrants, continuing operations, contract operations, and independent operations

bunching is not strictly limited to one individual state and is not occurring solely among new entrants, continuing operations, contract operations, or independent operations. If bunching were occurring in only specific subgroups, this would give a suggestion that something other than the federal regulation was leading to the distributional anomalies.

One possible alternative explanation is that some variable that determines farm size displays noncontinuous features near the regulatory threshold; operations therefore bunch below the threshold not because of the regulation but because of this other factor. While the empirical design controls for many factors that plausibly vary continuously across the regulatory threshold, we examine several observable variables to see if they display discontinuities at the threshold. Figure 6 displays the results of testing for discontinuities at the threshold



Note: LLR = local linear regression. The vertical line at 2,500 head represents the regulatory threshold.

Figure 6. Estimated covariate levels by operation size

for productivity, total value of operation-level product, and total operation-level expenditures. These curves are generated using local linear regressions and an RD method similar to that described in equation (9). As is evident, these variables do not display any discontinuities at the threshold, suggesting that these other factors are not leading to the bunching below the regulatory cutoff.[30]

A second alternative explanation is that there are increasing mass points in the distribution over time at the multiples of 500 (excluding the 1,000s; 1,500; 2,500; 3,500; etc.); in this case the discontinuities found at the regulatory threshold may exist only because the threshold is set at a multiple of 500. We therefore examine whether other multiples of 500 (and not 1,000) display discontinuities. Appendix table D4 shows these estimates for all subsamples in 2007 for 1,500; 2,500; 3,500; and 4,500. As is evident, the discontinuities at the nonthreshold multiples of 500 do not display statistically significant or sizable discontinuities.

The operation size of 2,400–2,499 appears to account for a large portion of the discontinuities witnessed in the previous figures. According to the model, this makes economic sense; this is the size at which

[30] For a fuller description of the analysis used to generate these figures as well as the estimates and statistical significance of the discontinuities, see Appendix E.

Table 4. Size of Discontinuity and Statistical Significance of Changes in Distribution Over Time

	1997–2002	2002–2007
Entire sample	−16.78	−95.65
	0.53	*2.07*
New entrants		−59.3
		1.82
Continuing operations		−36.35
		1.65
Contract producers—all		−69.15
		1.95
Contract producers—new entrants		−40.71
		1.63
Contract producers—continuing operations		−28.44
		1.69
Independent producers—all		−27.11
		2.18
Independent producers—new entrants		−19.09
		2.39
Independent producers—continuing operations		−8.02
		1.25

Note: Shown are estimates of size of discontinuity and *t*-value of test statistic (in italics). Sample includes finish-only hog operations with 100 or more head in the nine states listed in the text. The sizes of the discontinuities are estimated using local linear regression with a bin size of 100 and a bandwidth of 1,000. *t*-Values are generated by calculating bootstrapped standard errors (with 1,000 replications) and then dividing the estimate by the standard error and taking the absolute value.

operations can gain the greatest scale economies without paying the costs of regulations. However, because the 2,400-size class appears to have such an effect on the results, it must bear further scrutiny. First, we remove this size class and reestimate the discontinuities (Appendix table D5). Obviously, the estimated discontinuities are smaller, but they are still statistically significant in 2007. This suggests that the 2,400-size class is not completely driving the results.

A suggested alternative explanation for the preponderance of operations with 2,400–2,499 head is that this is just a popular operation size because of the growing predominance of the 1,200-head barn size. In this case, the estimated avoidance is just a product of market evolution given this new technology. If this were so, we would expect to see a growing percentage of operations at all multiples of 1,200, and we may expect the percentage of these types of operations to grow in a connected manner. To examine these proposals, we calculate the percentage of operations in each year that are multiples of 1,200 (Appendix figure D1). These show a declining percentage in successively larger sizes for 1997 and 2002 but not 2007. In 2007, the 2,400-size class makes up a larger percentage than any other multiple of 1,200. This suggests that the growth pattern for operations with 1,200-head barns changed in 2007.

To further address the issue of the 1,200-head barn size, we can also reexamine figure 5, which shows distributional change by size between 1997 and 2002, and between 2002 and 2007. If the 1,200-head barn size were consistently becoming more prevalent we would expect discontinuities at other multiples of 1,200, not just 2,400. However, we do not. The only multiple of 1,200 that obviously shows an "unexpected" growth (given the rest of the distribution) is at 2,400.

As a final check of the 1,200-barn size yielding the witnessed discontinuities, we can examine the percentage of continuing 2,400-head operations that grew from 1,200 head. In 2002 and 2007 these percentages were 6.1 and 3.5, respectively. The low percentages suggest that the increasing percentage of operations with 2,400 head is largely not a result of 1,200-head operations doubling in size. All of these checks suggest that the increasing commonness of the 1,200-head barn size does not explain the large percentage of 2,400-head operations.

Discussion and Conclusion

We find evidence of a statistically significantly large percentage of finish-only hog farms operating at a size just below that at which they would be designated large CAFOs and therefore subject to CWA regulations. This suggests that some continuing hog farm operators avoid environmental regulations by shrinking or growing less than they would have otherwise and that some new operations enter at a smaller size than they would have without regulation.

We also find evidence that "bunching" under the regulatory threshold increased in magnitude between 1997 and 2007. This period coincides with increasing environmental regulation of large CAFOs at the state and federal levels.

Table 5. State-Level Discontinuities and Avoidance Rates

State		1997	2002	2007
States in Main Sample				
Illinois	Discontinuity	−3.71	3.22	−4.04
	t-statistic	*1.77*	*1.20*	*1.56*
	Avoidance Rate 1	6.54%	2.53%	2.21%
	Avoidance Rate 2	8.48%	3.31%	3.77%
Iowa	Discontinuity	8.99	−5.35	−58.73
	t-statistic	*1.74*	*0.86*	*7.15*
	Avoidance Rate 1	2.08%	0.60%	4.72%
	Avoidance Rate 2	2.84%	0.83%	7.31%
Kansas	Discontinuity	−0.68	−0.54	−1.22
	t-statistic	**	*0.49*	*0.96*
	Avoidance Rate 1	4.37%	1.70%	3.10%
	Avoidance Rate 2	6.41%	2.89%	7.49%
Missouri	Discontinuity	0.36	−2.81	−6.69
	t-statistic	*0.28*	*1.74*	*2.77*
	Avoidance Rate 1	0.75%	7.06%	12.94%
	Avoidance Rate 2	1.33%	9.42%	19.86%
Minnesota	Discontinuity	−7.02	−7.92	−22.06
	t-statistic	*2.40*	*1.79*	*4.09*
	Avoidance Rate 1	4.18%	2.15%	4.61%
	Avoidance Rate 2	6.21%	3.05%	6.73%
Nebraska	Discontinuity	0.55	1.43	−1.91
	t-statistic	*0.35*	*0.80*	*0.95*
	Avoidance Rate 1	1.39%	2.00%	1.72%
	Avoidance Rate 2	2.34%	2.89%	2.59%
Ohio	Discontinuity	0.47	−6.38	−15.74
	t-statistic	*0.33*	*2.71*	*4.14*
	Avoidance Rate 1	2.19%	15.79%	17.54%
	Avoidance Rate 2	2.54%	18.55%	22.90%
South Dakota	Discontinuity	−0.87	0.75	−3.86
	t-statistic	*0.96*	*0.86*	*1.89*
	Avoidance Rate 1	7.30%	1.95%	6.24%
	Avoidance Rate 2	8.78%	2.45%	8.23%
Wisconsin	Discontinuity	0.20	−0.91	0.11
	t-statistic	*0.20*	*1.01*	*0.28*
	Avoidance Rate 1	2.14%	7.66%	1.20%
	Avoidance Rate 2	2.40%	7.66%	1.20%
Other major hog-producing states (not in main sample)				
Indiana	Discontinuity	0.02	6.31	0.08
	t-statistic	*0.02*	*2.69*	*0.04*
	Avoidance Rate 1	0.08%	6.17%	0.06%
	Avoidance Rate 2	0.09%	9.66%	0.11%
Michigan	Discontinuity	−0.20	−2.00	−0.38
	t-statistic	*0.19*	*1.29*	*0.24*
	Avoidance Rate 1	0.94%	4.26%	0.56%
	Avoidance Rate 2	1.23%	5.72%	0.77%
North Carolina	Discontinuity	−0.56	−5.75	−11.92
	t-statistic	*0.11*	*1.23*	*2.87*
	Avoidance Rate 1	0.08%	0.92%	1.99%
	Avoidance Rate 2	0.14%	1.72%	3.95%
Pennsylvania	Discontinuity	1.28	0.40	−8.73
	t-statistic	*1.12*	*0.23*	*3.03*
	Avoidance Rate 1	2.83%	0.85%	10.07%
	Avoidance Rate 2	3.26%	0.91%	12.52%

Note: Avoidance Rate 1 refers to the number of avoiders as a percentage of all potentially regulated operations (≥2,500); Avoidance Rate 2 refers to the percentage of all potentially regulated operations sized 2,500–5,000 head. ** = the prediction on the left-hand side of the discontinuity is negative, preventing estimation of theta. The sizes of the discontinuities are estimated using local linear regression with a bin size of 100 and a bandwidth of 1,000.

We do not attempt to attribute the estimated increases in avoidance rates to particular state or federal policies.

We also find that avoidance is more prominent for entering farms, suggesting that the "irreversible" nature of capital investments play a role in reacting to regulation. In this sense, regulations may be more costly to continuing producers than to new entrants, implying that potential entrants have an incentive to wait until regulation specifics are confirmed before initiating production.

Results indicate that avoidance is more prevalent amongst contract producers relative to independent producers. To the extent that contractors can control growers' barn sizes, this result suggests that some contractors are essentially requiring regulatory avoidance. Such a strategy makes sense from the contractor's perspective if regulation compliance is costly because avoidance would permit contractors to pay growers lower fees for their services.

The finding that contract producers have higher avoidance rates than independent producers does not necessarily indicate that contract producers are more likely to avoid regulation than independent producers *in similar regulatory settings*. Higher avoidance rates among contract growers could be expected if contract production were more prevalent in states with stronger enforcement while independent production were more common in states with fewer regulatory costs. It is also plausible that contracting enabled faster growth and larger operations in certain regions, spurring stronger enforcement and consequently greater incentives to avoid regulations.

The findings of this study are relevant to a variety of policy questions. In estimating the costs and benefits of the 2003 CAFO Rule, the EPA did not consider the changing distribution of farm sizes. Without accounting for regulatory avoidance, estimates of the number of operations falling under the new regulatory purview may be exaggerated, as would estimates of pollution abatement from the regulation. On the other hand, avoidance is more prevalent in certain states, suggesting that avoidance may cause environmental regulation to be substantially less effective in certain regions. For example, in Ohio and Missouri in 2007, we find that about one in five farms that may have had between 2,500 and 5,000 head avoided regulation.

The heterogeneity in avoidance rates may indicate differing regional regulatory compliance costs for operators because of differences in state regulations and in the enforcement of these regulations. Avoidance rates providing an indication of relative compliance costs could be useful to state policymakers considering the retention or growth of the hog industry in their states. Future research could examine in more detail why some states exhibit avoidance while others do not.

Finally, the findings may help inform the design of private and public programs that seek to regulate small or medium-scale operations. Producers may attempt avoidance if regulations impose discrete additional costs on operations above the size threshold. To create fewer distributional distortions, regulations could be phased in with the size of the operation in a continuous manner. Alternatively, program dollars could be made available to lessen the lump sum regulatory cost at the threshold by targeting the operations with the greatest incentive to avoid regulations.

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