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The Impact of Environmental Regulation on the Structure of the US Hog Industry

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Abstract

While some research finds that environmental regulation of hog production reduces output by small farms, other work finds that large farms downsize to avoid regulation. None consider the potential size-bias of regulation. We show theoretically that when size-based regulations are also size-biased, large farms downsize, expand, or do neither depending on how regulations shift their marginal production cost relative to their average cost. Empirical testing suggests limited impact on small farms and large farms downsize because regulations have a negative size-bias. In this context, regulatory avoidance is simply one of the three outcomes determined by how regulations affect cost structure.

1 Introduction

The swine industry in the United States has become highly concentrated: today, about 71,000 hog farms produce roughly the same hog inventory produced by ten times as many farms thirty years ago, and 2 percent of the farms produce 46 percent of the inventory.[1] A significant feature of the industry is production in large-scale hog confinement facilities, resulting in large volumes of hog manure within small areas. Being an organic source of crop nutrients, hog manure, if properly managed, can substitute for chemical fertilizers. However, proper management requires sufficient cropland to spread the manure and/or a market to sell the excess.

Because hog facilities often do not have sufficient cropland for proper manure disposal, and manure is less consistent in quality than synthetic fertilizers, hog producers may revert to applying manure in excess of agronomic requirements (Sneeringer and Key, 2011). The result is water pollution and deterioration of soil quality through contamination of water and soil with excess nitrogen and phosphate, not to mention through manure leaks from waste storage lagoons. Excess nitrogen and phosphate cause stunted growth in plants as well as accelerated eutrophication[2] of water systems (Ni et al., 2002). Crowded hog production also affects air quality through odor, which occurs from the hydrogen sulfite originating from anaerobic fermentation of manure. High concentrations of hydrogen sulfite are toxic to human and animal life as they can cause dizziness, irritation of the respiratory tract, nausea, and headaches (Ni et al., 2002; Sneeringer, 2010). An increase in livestock production has been found to be associated with an increase in infant mortality (Sneeringer, 2009a). If the atmosphere is moist, hydrogen sulfite can turn into sulfuric acid which can be detrimental to concrete and metal (Ayoub et al., 2004).

Federal regulation governing management and disposal of the millions of tons of hog manure produced every year is derived from the Clean Water Act (CWA). Enacted in 1972, the CWA amended the 1948 Federal Water Pollution Control Act to shift regulatory oversight from states to the federal government by requiring the former to adopt a federally-mandated National Pollutant Discharge Elimination System (NPDES) permit program (Environmental Protection Agency, 2008).[3] Administered by the Environmental Protection Agency (EPA), the program empowers the agency to issue permits to facilities applying for permission to discharge and to do so within the agency's Effluent Limitations Guidelines and Standards. Discharge permits may also be issued by states authorized to implement the CWA. However, the EPA retains the authority to enforce any violation of state-issued permits. The EPA also has the power to overrule state decisions on water pollution.

The first set of regulation based on CWA and specifically targeting water pollution from Concentrated Animal Feeding Operations (CAFOs) were enacted in 1976, with subsequent revisions in 2003, 2008, and 2012. Under the 1976 regulation, the requirement for a permit to discharge was tied to three CAFO size categories: Large CAFOs, Medium CAFOs, and Small CAFOs.[4] All large CAFOs who wanted to discharge had to apply for a NPDES permit. The same applied to Medium CAFOs but only for some types of discharges. Small CAFOs were not required to apply for a permit unless designated as a significant source of pollution.

In 2003, the EPA implemented a rule requiring all CAFOs to apply for a NPDES permit whether they discharged or not, and to adopt a Nutrition Management Plan (NMP) that spells out site-specific best management practices for adequate storage and appropriate disposal of manure. The premise of the new rule is that all CAFOs have a potential to discharge unless determined otherwise by the EPA, in which case a CAFO would be exempt from applying for the permit. The "potential discharge" rule was successfully challenged in the courts on the grounds that the CWA granted authority to the EPA to regulate actual, not potential discharge. In response to the court ruling, the EPA in 2008 required only CAFOs that discharge or "propose to discharge" to apply for a permit. A CAFO proposes to discharge if it is "designed, constructed, operated, or maintained such that a discharge would occur.” (Environmental Protection Agency, 2008). The 2008 rule was in turn challenged in court and was not upheld, again because the wording of the CWA is restricted to actual discharge. As the law stands now, the EPA can only require a permit for CAFOs that are discharging, along with a requirement to include an NMP with a NPDES permit (Environmental Protection Agency, 2012).

While the EPA rules must be adopted nationwide, many states have adopted more stringent regulation than the federal standards. For example, the states of North Carolina, Minnesota, Nebraska, and Kansas have adopted zoning requirements. Another regulation that varies by state is the required setback between a facility and the nearest residence. The federal government requires a setback of 1000 feet but the states of Iowa, North Carolina, Missouri, Illinois, Kansas, and Oklahoma have adopted more stringent setback requirements of 1875 feet, 2500 feet, 3000 feet, 4000 feet, 1 mile, and 3 miles, respectively. In addition to regulation required by the federal government, some states require facility design approval; construction and operation permits; zoning requirements; and hydrogen sulfide regulation. Regulation of hog production varies between states for three reasons. First, the design of federal water policy laws gives states sufficient authority and flexibility to design and implement their own environmental laws. States have the option to provide funding for voluntary programs to address the environmental needs of local areas. Second, the characteristics of the nonpoint-source pollution vary by state. For example, states that are more flood-prone are at a greater risk of contamination when manure is poorly managed. Due to these differences states may make different judgments when linking observations of particular management practices associated with confined hog feeding operations to changes in water quality. Third, there is heterogeneity between the socioeconomic characteristics of different hog producing states. States with higher population densities located close to hog production facilities may be more likely to impose stringent regulation. It is well known in the environmental economics literature that when the marginal damage of pollution varies by location it is not optimal to have uniform regulation standards. Differences between states in farming practices, topography, climate and hydrologic characteristics may require different environmental laws (Sullivan, Vasavada, and Smith, 2000).

The variation in state environmental stringency has been used to examine the effect of environmental regulation on three aspects of hog industry structure, namely (1) hog production, (2) farm exit, and (3) regulatory avoidance. Hog production has consistently been found to decrease with increased environmental stringency (Metcalfe, 2001; Roe, Irwin, and Sharp, 2002; Herath, Weersink, and Carpentier, 2005). Metcalfe (2001) reported that environmental stringency only affected small hog farms (SHFOs) and had no effect on large hog farms (LHFOs). Of these papers, Roe, Irwin, and Sharp (2002) and Herath, Weersink, and Carpentier (2005) do not attempt to separate inventory in small and large hog operations. Metcalfe (2001) does separate small and large farm inventory but his methodology does not incorporate the fact that regulation are size-based. Therefore, Metcalfe's results that only small farms are affected by environmental regulation may be due to the fact that technological changes that negatively affect SHFOs happen simultaneously with increases in regulatory stringency. In a study addressing the determinants of exit behavior of SHFOs, and whether LHFOs are displacing SHFOs in the U.S hog industry, Kuo (2005) found that technological improvement, unemployment rate, and hog price affect the exit of SHFOs. The study also reported that state-level policies such as environmental regulation and incumbent LHFOs have no effect on the exit of SHFOs. In a study of new entrants to the Canadian livestock industry, Weersink and Eveland (2006) find no evidence that regulatory stringency affects the location decision of producers.

Surprisingly, none of the studies related to hog production or farm exit consider the fact that environmental regulation affecting the hog industry is size-based (see footnote 4). So not only is there variation in stringency across states, but also variation across size thresholds. The only study we are aware of that used the two types of variation to relate environmental regulation to industry structure is that by Sneeringer and Key (2011). In it, the authors examine the effects of size-based regulation on industry structure through regulatory avoidance. Observing that the largest CAFOs (2500 animals or more) face more stringent environmental regulation and, hence, higher costs of compliance, the authors examined how that affects industry structure by inducing incumbent large operations to downsize below 2500 animals or entrants to choose an operation size also below 2500 animals. Using regression discontinuity techniques, Sneeringer and Key (2011) report regulatory avoidance primarily among entrants.

The findings by Sneeringer and Key (2011) are insightful and prompt further questions that motivate in part the analysis in our paper. Granted that size-based environmental regulation induces "regulatory avoidance" through downsizing, the question is why some incumbents among large farms do not downsize, or may in fact increase in size, and why some entrants still enter at sizes that trigger more stringent regulation. Is one to say, in the latter cases, that size-based regulation also induces "regulatory neutrality or seeking"? What we show in our paper is that size-based regulation may induce farms to downsize, increase in size, or not change in size because size-based regulation may not be size-neutral, i.e., they may induce unequal shifts in marginal cost and average cost of pork production. Specifically, if there are unequal shifts in the marginal and average cost functions, the equilibrium size of a representative producer will change, with positive (negative) size bias occurring when the shift in the average cost curve is larger (smaller) than the shift in the marginal cost curve.

Moreover, since regulation-induced entry or exit in the hog industry may affect the price of hogs through shifts in the supply of hogs, and the shifts, as we show in this paper, hinge on the direction of the size-bias effect of the regulation, a model linking regulation and industry structure should account for cost structure, and explain supply, price, and the number of firms in the long run. Our objective in this paper is to provide such a model. Specifically, we develop a comparative statics model of long-run industry equilibrium in the presence of environmental regulation, and test the model predictions using state-level data.

The rest of the paper is organized as follows: Section 2 provides the conceptual model; Section 3 describes the empirical model; Section 4 discusses the data; Section 3 presents the estimation procedure; Section 6 shows results; and section 7 summarizes and concludes.

2 Conceptual Model

The starting point of the model is a perfectly competitive hog industry consisting of SHFOs and LHFOs. Using EPA size thresholds, we designate as SHFOs all CAFOs feeding less than 2500 head of hogs and as LHFOs all CAFOs feeding 2500 head or more. To account for EPA size-based regulation, only LHFOs are subject to environmental regulation and, to account for state-based implementation, we allow environmental stringency to vary by state. State j consists of n_j^s identical SHFOs and n_j^l identical LHFOs such that $N_j = n_j^s + n_j^l$, with $n_j^s > 0$ and $n_j^l > 0$. By identical, we mean that farms in each size category have the same cost structure. Ignoring factor prices for now, costs of production for a SHFO are given by $c_j^s = c_j^s(q_j^s)$ and for a LHFO by $c_j^l = c_j^l(q_j^l, E_j)$, where q_j^k is the level of hog output for an HFO of size k in state j and E_j is a measure of environmental stringency, recalling that it only affects LHFO's cost of production. We introduce E_j as a cost shifter in the same manner as in Katz and Rosen (1985), Lichtenberg, Parker, and Zilberman (1988), and Sunding (1996). We model the effect of regulation on the firm and industry, assuming the industry is initially in a long-run equilibrium. For ease of notation we do not include the j subscript in the model below but we recognize that the conditions are state-specific depending on the level of regulation.

The properties of the cost functions are:

1. $ac_E^l = \frac{\partial(c^l(q^l,E)/q^l)}{\partial E} > 0$, average production cost of a LHFO is an increasing function of the stringency of environmental regulation.

2. $mc^l_E = c^l_{qE} \geq 0$, marginal cost of a LHFO is a non-decreasing function of the stringency of environmental regulation.

3. $mc^k_q = c^k_{qq} > 0$, marginal cost is increasing in output for both LHFOs and SHFOs.

The inverse derived demand function facing the industry is given by $p = p(Q)$, where $Q = \sum_j (n^s_j q^s_j + n^l_q q^l_j)$, is total hog output and p is the hog price. The demand curve is downward sloping, $p' < 0$. Because only the marginal and average cost curves of LHFOs are affected by environmental regulation, the number of SHFOs, n^s, is unaffected by environmental regulation and $MC^s_E = AC^s_E = 0$. This, however, does not preclude SHFOs from adjusting their output level in response to regulation-induced changes in the market equilibrium price of finished hogs.

Since hog farmers have the choice of selling finished hogs on the spot market, through contracts, or a combination thereof, we model the supply decision of the representative hog farm operation (HFO) of size k in a manner similar to that of Buccola (1981). Denoting the price clause of a contract as the product of a price base B^k adjusted by a price parameter b^k, and the proportion of finished hogs sold under contract by $0 < r^k < 1$, profits of the representative HFO of size k are given by:

$$\max_{q^s}(1 - r^s)p(Q)q^s + r^s z^s q^s - c^s(q^s), \tag{1a}$$

$$\max_{q^l}(1 - r^l)p(Q)q^l + r^l z^l q^l - c^l(q^l, E), \tag{1b}$$

where $z = bB$. So, for example, under a formula contract B is tied to an observable hog price in the open market and, under a cost-plus contract, B is the farmer's per unit variable cost of production and $b > 1$ is some negotiated factor. Because our focus is on the effect of environmental regulation, we remain agnostic as to the type of contract and assume a fixed price arrangement that is independent of the stringency of environmental regulation, in which case z is constant. We also assume that, although r^k, the proportion of finished hogs sold under contract is not invariant to such factors as market prices, technology, and risk preferences, it is independent of environmental stringency (Zheng, Vukina, and Shin, 2008).

Differentiating Equations 1a and 1b with respect to output yields the following first-order conditions:

$$p(Q) = \rho^s c^s_{q^s}(q^s) - \rho^s r^s z^s \tag{2}$$

and

$$p(Q) = \rho^l c^l_{q^l}(q^l, E) - \rho^l r^l z^l \tag{3}$$

where $\rho^k = (1 - r^k)^{-1}$.

Our objective is to examine the change in the output of SHFOs and LHFOs, and entry and exit of LHFOs due regulation-induced shifts in their production cost. In the long-run, short-run profits or losses will induce LHFOs to enter or exit the industry until profits are driven to zero.

The zero profit condition for LHFOs is:

$$\pi^l = (1 - r^l)p(Q)q^{l*} + r^l z^l q^{l*} - c^l(q^{l*}, E) = 0, \tag{4}$$

or equivalently,

$$p(Q) = \rho^l \frac{c^l(q^{l*}, E)}{q^{l*}} - \rho^l r^l z^l = ac^l(q^{l*}, E) - \rho^l r^l z^l. \tag{5}$$

The comparative static effects of changing environmental regulation stringency are determined by totally differentiating Equations 2, 3, and 5 with respect to E. Since environmental regulation does not affect the cost of production for small farms (i.e., entry and exit conditions) we do not perform comparative statics with respect to n^s. The result, expressed in matrix form, is:

$$\begin{bmatrix} \theta^s & p'n^l & p'q^l \\ p'n^s & \theta^l & p'q^l \\ p'n^s & p'n^l & p'q^l \end{bmatrix} \begin{bmatrix} q^s_E \\ q^l_E \\ n^l_E \end{bmatrix} = \begin{bmatrix} 0 \\ \rho^l mc^l_E \\ \rho^l ac^l_E \end{bmatrix} dE \tag{6}$$

where $\theta^s = n^s p' - mc^s_q$ and $\theta^l = n^l p' - mc^l_q$. Denoting the coefficient matrix by Ω, its determinant is $\det(\Omega) = p'q^l \rho^s mc^s_q \rho^l mc^l_q < 0$.

Solving Equation 6, the effect of environmental regulation on SHFO output, LHFO output, and the number of LHFOs is given by:

$$\frac{\partial q^s}{\partial E} = \frac{\rho^l ac^l_E}{\rho^s mc^s_q} > 0 \tag{7}$$

$$\frac{\partial q^l}{\partial E} = -\frac{mc^l_E - ac^l_E}{mc^l_q} \tag{8}$$

$$\frac{\partial n^l}{\partial E} = -\frac{1}{q^l}(n^l \frac{\partial q^l}{\partial E} + n^s \frac{\partial q^s}{\partial E} - \frac{\rho^l ac^l_E}{p'}) \tag{9}$$

Equation 7 is positive by the properties of the cost function, a result that implies that the higher the stringency of environmental regulation facing LHFOs the higher the output of SHFOs. All else equal, an upward shift in LHFOs' average cost due to environmental regulation leads to a higher price of finished hogs in the long-run, leading to more output by SHFOs. The magnitude of the increase in output may be affected by the proportion of output contracted. In cases where the proportions for SHFOs and LHFOs are the same, $r^s = r^l$, contracting has no effect on the change in output level of SHFOs. The proportion of animals sold under contract affects the magnitude of the effect of environmental regulation on inventory decisions. Any shift therein is only determined by the relative changes in average and marginal cost of SHFOs and LHFOs, respectively. On the other hand, if $r^l > r^s$ ($r^s > r^l$), the increase in output from SHFOs induced by more stringent environmental regulation on LHFOs is greater (smaller) than with equal or no use of contracting.

The story is not as straightforward for equations 8 and 9 because of the possibility of regulation-induced farm-size bias. Farm-size bias results when the shift in the marginal cost curve is different from the shift in the average cost curve. This is analogous to the firm-size bias in technology-induced cost shifts (Perrin, 1997). In the context of our study, a positive (negative) farm-size bias results when the shift in the average cost curve is larger (smaller) than the shift in the marginal cost curve. The farm-size bias is neutral when the marginal-and average cost curves shift by the same magnitude. A positive (negative) size bias implies that regulation will increase (decrease) the size of a representative LHFO. Any of these outcomes are possible with environmental regulation. For example, a requirement for a siting permit will increase the average cost but have little effect on the marginal cost, leading to a positive size bias. Regulation that causes a representative LHFO to acquire additional capital to conform to regulation will increase average cost, leading to an increase in its scale of production. On the other hand, a requirement to reduce the application rate for manure spreading will have a large effect on the marginal cost curve because land and transportation costs for manure spreading are higher with increased distance. Thus, a regulation about manure spreading rates will likely have a negative size bias. In this case, the size bias of environmental regulation induces a farm to downsize, a decision that may seem as though a firm is avoiding regulation when in fact it is maximizing profits under conditions of a negative size bias of the environmental regulation. When there is a positive size bias, we know from equation 9 that the number of LHFOs will decrease due to environmental regulation. This result is ambiguous with negative size bias as the increase in output from SHFOs and ratio of the change in cost to the change in price will reduce the number of large farms while the decrease in output from LHFOs will have the opposite effect. These results are summarized in Table 1. In addition, the level of contracting will change the impact of environmental regulation on the number of LHFOs. Differentiating equation 9 with respect to ρ^l and ρ^s shows that any entry or exit of large farms due to environmental regulation is reduced (increased) with contracting by large (small) farms.

<< Insert Table 1 >>

Hence the nature of LHFO technology determines the signs of equations 8 and 9. When both pre- and post-regulation technologies are homothetic, regulation shifts the total cost curve without changing its slope at every output level. This results in a shift in the average cost curve and not the marginal cost curve, which has an unambiguous positive size bias on large farms. On the other hand, with non-homothetic technology, regulation will shift the total cost curve at the same time altering its slope at every point. Because regulation will have an effect on both marginal and average cost curves, there is a possibility for positive farm-size bias, negative farm-size bias, or no farm-size bias. The most commonly documented long-run competitive equilibrium supply shift in economics textbooks is the technical change induced shift, which shifts both long run marginal and average cost curves.[5] As explained earlier, when environmental regulation shifts marginal and average cost curves, it is not readily apparent whether it shifts the marginal cost curve more or less than the average cost curve.

<< Insert Figure 1>>

Illustrations of the various possible outcomes are shown in Figure 1. Figure (1a) illustrates the case where regulation-induced shift in the average cost curve is equal to the shift in the marginal cost curve. The impact of this shift takes the opposite direction of neutral technological change on the firm.[6] Figure (1b) illustrates the case where regulation-induced shift in the average cost curve is greater than the shift in the marginal cost curve. Regulation causes marginal and average cost curves to shift from MC to $MC3$ and from AC to $AC3$, respectively. The resulting effect would be to increase the long-run equilibrium output of an individual HFO from q to $q3$, implying positive farm-size bias, and to increase the long-run equilibrium price faced by the individual HFO from p to $p3$. This result implies that regulation has a positive effect on an individual HFO's output. Lastly, in the case when marginal cost shifts upward more than average cost, output decreases from q to $q4$. In this case, regulation will decrease HFO output. This case is shown in Figure (1c). In either case, however, price is higher in the long-run, inducing unregulated farms to increase output, as was shown by equation 7.

To determine the effect of environmental regulation on industry output, we first differentiate the equilibrium industry output $Q^* = n^s q^{s*} + n^{l*} q^{l*}$ with respect E and make use of equation (9). The yields

$$\frac{\partial Q}{\partial E} = \frac{\rho^l ac_E^l}{p'} < 0, \tag{10}$$

which implies

$$\frac{\partial p}{\partial E} = \rho^l ac_E^l > 0, \tag{11}$$

What transpires from our conceptual model is that while a SHFO's output increases with higher stringency of environmental regulation, the output and number of LHFOs may either increase or decrease with environmental regulation depending on the associated shifts in the marginal and average cost curves. However, in the long-run, regulation increases the hog price and decreases total industry output. These results are similar to the findings by Lahiri and Ono (2007) who studied the effects of an emission tax on price and output in a symmetric oligopoly - an emissions tax leads to a decrease in aggregate output but has an ambiguous effect on output per firm.

3 Empirical Model

For empirical implementation, we first augment the cost function with factor prices. So costs for hog farms of size k, for $k = s, l$, located in state j, at time t, are re-written as

$$c_{jt}^{k} = c_{t}^{k}(q_{jt}^{k}, w_{cjt}, w_{djt}, E_{jt}), \tag{12}$$

where q^k is output, w_c price of corn (the major feed), w_d, the price of transportation, and E is environmental stringency. It follows that the optimality conditions 2, 3, and 5 can be re-written as:

$$p_{jt} = \rho_{jt}^{s} mc_{jt}^{s}(q_{jt}^{s}, w_{cjt}, w_{djt}) - \rho_{jt}^{s} r_{jt}^{s} z_{jt}^{s} \tag{13}$$

$$p_{jt} = \rho_{jt}^{l} mc_{jt}^{l}(q_{jt}^{l}, w_{cjt}, w_{djt}, E_{jt}) - \rho_{jt}^{l} r_{jt}^{l} z_{jt}^{l} \tag{14}$$

and

$$p_{jt} = \rho_{jt}^{l} ac_{jt}^{l}(q_{jt}^{l}, w_{cjt}, w_{djt}, E_{jt}) - (\rho r z)_{jt}^{l} \tag{15}$$

Simultaneous solution of 13, 14, and 15 yields, in general form, the equilibrium quantities supplied by SHFOs and LHFOs, respectively, and the equilibrium number of LHFOs:

$$q_{jt}^{s} = q_{jt}^{s}(p_{jt}, w_{cjt}, w_{djt}, r_{jt}^{s}, r_{jt}^{l}, E_{jt}) \tag{16}$$

$$q_{jt}^{l} = q_{jt}^{l}(p_{jt}, w_{cjt}, w_{djt}, r_{jt}^{l}, r_{jt}^{s}, E_{jt}) \tag{17}$$

$$n_{jt}^{l} = n_{jt}^{l}(p_{jt}, w_{cjt}, w_{djt}, r_{jt}^{l}, r_{jt}^{s}, E_{jt}) \tag{18}$$

Second, we assume the respective estimating equations of 16-18 to take the linear forms:

$$\begin{aligned}\ln q_{jt}^{s} &= \beta_{o}^{s} + \beta_{p}^{s}\ln p_{jt} + \beta_{c}^{s}\ln w_{cjt} + \beta_{d}^{s}\ln w_{djt} + \beta_{sr}^{s} r_{jt}^{s} + \beta_{lr}^{s} r_{jt}^{l} + \beta_{e}^{s} E_{jt} \\ &\quad + \sum_{j}^{K-1} \beta_{jD}^{s} D_{j}^{s} + \beta_{t}^{s} T + \epsilon_{jt}^{s}, \end{aligned} \tag{19}$$

$$\begin{aligned}\ln q_{jt}^{l} &= \beta_{o}^{l} + \beta_{p}^{l}\ln p_{jt} + \beta_{c}^{l}\ln w_{cjt} + \beta_{d}^{l}\ln w_{djt} + \beta_{sr}^{l} r_{jt}^{s} + \beta_{lr}^{l} r_{jt}^{l} + \beta_{e}^{l} E_{jt} \\ &\quad + \sum_{j}^{K-1} \beta_{jD}^{l} D_{j}^{s} + \beta_{t}^{l} T + \epsilon_{jt}^{l}, \end{aligned} \tag{20}$$

and

$$\begin{aligned}\ln n_{jt}^{s} &= \beta_{o}^{n} + \beta_{p}^{n}\ln p_{jt} + \beta_{c}^{n}\ln w_{cjt} + \beta_{d}^{n}\ln w_{djt} + \beta_{sr}^{n} r_{jt}^{s} + \beta_{lr}^{n} r_{jt}^{l} + \beta_{e}^{n} E_{jt} \\ &\quad + \sum_{j}^{K-1} \beta_{jD}^{n} D_{j}^{s} + \beta_{t}^{n} T + \epsilon_{jt}^{n}. \end{aligned} \tag{21}$$

The variables D_j and T represent state-level fixed effects and the state of hog production technology, respectively. Random disturbance terms are denoted by ϵ. Our initial estimation assumes that the impact of more stringent environmental regulation is equal across all states (i.e., shifts in marginal and average costs are equal for different states that have the same regulation) but we recognize that there may be differences across states. As stated in the introductory section, although the EPA sets federal standards for regulation, authorized states can set their own with some states setting more stringent regulation than others because of pressure from environmental groups. In addition, each state has the ability to determine the level of enforcement through higher or lower levels of monitoring. Therefore, states may differ in enforcement and monitoring despite identical regulation codes for CAFOS.

To capture differences among states in regulation, enforcement, monitoring, and compliance, we add the interaction between state-level fixed effects and environmental regulation and rewrite Equations 19 - 21 as Equations 22 - 24:

$$\begin{aligned}\ln q^s_{jt} &= \beta^s_o + \beta^s_p \ln p_{jt} + \beta^s_c \ln w_{cjt} + \beta^s_d \ln w_{djt} + \beta^s_{sr} \ln r^s_{jt} + \beta^s_{lr} \ln r^l_{jt} + \beta^s_e \ln E_{jt} \\ &\quad + \sum_j^{K-1} \beta^s_{jD} D^s_j + \sum_j^{K-1} \beta^s_{jDE} D_j \ln E_{jt} + \beta^s_t T + \epsilon^s_{jt}, \end{aligned} \tag{22}$$

$$\begin{aligned}\ln q^l_{jt} &= \beta^l_o + \beta^l_p \ln p_{jt} + \beta^l_c \ln w_{cjt} + \beta^l_d \ln w_{djt} + \beta^l_{sr} \ln r^s_{jt} + \beta^l_{lr} \ln r^l_{jt} + \beta^l_e \ln E_{jt} \\ &\quad + \sum_j^{K-1} \beta^l_{jD} D^s_j + \sum_j^{K-1} \beta^l_{jDE} D_j \ln E_{jt} + \beta^l_t T + \epsilon^l_{jt}, \end{aligned} \tag{23}$$

and

$$\begin{aligned}\ln n^s_{jt} &= \beta^n_o + \beta^n_p \ln p_{jt} + \beta^n_c \ln w_{cjt} + \beta^n_d \ln w_{djt} + \beta^n_{sr} \ln r^s_{jt} + \beta^n_{lr} \ln r^l_{jt} + \beta^n_e \ln E_{jt} \\ &\quad + \sum_j^{K-1} \beta^n_{jD} D^s_j + \sum_j^{K-1} \beta^n_{jDE} D_j \ln E_{jt} + \beta^n_t T + \epsilon^n_{jt}. \end{aligned} \tag{24}$$

Based on size thresholds set by EPA (see footnote 2), all farms having less than 2500 head are designated as small and farms having 2500 or more as large. However, as we discuss in more detail in the data section, given the size thresholds used by the USDA, the main source of data for the hog industry, we use 2000 head as the threshold to categorize operations into small and large. While this will lead to some inventory in our sample attributed to the LHFO category that is not subject to regulation, this will not bias the results on the inventory levels if operation size is continuously distributed. For the estimation of the number of LHFOs, the threshold of 2000 head will bias downward any results we find on entry and exit of LHFOs. Thus, if we find an effect on the number of LHFOs, the actual effect will be of greater magnitude than our estimate.

4 Data

For data we focus on the top ten hog producing states for the years 1994 through 2006. The ten states are, in the order of their shares in U.S. hog inventory (slaughter hogs and breeding hogs), are Iowa (IA), North Carolina (NC), Minnesota (MN), Illinois (IL), Nebraska (NE), Indiana (IN), Missouri (MO), Oklahoma (OK), Ohio (OH), and Kansas (KS). Together, they account for 85 percent of the inventory, of which more than ninety percent of is slaughter hogs. USDA uses nine size categories in reporting the inventory: 1-24, 24-49, 100-199, 200-499, 500-999, 1000-1,999, 2,000-4,999, and 5000 or more. Because the 2500 EPA threshold falls in the middle of the USDA 2,000-4,999 category, we designate hog farms with less than 2000 head as SHFOs and hog farms 2000 head or more as LHFOs. Hence, output for each of the two size categories is equal to the total inventory in the 1-1,999 size categories for SHFOs and to the total inventory in the 2000 or more category for LHFOs. There has been a shift over time in the overall structure of the hog industry with a reduction in total farms and an increase in the average size of each farm. The total inventory in large farms has increased over time Kuo (2005).[7] Table 2 shows some of the state-level shifts in the industry during the sample period. While the percentages vary by state, all ten of the top hog-producing states have seen a decrease in SHFO inventory and an increase in LHFO inventory. The use of contracting has also increased over time in both small and large farms. While the proportion varies by state (e.g., the majority of hogs sold in North Carolina are sold through contracts while less than 20 percent of hogs in Nebraska are contracted), the general trend of an increase in contracting is consistent across all states.

With the exception of the data on environmental stringency and contracts, which we discuss shortly in more detail, the rest of the variables used to estimate equations 19, 20, and 21 are all from secondary sources. The list of all variables and their definitions is as follows:

q^s_{jt} = SHFO hog inventory (total hog inventory owned by operations of size less than 2000 head).

q^s_{jt} = LHFO hog inventory (total hog inventory owned by operations of size 2000 head or more).

n^l_{jt} = Number of LHFOs (size 2000 head or more).

p_{jt}= Hog price ($/hundredweight).

w_{cjt}= Corn price ($/bushel).

w_{djt}= Gasoline price (cents/gallon).

r^s_{jt} = SHFO contracts (percent of inventory).

r^l_{jt} = LHFO contracts (percent of inventory).

E_{jt} = Environmental stringency.

The summary statistics for all of these variables except for environmental stringency is in Table 3. The first four variables on the list (q^s_{jt}, q^s_{jt}, n^l_{jt}, p_{jt}, and w_{cjt}) were all taken from United States Department of Agriculture, National Agricultural Statistics Service Quickstats website.[8] We note that the variables on hog inventory are all at the aggregate state level, and cannot be interpreted as the size of any particular hog farm. However, based on the average numbers we know that the mean LHFO inventory is approximately 6000 head. The variable w_{djt} was taken from the website of the Energy Information Agency.[9] Hogs under production contracts by size category (r^s_{jt} and r^l_{jt}) are available by state only for the census years 2002 and 2007. To generate observations for noncensus years, we use the percent growth rate in contracts between 2002 and 2007 to backcast between the years 1999 and 2001 and forecast for the years between 2003 and 2006.

<< Insert Table 3 >>

The data series for the environmental stringency variable (E_{jt}) are a combination of three subsamples, two of which are from secondary sources and is shown in Table 4. For each state, we make use of a 1994-2006 time series qualitative environmental stringency data. Several studies have used qualitative environmental stringency indices to study regulation issues in the U.S hog industry (Metcalfe, 2000, 2001; Roe, Irwin, and Sharp, 2002; Herath, Weersink, and Carpentier, 2005). However, with the exception of Metcalfe (2000) these papers have not attempted to create panel variables for environmental stringency; each has used different cross sections. We directly use the measures from Metcalfe (2000) for the 1994-1997 and 1998-1999 periods. A detailed explanation of the methodology is explained in Appendix 1. Specifically, we examine legislation from each state to determine if certain categories of regulation existed in each of the benchmark years (2000 and 2003). We categorize each category as '0' for no regulation, '1' for existing regulation, and '2' for extensive regulation in each category. For example, the minimum federal setback for manure disposal near a stream is 100 feet, but many states have a more stringent requirement. We use the level of regulation existing at the beginning of each period, thus regulation in the year 2000 is considered as the measure for the 2000-2002 period and regulation in the year 2003 is considered the measure for the 2003-2006 period. [10] The environmental stringency variable is an index of state-level environmental regulation on HFOs.

<< Insert Table 4 >>

5 Estimation Procedure

The primary goal of the empirical analysis is to measure the effect of environmental stringency on the structure of the hog industry. Equations 19 - 21 show the form of the estimating equations for hog supply by SHFOs and LHFOs and the number of LHFOs. Of critical importance in the estimation is the variation over time and over states in environmental regulation. We use a two-stage estimation procedure. In the first stage, we instrument the state-specific hog prices and environmental stringency. In the second stage, we use the predicted values of the instrumented variables and estimate the three equations using seemingly unrelated regression (SUR).

Our rationale for treating hog prices and environmental stringency as endogenous variables is as follows. First, for a given demand schedule for hogs, the output price of hogs is likely to be simultaneously determined with hog supply. The environmental stringency variable may also be endogenous because states may respond to increased hog production by adjusting regulation. The endogeneity of environmental compliance costs was first noted by Metcalfe (2001) and later considered by Herath, Weersink, and Carpentier (2005). To find valid instruments for the environmental stringency variables we use a similar analysis as Fredriksson and Millimet (2002) and Levinson (2003) who estimate a reaction function for state level environmental regulation by using data from other states. The idea behind the reaction functions is that states may calibrate the regulation stringency in response to neighboring states to position themselves as hog friendly or un-friendly states. There are a couple of ways that surrounding states affect the level of environmental stringency in the target state. First, some of the literature has argued that there is a "race to the bottom", where states compete to be seen as business friendly by lowering environmental standards to attract businesses. While this has not been found to be the case in a previous study of livestock operations Weersink and Eveland (2006), we recognize that this is one method that policy decisions in the surrounding states affect decisions in the target state. On the other hand, states may increase environmental stringency in response to changes in a surrounding state due to political pressure from environmental groups. We also use the League of Conservation Voters (LCV) Congressional score as an additional instrument.[11] The LCV score has been used in other papers to measure the general attitude of a state toward environmental protection (Levinson, 2001; Harllee, Kim, and Nieswiadomy, 2009).

We estimate reaction functions for each of the states based on the following equation, where $i \neq j$ are the two highest producing adjacent states to state j:[12]

$$\ln(E_{jt}) = \gamma_{LCVj} \ln(LCV_{jt}) + \sum_{i \neq j} \gamma_i \ln E_{it} + \epsilon_j \tag{25}$$

<< Insert Table 5 >>

<< Insert Figure 2 >>

We estimate Equation 25 separately for each state. The results of the estimation are in Table 5. The results show that adjacent states are strong predictors of another state's level of regulation. Of the 20 state variables, 11 are statistically significant and 8 of those 11 are positive. This shows that states do tend to react to changes in regulation from other states, and in most cases the reaction is positively correlated, showing little evidence of a "race to the bottom". Figure 2 compares the actual and predicted values of environmental stringency. From this we see that while there is some variation in the predicted values at each level, the overall fit of the instruments for environmental stringency is quite good. We use the lagged prices for hogs and corn (p_{hjt-1} and p_{cjt-1}) and the current price for beef (p_{bjt}) as instruments for the current hog price:

$$\ln p_{hjt} = \alpha_h \ln p_{hjt-1} + \alpha_c \ln p_{cjt-1} + \alpha_b \ln p_{bjt} + \epsilon \tag{26}$$

Table 6 shows the results of the instrument estimation. We find that both the lagged corn and hog price are strong predictors for the current hog price instrument.

<< Insert Table 6 >>

We use the predicted values from Equation 26 and the J sets of predicted values from Equation 25 and estimate the inventory and the number of farms (Equations 19 - 21) for our second-stage SUR estimation. We test the need for instrumental variables by utilizing the regression form of the Hausman-Wu test separately on each of the three primary equations of the econometric model. We find that test statistic for the endogeneity of hog price is statistically significant in all three equations and the test statistic for environmental stringency is significant in the supply of LHFO equation.

Because of the two-stage estimation, we adopted the following procedure for second-stage standard error correction. Let V_{SUR} be the variance-covariance matrix from the SUR estimation of Equations 19 - 21 (we refer to each of these as Equation m where $m = 1, 2, 3$) and let V_1, V_2, and V_3 be the portion of V that corresponds to the variance-covariance matrix from the estimation of Equation m. Specifically,

$$\begin{bmatrix} V_{SUR} \end{bmatrix} = \begin{bmatrix} V_1 \; V_{12} \; V_{13} \\ V_{21} \; V_2 \; V_{23} \\ V_{31} \; V_{32} \; V_3 \end{bmatrix}$$

We calculate the ratio of the mean-squared errors from the estimates that use the actual values and the estimates that use the predicted instrumental variables. Specifically, denoting y_m as the dependent variable for Equation m, df_m is the degrees of freedom from Equation m, $\hat{\delta}_m$ as the estimated coefficients from the SUR estimation, X_m as the actual explanatory variables, and $\hat{X}_m$ as the predicted instruments for X_m, we calculate the following for each equation:

$$MSE_m = (\frac{1}{N} \sum (y_m - X'_m \hat{\delta}_m)^2)/df_m$$

By definition, the $M\hat{S}E_m$ calculated from the SUR estimation is:

$$\widehat{MSE}_m = (\frac{1}{N} \sum (y_m - \hat{X}'_m \hat{\delta}_m)^2)/df_m$$

Using these results we calculate the corrected variance-covariance matrix for Equation m as:

$$V_m^{adj} = \frac{MSE_m}{\widehat{MSE}_m} V_m \tag{27}$$

The corrected standard errors are listed in Table 7 and are also used to estimate the standard errors for the marginal effects listed in Table 8. << Insert Table 7 >>

6 Results

The results from the SUR estimation of Equations 19 - 24 are in Table 7. The standard errors from Equation 27 are used to measure the statistical significance of the coefficient estimates. Examining first the coefficients associated with prices, we find that most are not statistically significant. The price of hogs is only significant in the output of SHFOs. The price of corn is significant and had a positive sign for SHFO inventories and a negative sign for LHFO inventories and the number of LHFOS. Lack of statistical significance may be explained by presence of hog contracts because they may decouple hog supply from output and factor prices. Hog supply by independent hog farmers (those who do not contract) may still respond to market prices but, to the extent that the output share of independent hog producers has declined over time, as shown in Table 2, their contribution to overall supply response has also declined.

The effect of SHFO and LHFO contracts on hog supply by both types of farms and the number of LHFOs have some of the expected signs (positive coefficients for LHFO contracts on LHFO output and the number of LHFOs), showing that contracts do affect industry structure. The number of SHFO contracts has a negative effect on SHFO output, possibly due to the fact that the role of contracts for small producers is to assure a market for output rather than increase it as implied by the structure of our model, i.e., contracts, by offering a premium over the market price, lead to more quantities supplied. The coefficients of the time variable confirm that the change in the state of technology has moved the industry towards large scale production. This is consistent with observed trends that the number of livestock operations in the United States has been decreasing and the average size of each operation is increasing in the past several decades. The coefficients of the state indicator variables show the magnitude of the dependent variables relative to Iowa, the largest hog producing state in the country. Not surprisingly most of these values are statistically significant and negative since all produce fewer hogs than Iowa.

Of particular interest are the results associated with the environmental stringency (ES). The theoretical effects of ES are captured by the comparative statics predictions shown in Equations 7 - 9. With respect to Equation 7, which shows the effect of environmental stringency on SHFO supply, the predicted change is positive but the magnitude hinges on response of LHFO average production cost to increased ES. With respect to Equation 8, which captures the effect on LHFO supply, the predicted change hinges on the response of LHFO average production cost relative to the response to LHFO marginal production cost. The direction of change of the number of LHFOs (Equation 9) is determined by the interaction between market demand and regulation-induced industry supply.

When we examine the SUR results without the interaction terms (the first three columns of Table 7) we find that environmental stringency has a positive but insignificant effect on SHFO inventory and a negative and statistically significant effect on LHFO inventory and the number of LHFOs. It is not that surprising that environmental stringency is not significant in the SHFO inventory estimation since any impact is due to a shift in the long-run equilibrium because of higher pork prices. As environmental stringency continued to change during our sample period it is possible that SHFOs have not fully adjusted to higher overall prices. The negative impact of environmental stringency on LHFO inventory is consistent with a negative size bias. The final result also shows that environmental stringency has a negative effect on the number of LHFOs. Examining Equation 9 shows that this result is consistent with some increase in production from SHFOs, an increase in contracting for LHFOs, and a shift in the average cost function of LHFOs.

Due to differences in state-level enforcement we want to estimate if the impact of increased environmental stringency differs by state. The left three columns of Table 7 show the estimation results with interaction terms for each state.[13] We find that the coefficient on environmental stringency is positive and significant for all three equations. As stand-alone coefficients, these are difficult to interpret due to the state-level effects of increased environmental stringency. With the interaction variables the most significant is the effect on LHFO inventory, with 7 of the 9 coefficients negative and significant. The magnitude of the coefficient is larger for most of the interaction effects than for the *EnvironmentalStringency* variable, but we need to estimate the marginal effects to determine if the combined effect is significant. The coefficients on the interaction variables in the estimation of the number of LHFOs are negative and significant for 5 of the 9 states. While 5 of the coefficients on SHFO inventory are significant, the sign of the coefficients varies. This is consistent with the general results that show an overall decrease in LHFO inventory and the number of LHFOs, but this also shows that the effects are not consistent across states. In particular, the effects of environmental stringency stand out in North Carolina, Nebraska, Illinois, and Indiana. Increased stringency in North Carolina has had a significant negative effect on the LHFO inventory and numbers. This is consistent with a previous study that focused specifically on North Carolina's hog industry (Sneeringer, 2009b).

<< Insert Table 8 >>

The state-specific marginal effects of environmental stringency in Table 8. Signwise, the direction of change of small-farm hog supply is consistent with comparative statics predictions for all states except Missouri, Nebraska, and North Carolina. While most of the marginal effects are not statistically different from zero, we use a joint test of the magnitudes of the estimated coefficients. Of the estimates, 7 of 9 are positive in the SHFO inventory estimation and 7 of 9 are negative in the LHFO inventory estimation. We use a chi-squared to determine if the distribution of coefficients is random and we find statistical significance that the overall effect of environmental stringency is positive for SHFO output and negative for LHFO output. The marginal effect of environmental stringency on the number of LHFOs is negative in 6 of 9 states. While this is not statistically significant, the direction is the same as in the estimation without interaction terms. When we examine the effects for the individual states, we find some interesting results. For example, Minnesota has a positive marginal effect in all three categories. This is likely due to the fact that Minnesota has had more stringent environmental regulations than federal standards and most of the other states for the entire sample period and has still had considerable growth in hog production (see Table 2). Thus, farms in Minnesota had already altered practices due to stringent environmental regulation at the beginning of the sample period. Most of the other states show the same trend as the overall result, that environmental stringency has a positive or no effect on SHFO output and a negative effect on LHFO output and the number of LHFOs. These results provide evidence that the technology embodied in environmental regulation has a negative size bias on LHFOs, affecting their marginal cost of production more than their average cost of production. This could be due to regulation such as additional record keeping or to increasing marginal costs associated with manure disposal. As shown in our results in Table 1, the effect of negative size bias on the number of LHFOs is complicated, which may be why we are unable to determine the sign of the impact. While the industry level effects are significant, the data is not sufficiently detailed to estimate state-level trends and impacts of environmental regulation.

7 Summary and Conclusion

In this paper we develop a comparative statics model of long-run industry equilibrium in the presence of environmental regulation and apply the model to the U.S. hog industry. As part of the Clean Water Act, the environmental regulation facing the hog industry sets the rules for the management and disposal of the millions of tons of hog manure produced from confined hog operations. Because the regulation is size-based, with hog operations feeding 2500 head of hogs or more facing more stringent rules than operations feeding less 2500 head, some suspect that it induces regulatory avoidance, with incumbent farms downsizing or entrants choosing a output levels that are exempt of regulation. However, since there are farms in the industry that still operate at output levels above 2500 head, what may appear to be regulatory avoidance could be strictly an outcome of how environmental regulation affects the cost structure of farms. In contrast to most of the previous literature[14] we incorporate the fact that environmental regulation is not applied to all farms regardless of size and, unlike Sneeringer and Key's work, we provide an explicit structural model that links environmental regulation to industry structure. Our economic model shows that with size-based regulation we should unambiguously observe an increase in output from SHFOs but that the impact on output and number of LHFOs depends on the size bias embodied in the technology and practices embodied in environmental regulation.

While we find little evidence of differences between states in the effect of environmental regulation, we do find evidence that such regulation has decreased LHFO inventory and the number of LHFOs. This result shows that industry shifts to fewer large livestock farms have been in spite of, not because of, environmental regulation. The findings in our paper are relevant to understanding the impact of regulation on the structure of an industry undergoing high rates of technological change. For regulators who are concerned about both environmental quality and the protection of small family farms, environmental regulation does not seem to adversely affect the viability of such operations. While the results of our paper provide useful evidence of the impact of regulation more research is needed. We use an index of environmental stringency that does not account for the differences in cost associated with various practices. Further investigation of this is left for future work. Also, it is well-known that the enforcement of existing regulation varies by state and our empirical analysis is unable to explicitly take those differences into account. Accounting for this is a difficult but necessary step to better understanding the effect of environmental regulation on industry structure.

Table A-1: State Regulation on Hog Animal Feeding Operations: 2003-2006

STATE	LC	FDA	WSA	GT	PN	SETS	NMP	MSTN	BOND	MORA	CSP	TOTAL
GA	1	1	1	1	1	2	1	1	1	0	0	10
IL	0	1	1	1	1	2	1	1	1	0	1	9
IN	1	1	1	1	1	2	1	1	0	0	1	9
IA	0	1	2	1	1	2	1	1	1	0	1	10
KS	1	2	1	1	1	2	1	1	0	1	1	11
MN	1	1	1	1	0	2	1	1	1	2	1	11
MO	0	1	1	1	1	2	1	1	1	0	1	9
NE	1	1	1	1	1	2	1	1	0	0	1	9
NC	1	1	1	0	1	2	1	1	0	2	1	10
OH	0	1	1	1	1	2	1	1	0	0	1	8
OK	0	1	1	1	1	2	1	1	1	1	1	10
PA	1	1	1	1	1	1	1	1	0	0	1	8
SD	1	1	1	1	1	1	1	1	0	0	1	8
VA	1	1	1	0	1	1	1	0	0	0	0	6

Source: State level information from various state agencies.

Appendix 1: Construction of Environmental Stringency Indices

Table A-1 shows how we constructed the environmental stringency indices for the 2000-2002 and 2003-2006 periods. We follow the methodology used by Metcalfe (2000) so that our stringency indices are consistent with the values calculated by Metcalfe. The index uses the following categories of regulation: local control (LC), facility design approval (FDA), waste system approval (WSA), geologic testing (GT), public notice (PN), setbacks (SETS), nutrient management plan (NMP), a more stringent than NPDES indicator (MSTN), bonding (BOND) and moratoria (MORA). Following Metcalfe, information on cost-share programs (CSP) is collected for each state but is not included in the calculation of the index. A ‘0’ indicates that the type of regulation is not used at the state level; a ‘1’ indicates that the type of regulation is enforced at the state-level; and a ‘2’ indicates that the regulation is extensive (significantly stringent) at the state level. For example, while the federal location setback requirement (SETS) is 1000 feet, the individual state requirements range from 1875 feet (IA) to three miles (OK). The federal government requires a manure application setback of 100 feet to 300 feet, while state-required setbacks ranging from 500 feet (IN and OK) to 3960 feet (IL). The environmental stringency index for a state is the sum of the indicators for each category.

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Table 1: Effect of Environmental Regulation Size-Bias on Industry Structure

Industry characteristic	Positive bias	Neutral bias	Negative bias
Small farm supply	+	+	+
Large farm supply	+	0	-
Number of large farms	-	-	+ if $\lvert n^l \frac{\partial q^l}{\partial E} \rvert > n^s \frac{\partial q^s}{\partial E} - \frac{\rho^l ac^l_E}{p'}$
			- if $\lvert n^l \frac{\partial q^l}{\partial E} \rvert < n^s \frac{\partial q^s}{\partial E} - \frac{\rho^l ac^l_E}{p'}$

In the table +, 0, and - denote positive, zero, and negative impacts on the specified variable.

Table 2: Hog Industry Trends

	Small Farm Inventory (thousands)			Large Farm Inventory (thousands)		
State	1995	2000	2005	1995	2000	2005
Illinois	3,072	1,619	1,120	1,728	2,532	2,880
Indiana	2,280	1,307	845	1,720	2,044	2,405
Iowa	9,653	5,738	4,017	3,848	9,362	12,583
Kansas	728	289	252	572	1,231	1,548
Minnesota	3,069	1,914	1,518	1,881	3,886	5,082
Missouri	1,775	537	351	1,775	2,364	2,349
Nebraska	2,815	1,190	870	1,235	1,861	2,030
N. Carolina	820	400	294	7,380	8,900	9,506
Ohio	1,458	924	725	342	566	835
Oklahoma	195	150	142	805	2,160	2,228
	Contracts: Small Farms			Contracts: Large Farms		
State	1995	2000	2005	1995	2000	2005
Illinois	0.106	0.154	0.202	0.196	0.224	0.251
Indiana	0.332	0.297	0.261	0.128	0.204	0.280
Iowa	0.172	0.259	0.347	0.303	0.351	0.399
Kansas	0.010	0.093	0.187	0.010	0.268	0.346
Minnesota	0.290	0.308	0.325	0.369	0.351	0.332
Missouri	0.095	0.139	0.182	0.174	0.255	0.337
Nebraska	0.107	0.163	0.219	0.007	0.061	0.115
N. Carolina	0.566	0.690	0.814	0.667	0.694	0.720
Ohio	0.250	0.297	0.345	0.223	0.342	0.461
Oklahoma	0.574	0.582	0.590	0.026	0.080	0.135

Table 3: Summary Statistics of Dependent and Exogenous Variables

Variable	Mean	Std Deviation	Minimum	Maximum
Small farm hog inventory (q^s_{jt})	1,621,057	1,849,437	128,150	11,020,000
Large farm hog inventory (q^s_{jt})	3,356,642	3,141,277	252,000	13,303,700
Number of large farms (p_{jt})	558.4	539.9	30	2270
Hog price (p_{jt})	41.95	7.37	27.4	55.4
Corn price (w_{cjt})	2.37	0.471	1.6	3.7
Gasoline price (w_{djt})	101.2	31.7	59.8	179.7
Small farm contracts as % percent of inventory (r^s_{jt})	0.298	0.192	0.01	0.839
Large farm contracts as % percent of inventory (r^l_{jt})	0.281	0.178	0.007	0.725

Table 4: Variation over Years and between States in CAFO Environmental Stringency

State	1994	1995	1996	1997	1998	1999	2000	2001	2002	2003	2004	2005	2006
Illinois	2	2	2	2	8	8	9	9	9	9	9	9	9
Indiana	4	4	4	4	6	6	6	6	6	9	9	9	9
Iowa	4	4	4	4	9	9	10	10	10	10	10	10	10
Kansas	4	4	4	4	9	9	9	9	9	11	11	11	11
Minnesota	8	8	8	8	9	9	9	9	9	11	11	11	11
Missouri	6	6	6	6	7	7	8	8	8	9	9	9	9
Nebraska	3	3	3	3	7	7	8	8	8	9	9	9	9
North Carolina	1	1	1	1	8	8	10	10	10	10	10	10	10
Ohio	5	5	5	5	7	7	8	8	8	8	8	8	8
Oklahoma	4	4	4	4	6	6	9	9	9	10	10	10	10

Table 5: Estimation of Environmental Stringency Reaction Functions

	IL	IN	IA	KS	MN	MO	NE	NC	OH	OK
LCV	0.064*	-0.001	0.030	0.008	-0.210**	-0.093***	0.037	-0.000	-0.070	-0.083
	0.034	0.204	0.039	0.054	0.076	0.019	0.027	0.000	0.043	0.054
GA								13.263***		
								0.026		
IL		0.464	0.593***			-1.929***				
		0.390	0.015			0.311				
IN	0.076								-0.245	
	0.054								0.145	
IA	1.653***				0.088	3.449***	0.825***			
	0.030				0.506	0.520	0.078			
KS										-0.068
										0.184
MN			-0.005							
			0.097							
MO				0.037			0.665**			2.729***
				0.511			0.272			0.577
NE				0.968***						
				0.187						
NC										
OH		-1.011								
		1.329								
OK										
PA									0.355***	
									0.059	
SD					-0.015					
					0.310					
VA								-6.455***		
								0.020		
R-sq	0.9993	0.9969	0.9993	0.9995	0.9987	0.9999	0.9997	0.9933	0.9974	0.9981

Standard errors are shown below the coefficients. Significance at the 0.01, 0.05, and 0.1 levels denoted by ***, **, and * respectively. The other exogenous variables included in the final estimation are included for consistency but coefficients are not reported for brevity.

Table 6: Estimation of Hog Price Instruments (log)

	Coefficient	T-Statistic
Constant	-0.194	-0.60
Lagged Hog Price (log)	0.133**	2.43
Lagged Corn Price (log)	0.403***	6.36
Beef Price (log)	-0.002	-1.42
R-squared	0.6779	

All prices in 2004 dollars. Significance at the 0.01, 0.05, and 0.1 levels denoted by ***, **, and * respectively. The other exogenous variables included in the final estimation are included for consistency but coefficients are not reported for brevity.

Table 7: Estimation of Hog Industry Model

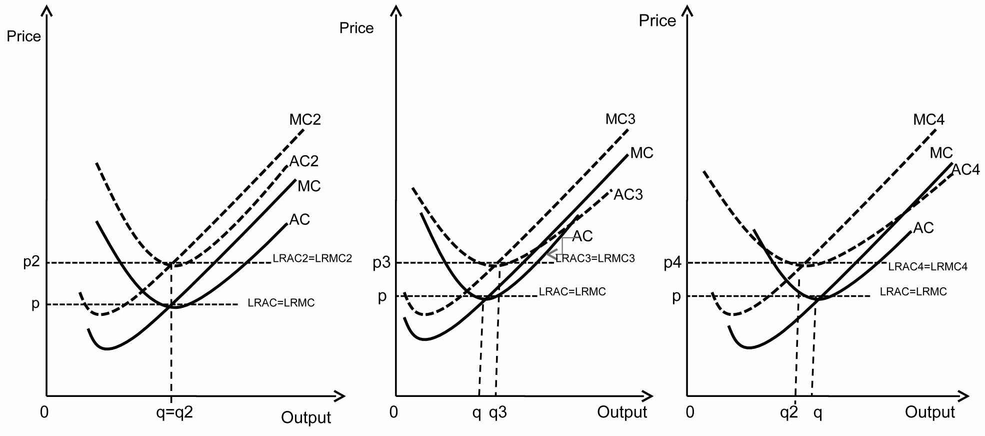
	SHFO Output (log)	LHFO Output (log)	LHFO Numbers (log)	SHFO Output (log)	LHFO Output (log)	LHFO Numbers (log)
Constant	14.303***	18.272***	9.735***	13.706***	16.988***	8.478***
	0.488	0.512	0.487	0.571	0.543	0.487
Hog Price	0.242	-0.045	-0.291	0.352*	-0.085	-0.236
(log)	0.219	0.230	0.219	0.189	0.180	0.161
Corn Price	0.271***	-0.195**	-0.279***	0.295***	-0.169**	-0.215***
(log)	0.094	0.098	0.093	0.076	0.072	0.065
Transportation Price	0.044	-0.457**	-0.255	0.033	-0.373***	-0.214*
(log)	0.181	0.190	0.181	0.146	0.138	0.124
Small Farm	-0.278***	0.036	-0.066	-0.155	-0.080	-0.226**
Contracts (log)	0.054	0.057	0.054	0.129	0.123	0.110
Large Farm	0.061	0.073*	-0.047	0.002	0.176***	0.090**
Contracts (log)	0.038	0.040	0.038	0.048	0.045	0.041
Environmental	0.042	-0.162***	-0.196***	0.245**	0.340***	0.199**
Stringency (log)	0.048	0.050	0.048	0.120	0.114	0.102
Time	-0.072***	0.086***	0.069***	-0.086***	0.081***	0.059***
	0.012	0.013	0.012	0.012	0.012	0.011
Illinois	-1.311***	-1.194***	-1.205***	-0.947***	-0.246	-0.551***
	0.066	0.070	0.066	0.209	0.199	0.178
Indiana	-1.272***	-1.414***	-1.378***	-1.751***	0.810**	0.635*
	0.068	0.072	0.068	0.414	0.393	0.352
Kansas	-3.092***	-1.922***	-2.781***	-2.906***	-1.142**	-2.338***
	0.089	0.093	0.088	0.572	0.544	0.488
Minnesota	-0.993***	-0.829***	-0.705***	-2.489***	-2.022**	-1.853**
	0.064	0.067	0.063	0.859	0.817	0.732
Missouri	-2.261***	-1.272***	-1.889***	0.434	1.498***	-1.771***
	0.068	0.071	0.068	0.517	0.492	0.441
Nebraska	-1.411***	-1.472***	-1.950***	-0.947***	0.263	-0.512**
	0.092	0.097	0.092	0.299	0.285	0.255
N. Carolina	-2.322***	-0.095	-0.254***	-1.999***	0.955***	0.464**
	0.082	0.086	0.082	0.260	0.248	0.222
Ohio	-1.765***	-2.713***	-2.403***	-2.703***	-1.976***	-2.858***
	0.062	0.065	0.062	0.427	0.406	0.364
Oklahoma	-3.287***	-1.563***	-3.164***	-4.215***	-0.814*	-2.190***
	0.114	0.119	0.114	0.476	0.453	0.406
Illinois x ES				-0.160	-0.478***	-0.332***
				0.102	0.097	0.087
Indiana x ES				0.259	-1.138***	-1.020***
				0.207	0.197	0.176
Kansas x ES				-0.032	-0.430**	-0.280
				0.216	0.205	0.184
Minnesota x ES				0.640*	0.496	0.490
				0.378	0.360	0.323
Missouri x ES				-1.316***	-1.399***	-0.086
				0.255	0.242	0.217
Nebraska x ES				-0.271**	-0.822***	-0.642***
				0.133	0.126	0.113
N. Carolina x ES				-0.208**	-0.500***	-0.313***
				0.104	0.099	0.089
Ohio x ES				0.485**	-0.348*	0.272
				0.215	0.205	0.184
Oklahoma x ES				0.388**	-0.229	-0.304**
				0.173	0.165	0.148
R-squared	0.9732	0.9641	0.9822	0.9836	0.9831	0.9909

All prices in 2004 dollars. Significance at the 0.01, 0.05, and 0.1 levels denoted by ***, **, and * respectively. Robust standard errors listed below the estimated coefficients.

Table 8: State-Specific Marginal Effects of Environmental Stringency

	SHFO Output (log)	LHFO Output (log)	LHFO Numbers (log)
Illinois	0.085**	-0.138*	-0.133***
	0.044	0.081	0.047
Indiana	0.504***	-0.798***	-0.821***
	0.053	0.239	0.187
Kansas	0.213***	-0.090	-0.081
	0.031	0.103	0.059
Minnesota	0.885***	0.836***	0.690***
	0.249	0.189	0.163
Missouri	-1.071***	-1.059***	0.113***
	0.333	0.336	0.026
Nebraska	-0.025	-0.482***	-0.443***
	0.058	0.130	0.086
N. Carolina	0.038	-0.160*	-0.113**
	0.050	0.087	0.047
Ohio	0.731***	-0.008	0.471***
	0.107	0.083	0.053
Oklahoma	0.634***	0.111*	-0.105*
	0.060	0.065	0.057
Chi-squared value	2.889*	2.889*	1.111

Marginal Effects are calculated from the second regression with interaction terms. Environmental stringency is measured as the log of the index value. Significance at the 0.01, 0.05, and 0.1 levels denoted by ***, **, and * respectively. Robust standard errors listed below the estimated coefficients.



(1a) No size bias

(1b) Positive size bias

(1c) Negative size bias

Figure 1: Different Types of Size Bias due to Regulation

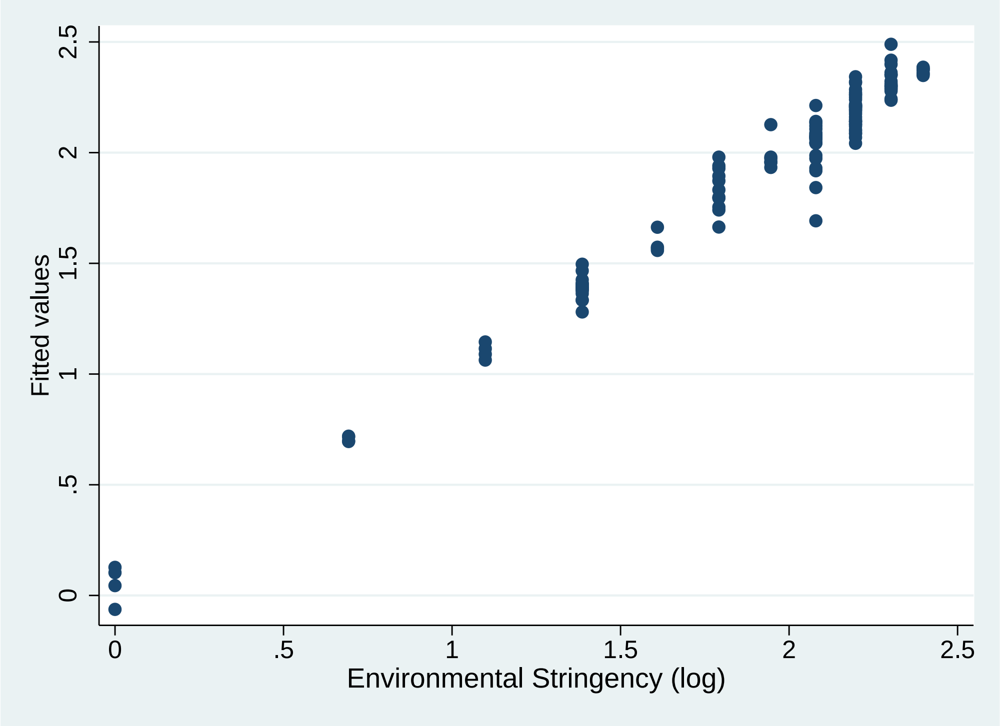


Figure 2: Comparison of Actual and Predicted Values for Environmental Stringency

Notes

[1] See http://www.nass.usda.gov/ for historical information on livestock inventory and operations.

[2] Eutrophication is a process whereby water bodies receive excess nutrients (nitrogen and phosphates) that stimulate excessive plant growth (e.g. algae). This enhanced plant growth reduces dissolved oxygen in the water when dead plant material decomposes and can cause other organisms to die.

[3] Our account of the background of the CWA in this paper draws from the EPA (2008, pp. 70419-70422).

[4] The size thresholds specific to hogs are as follows. For operations with animals weighing over 55 pounds, the size thresholds for small, medium, and large CAFOs are less than 750, between 750 and 2,499, and 2,500 or more, respectively. For hog operations with animals weighing less than 55 pounds, the corresponding size thresholds are less than 3,000, between 3,000 and 9,999, and 10,000 or more, respectively.

[5] In the case of new technology adoption both marginal-and average cost curves shift down leading to reduction in price and an increase in output.

[6] Figure (1a) assumes that regulation shifts marginal and average cost curves upward in the same manner as a neutral technological change induces a downward shift.

[7] Key and McBride (2007) provide an excellent review of changes in the hog industry during the 1990s and 2000s.

[8] Available at http://www.nass.usda.gov.

[9] Available at http://www.eia.gov

[10] We recognize that due to the Waterkeeper Alliance court case many of the states delayed implementation of the 2003 regulation until much later, thus, some of the 2003-2006 environmental stringency levels may be overestimated. To test if this fact has an effect on the results we ran the same econometric models on the pre-2003 data and found very similar results. We thank an anonymous reviewer for pointing out this issue.

[11] We follow the same methodology as Levinson (2001) in determining a state-level LCV score and we average the Senate and House of Representatives score for a particular state.

[12] Using the two highest producing adjacent states required us to create indices for four states that are not in the top-ten (Georgia, Pennsylvania, South Dakota, and Virginia). North Carolina is geographically isolated from the other top-ten producing states and two of

the other states only have one adjacent state in the top-ten. Metcalfe (2000) included indices for the earlier periods for these states. We updated these using the same methodology as the other states.

[13] As with the state indicator variables, Iowa is omitted since it has the highest value of production.

[14] One exception is Sneeringer and Key (2011).