Environmental Regulations and the Structure of U.S. Hog Farms

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Abstract

The U.S hog production industry has been continually subjected to rapid structural changes since the early 1990s. The industry's move towards more concentrated large hog farms and geographical concentration of such farms, have triggered public concerns over the dangers such big animal feeding operations are likely to pose to the waters of the country. This study investigates the implications of state-level environmental regulations on the structure of hog farms. The results of this study suggest that environmental regulations will result in one of three possible scenarios: (1) a more competitive industry in which small hog operations are not adversely affected which will allow more small operations to enter rather than exit the industry; (2) a more concentrated hog production industry in which large operations survive while small operations exit the industry; (3) no change in the structure of the industry where both sizes of operations are not significantly affected by environmental stringency.

Key words: Perfect competition, U.S. hog production industry, Environmental regulations

1. Introduction

The U.S. hog industry, once dominated by small owner-operated crop-hog farms, has been the subject of significant changes in operation size, organizational structure, and technological base during the past decade (McBride and Key, 2003). The industry is currently dominated by large specialized operations characterized by low costs, improved technologies in areas such as breeding, feeding and facilities management and a primary occupation in livestock production. High cost small operations have been vulnerable to declines in hog prices, especially in the 1990s, and are among the first to exit the industry when faced with such economic hardships, while low cost operations tend to survive, (McBride and Key, 2003). The U.S. hog production industry which had about 3million operations during the 1950s, only comprised of about 70 000 and 65000 hog farms in 2004 and 2007, respectively. The top three hog producing states, Iowa, North Carolina, and Minnesota accounted for about 55% of the U.S. total hog inventories in 2007, reflecting significant structural changes in this industry over the years.

The changes in animal production saw an expansion in concentrated animal feeding operations, and a rise in issues associated with large numbers of animals in confined areas, which include: water contamination; air pollution; health effects; concern about antibiotics; animal welfare; and loss of resources, Centner (2006). To address these environmental issues, the federal government requires states with animal feeding operations (AFOs) to enforce environmental regulations such as waste management plans (WMPs), mandatory record keeping (MRK), odor abatement plans (OAPs), handling of dead swine (HDS), reports on waste spillage (RWS), nutrient management plans (NMPs), manure (dry and liquid) application setbacks (MAPs), cost share programs (CSPs) and AFO location setbacks (ALSB). Federal involvement in environmental regulations on AFOs began with the inception of the Clean Water Act of 1972.

While federal regulations must be met nationwide, states with such large hog animal feeding operations (HFOs) are facing environmental pressure from people of all walks of life and have been continually adopting more stringent regulations as well as more regulations since the 1990s[1]. In addition, to regulations required by the federal government, some states require: facility design approval (FDA); and construction and operation permits (COPs), zoning requirements, and hydrogen sulfide regulations.

Since the majority of regulations on nonpoint pollution are set at the state level, hog producers have to deal with ever increasing manure management compliance costs (Metcalfe, 2000, 2001), as a result of the increased regulatory stringency. The question on how increases in environmental stringency affect the competitiveness of AFOs prompted several economists who wanted to understand: (1) how this increase in

[1] A table showing the variation of environmental regulation stringency among the top ten hog producing states and the federal government is provided in appendix A.

environmental stringency affect U.S. hog production, (2) how important the increase in compliance costs is to the competitiveness of AFOs, (3) how these costs affect the geographical concentration of hog farms in the U.S. A number of studies have addressed environmental regulation issues affecting U.S. hog production. These studies are discussed in section 2 of the paper.

2. Literature Review

Fleming, Babcock, and Wang (1998) investigated the cost of delivering manure nutrients from Iowa swine production. The study considered: two forms of manure storage (anaerobic lagoon and slurry basin); two target nutrients (nitrogen and phosphate); two crop rotations; and two levels of field incorporation (tillage of manure into soil). Results of the study suggest that manure nutrient returns are maximized when: high nutrient using crops are grown close to a medium sized swine facility that uses nutrient conserving methods to store manure; and that incorporating manure increases production returns while improving air quality. The study also found that: the value of manure nutrients (i.e. applied nutrients); tend to match crop requirements under a phosphate standard rather than under a nitrogen standard and that the profit maximizing number of hogs and profits are greater under a phosphate standard.

Fleming (1999) estimated how much larger the setback length for surface application of manure must be relative to the setback length for soil incorporation to encourage incorporation in Kentucky. Results suggested that setback lengths do not encourage odor control through incorporation and that the setback length for surface application has to be substantially longer than that of incorporation.

Sullivan, Vasavada and Smith (2000), identified three possible reasons for the variation in states' policies regulating nonpoint-source pollution. These include; the design of Federal water policy laws, characteristics of the nonpoint-source pollution, and characteristics of the states that have to deal with water quality issues.

Metcalfe (2000) examined the change in state legislation imposed to regulate manure management and to protect water quality between 1994 and 1998. Based on the state to state variation of the regulation, the study constructs a stringency index which is dependent on the number of legislations imposed in each state. Examination of state legislation between the two years showed that the stringency of state manure management regulation significantly increased between 1994 and 1998. The study noted that a majority of the increases in regulation were imposed in response to the expansion of hog production.

Metcalfe (2001) investigated the influence of water quality regulatory stringency on hog production in the U.S. The author used a profit maximization model for hog production in which the environment was included as an input in the production process. Results show that there are significant environmental compliance costs for small hog feeding operations, and large operations did not appear to be influenced by the level of state environmental stringency.

Gillespie and Fulton (2001), examined the movement of hog farms among three different size categories. They found that the hog–corn price ratio has continued to affect the entry and exit of small hog farms. They also find the hog-corn price ratio to have influenced the movement of hog farms among size categories.

Centner and Mullen (2002) analyzed enforcement mechanisms and opportunities for greater enforcement of AFO regulations and found that reductions in pollution could be a result of more effective enforcement of the existing regulations, and not from coming up with more regulations.

Agapoff and Cattaneo (2003), addressed the effectiveness of environmental quality incentive program (EQIP) in helping farmers meet nitrogen and phosphorous based manure application standards. They found that EQIP helps cover the costs of most of the small farmers and some of the large farmers.

McBride and Key (2003, 2004), found that the U.S. swine industry has been the subject of significant changes in size and ownership structure of operations during the past decade. They further argued that large operations are owned by farmers whose primary occupation is farming, and better technologies in areas such as breeding, feeding and facilities management. High cost operations have been vulnerable to declines in hog prices especially in the 1990s and are among the first to exit the industry when faced with such economic hardships, while low cost operations tend to survive.

Herath, Weersink, and Carpentier (2005) described the patterns of regional and national change in the geographical concentration of hog, dairy, and fed-cattle inventories for 48 states in the United States from 1975 to 2000. Results show evidence of all three sectors becoming more geographically concentrated within states across the country. Findings also show that Hog and dairy inventories increased in nontraditional production regions while fed-cattle inventories increased only in three major producing states. The northwestern region of the U.S. experienced reduced geographical concentration of livestock production while the western regions experienced both increased livestock production and increased geographical concentration.

Herath, Weersink, and Carpentier (2005) examined the factors affecting state annual share of national inventory for each of the hog, dairy, and fed-cattle sectors using data from the 48 contiguous states for 1976 to 2000. Results indicated that differences in environmental stringency facing livestock producers had a significant influence on production decisions in the dairy and mainly the hog sector.

Kuo(2005) estimated the factors behind the exit behavior of small swine producers in the U.S swine industry for the period 1988 through 2003. The author finds evidence against new large producers entrants displacing incumbent small producers ruling out the existence of any crowding-out effect between the two producer sizes. The study also finds evidence that the expanding larger producer hog operation sizes pressure the small producers to leave swine industry. Contrary to the findings by Metcalfe, 2001, and Herath, Weersink, and Carpentier (2005), state specific environmental regulations were found to have no influence on why small producers are leaving the industry.

Weersink and Raymond (2006) investigated the regional characteristics where livestock spills occur, whether the spills are generating complaints, the types of citizens who are complaining, and whether environmental policy deters either spills or complaints. Results indicated that the distance between livestock producers and both environmentally sensitive areas and people serves to reduce conflicts between farmers and the local community.

While the foregoing studies are important in providing insights on the economic impact of environmental regulations on hog production, with the exception of Kuo

(2005), they are all limited to short-run implications. The short-run and long-run impact of environmental regulations on the structure of U.S. hog farms remains theoretically and empirically unanswered. Understanding the impact of regulations on the distribution of hog production is an important question for policymakers. If environmental regulation affects the distribution across farms, it must be due to differential cost structures of large and small hog farms.[2] In this research, we answer the following question: What is the effect of environmental regulations on the structure of hog farms?

The purpose of this study is to investigate the implications of state-level environmental regulations on the structure of hog farms. To address this question we develop a theoretical model that addresses supply shifts due to the increase in environmental regulation compliance costs in a perfectly competitive hog industry in both the short-run and the long-run. Addressing environmental regulations in the model as a supply shifter is not new in economics literature. Litchenberg, Parker and Zilberman (1988), and Sunding (1996), applied the same method to address environmental regulations on the use of pesticides in the agricultural indiustry. Litchenberg, Parker and Zilberman(1988) estimating marginal costs of environmental regulations on pesticides affecting agriculture, in the short-run. Sunding(1996) extended the work by Litchenberg, Parker and Zilberman(1988) by explicitly considering temporal as well as spatial diversity when measuring marginal welfare costs of non-uniform environmental regulations (i.e. pesticide application reduction requirement) affecting agriculture, in the short-run. Kartz and Rosen (1983) analyzed the effects of taxation as a cost shifter using the conjectural variations model of oligopoly. Hamilton and Sunding (1997) examined

[2] Indeed the link between environmental and industry structure is the basis for some suggestions to use environmental regulation to influence industry structure after Initiative 300, the Nebraska Anti-Corporate Law, has been invalidated by the courts.

the effect of changing supply on the market structure of the downstream food processing sector allowing for cost differences and endogenous downstream entry and exit. The work by Hamilton and Sunding (1997) is the only work that utilizes this methodology to address long-run implications of supply shifts. The rest of the paper is organized as follows: section 3 presents the model, and section 4 summarizes and concludes the paper.

3. Economic Model

We present a general profit maximization model for a perfectly competitive industry which will be used to analyze the impact of environmental regulations on HFOs both in the short-run and in the long-run. The model is an adaptation of the framework developed by Hamilton (1999) to an atomistic industry. Hamilton (1999)'s framework addresses demand shifts in an oligopolistic industry.

We assume a perfectly competitive industry consisting of N hog farms of two distinct sizes, $N = n_s + n_l$, with $n_s > 0$ and $n_l > 0$ representing the number of small and large HFOs , respectively. Short and long-run impacts of environmental regulations will be analyzed. Costs of production for a single HFO of size i, for $i = s, l$, are given by $c_i = c_i(q_i; E)$, where q_i is the level of hog output for a HFO of size i and E represents environmental regulations imposed on HFOs. We introduce, E, as a cost shifter the same manner as in Katz and Rosen (1983), Litchenberg, Parker and Zilberman(1988), Sunding (1996) and Hamilton and Sunding (1997) . The properties of the cost functions are:

1. $mc^i = c^i_{q_i} = \dfrac{\partial c_i(q_i, E)}{\partial q_i} > 0$, marginal cost is increasing in output.

2. $mc^i_{q_i} = c^i_{q\,q_i} = \dfrac{\partial^2 c_i(q_i, E)}{\partial q_i^2} \geq 0$, the marginal expansion of output raises the marginal cost of each HFO of size i.

3. $mc^i_E = c^i_{q_i E} = \dfrac{\partial^2 c_i(q_i, E)}{\partial q_i \partial E} \geq 0$, the marginal cost of a HFO of size i is a nondecreasing function of the levels of environmental regulations.

4. $ac^i_E = \dfrac{\partial ac_i}{\partial E} > 0$, the average cost function is a nondecreasing function of the levels of environmental regulations.

Assuming that large HFOs are more efficient than small HFOs (Rhodes, 1995; Kuo, 2005), due to economies of scale, we can write;

$$\frac{\partial c_s(q_s, E)}{\partial q_s}\Big|_{q_s = q_s^*} \geq \frac{\partial c_l(q_l, E)}{\partial q_l}\Big|_{q_l = q_l^*}$$

The above condition, states that the marginal cost of a small HFO is at least greater than that of a large HFO, in equilibrium. This condition was found to be empirically true by Rhodes (1995). Characteristics of efficient producers such as: quick access and adoption of new technology; easy access to market information and ease of its use; increased specialization; and easy or superior access to all inputs including capital are less likely to be associated with small producers (Rhodes, 1995). Fulton and Gillespie (1995) also argue that technological progress in the swine industry has lowered the cost of production. This technological progress is found to be associated with large operations as it requires substantial investment, (Kuo, 2005).

$\frac{\partial^2 c_s(q_s, E)}{\partial (q_s)^2}|_{q_s = q_s^*} \geq \frac{\partial^2 c_l(q_l, E)}{\partial (q_l)^2}|_{q_l = q_l^*}$, this condition states that the marginal expansion of output does not raise the marginal cost function of large HFOs by more than that of the small HFOs. This follows from the argument that larger operations are more efficient than small operations. The inverse derived demand function facing the hog production industry is given by $p = p(Q)$, where $Q = n_s q_s + n_l q_l$, is the total hog output produced by the hog production industry and p is the hog price. The demand curve is downward sloping, that is $\frac{\partial p}{\partial Q} < 0$.

The representative HFO of size, i 's objective is to

$$\max_{q_i} \pi^i = pq_i - c_i(q_i, E) \quad (1)$$

Differentiating equation (1) with respect to q_i and setting equal to zero yields the first-order condition for a HFO of size i ,

$$\pi^i_{q_i} = p - c^i_{q_i}(q_i, E) = 0$$

$$p = c^i_{q_i}(q_i, E) \quad (2).$$

The sufficient second order condition of the i^{th} HFO,

$$-c^i_{q_i q_i} < 0 \quad (3).$$

3.1. Short-run implications of environmental regulations on hog farms

In the short-run, the number of hog farms in each HFO size category is fixed. An HFO of size i earns a profit in the short-run, which in turn provides an incentive for other HFO's to enter the market. Entry of new HFOs is however not possible since HFOs cannot build new establishments in the short run. The short-run equilibrium is determined by industry demand and HFO supply functions. The supply function is determined by the first order condition for profit maximization, and demand is given by the inverse demand function, $p = p(Q)$. To determine the short-run equilibrium, we totally differentiate first-order condition for each HFO of size i (2) and the inverse demand function. Presenting the resulting equations in matrix form we have:

$$\begin{bmatrix} \theta_s & n_l p \\ n_s p & \theta_l \end{bmatrix} \begin{bmatrix} dq_s \\ dq_l \end{bmatrix} = \begin{bmatrix} mc_E^s \\ mc_E^l \end{bmatrix} dE \quad (4)$$

Where $\theta_s = n_s p' - mc_{q_s}^s$ and $\theta_l = n_l p' - mc_{q_l}^l$. First, we let the coefficient matrix in (4) be denoted by Ω. The determinant of the coefficient matrix, $\det(\Omega)$, given by

$$\det(\Omega) = mc_{q_s}^s (mc_{q_l}^l - n_l p') - n_s p' mc_{q_l}^l \quad (5),$$

is positive by the second order condition $mc_{q_i}^i \geq 0$, the slope of the inverse demand function, $p' = \frac{\partial p}{\partial Q} < 0$, and the number of HFOs in each subgroup, $n_i > 0$.

The effects of environmental regulations on the hog output of a representative small HFO, representative large HFO and the hog production industry are:

$$\frac{\partial q_s}{\partial E} = \frac{n_l p'(mc_E^s - mc_E^l) - mc_E^s (mc_{q_l}^l)}{mc_{q_s}^s (mc_{q_l}^l - n_l p') - n_s p' mc_{q_l}^l} \quad (6),$$

$$\frac{\partial q_l}{\partial E} = \frac{n_s p'(mc_E^l - mc_E^s) - mc_E^l (mc_{q_s}^s)}{mc_{q_s}^s (mc_{q_l}^l - n_l p') - n_s p' mc_{q_l}^l} \quad (7), \text{ and}$$

$$\frac{dQ}{dE} = -\frac{n_l mc_E^l mc_{q_s}^s + n_s mc_E^s mc_{q_l}^l}{mc_{q_s}^s (mc_{q_l}^l - n_l p') - n_s p' mc_{q_l}^l}$$ (8) , respectively. All the terms in the numerator of (6) are negative, henceforth, (6) is negative since the denominator is positive by (5), supporting the empirical findings by Metcalfe (2001). The first expression in the numerator of (7) is positive and the second expression is negative. The numerator in (7) is positive when $\frac{n_s p'(mc_E^l - mc_E^s)}{mc_E^l} > mc_{q_s}^s$, and its negative when $\frac{n_s p'(mc_E^l - mc_E^s)}{mc_E^l} < mc_{q_s}^s$, suggesting that, increasing environmental regulations can either increase or decrease the output of a large HFO. The numerator of (8) is negative and the denominator is positive, suggesting that environmental regulations have the effect of reducing total hog production in the short-run.

The market share for a HFO of size $\boldsymbol{i}$, is given by $k_i = \frac{q_i}{Q}$. Differentiating this condition with respect to E, yields the effect of environmental regulations on market share,

$$\frac{\partial k_i}{\partial E} = \frac{Q\frac{\partial q_i}{\partial E} - q_i \frac{\partial Q}{\partial E}}{Q^2}$$. (9) Using (6), (7) and (8) and (9), the effects of environmental regulations on the share of marketing for small and large HFOs are given by:

$$\frac{\partial k_s}{\partial E} = \frac{n_l p' Q(mc_E^s - mc_E^l) - Q mc_E^s mc_{q_l}^l + n_l q_s mc_E^l mc_{q_s}^s + n_s q_s mc_E^s mc_{q_l}^l}{Q^2 (mc_{q_s}^s (mc_{q_l}^l - n_l p') - n_s p' mc_{q_l}^l)}$$ (10), and

$$\frac{\partial k_l}{\partial E} = \frac{n_l p' Q(mc_E^l - mc_E^s) + mc_{q_s}^s (n_l q_l mc_E^l - Qmc_E^s) + n_s q_l mc_E^s mc_{q_l}^l}{Q^2 (mc_{q_s}^s (mc_{q_l}^l - n_l p') - n_s p' mc_{q_l}^l)}$$ (11), respectively.

The denominators in (10) and (11) are positive by (5). The numerator of (10) is positive when $n_l p' Q(mc_E^s - mc_E^l) - Qmc_E^s mc_{q_l}^l < n_l q_s mc_E^l mc_{q_s}^s + n_s q_s mc_E^s mc_{q_l}^l$ and negative when $n_l p' Q(mc_E^s - mc_E^l) - Qmc_E^s mc_{q_l}^l > n_l q_s mc_E^l mc_{q_s}^s + n_s q_s mc_E^s mc_{q_l}^l$. The numerator of (11) is positive and negative when,

$mc_{q_s}^s (n_l q_l mc_E^l - Qmc_E^s) < n_s q_l mc_E^s mc_{q_l}^l + n_l p' Q(mc_E^l - mc_E^s)$ and

$mc_{q_s}^s (n_l q_l mc_E^l - Qmc_E^s) > n_s q_l mc_E^s mc_{q_l}^l + n_l p' Q(mc_E^l - mc_E^s)$, respectively. We cannot sign (10) and (11) implying that environmental regulations can either increase or decrease the share of hog marketing for both small and large HFOs.

3.2. Long-run implications of environmental regulations on hog farms

In the long-run, short-run profits or losses will induce HFOs to enter or exit the industry until profits are driven to zero. We assume that there are barriers to entry and exit for large HFOs so that only small HFOs enter and exit the industry. Small HFOs enter until profit is driven to zero in the industry. In equilibrium (market equilibrium) the number of small HFOs, n_s^* is determined by:

$\pi^{s^*} = p(Q^*)q_s^* - c_s(q_s^*, E) = 0$ or $p(Q^*) = ac^s(q_s^*, E) = 0$ (12), where, $Q^* = n_s^* q_s^* + n_l q_l^*$ is the total output of the hog production industry in the long run, and

$ac^s(q^*, E) = \frac{c(q_s^*, E)}{q_s^*}$, represents the average cost function for small HFOs. Equation

(12) states that in equilibrium when firms are earning zero economic profits, price equals average cost.

$$\begin{bmatrix} \theta_s & n_l p' & q_s p' \\ n_s p' & \theta_2 & q_s p' \\ \omega_s & n_l p' & q_s p' \end{bmatrix} \begin{bmatrix} dq_s \\ dq_l \\ dn_s \end{bmatrix} = \begin{bmatrix} mc_E^s \\ mc_E^l \\ ac_E^s \end{bmatrix} dE \quad (13)$$

Where $\theta_s = n_s p' - mc_{q_s}^s$, $\theta_l = n_l p' - mc_{q_l}^l$, $\omega_s = n_s p' - ac_{q_s}^s$, and the other elements are as defined earlier.

Calculating the determinant of the coefficient matrix, Ω , and using the definition of θ_s, θ_l and ω_s , we have; $\det(\Omega) = q_s p' mc_{q_l}^l (mc_{q_s}^s + ac_{q_s}^s) < 0$ (14), which is negative, since $p' < 0$, $q_s > 0$, $mc_{q_l}^l > 0$, $mc_{q_s}^s > 0$,and $ac_{q_s}^s > 0$.

The effect of environmental regulations on the hog output of a representative small HFO is:

$$\frac{\partial q_s}{\partial E} = \frac{ac_E^s - mc_E^s}{mc_{q_s}^s + ac_{q_s}^s} \text{ (15),}$$

The sign of (15) depends on how the change in marginal costs for small HFOs due to environmental regulation compares to the change in the average costs for small HFOs due to environmental costs. The relative sizes of the changes in marginal and average costs due to environmental regulation mainly depend on the type of regulation. If the environmental regulation shifter affects fixed costs only, then it will have an effect on average costs and not marginal costs[3]. In such a case, (15) is positive (i.e. $ac_E^s > mc_E^s$), implying that environmental regulations have a positive effect on the output for small HFOs in the long-run. When environmental regulations shift the marginal cost curve more than the average cost curve (i.e. $ac_E^s < mc_E^s$), then (15) is negative and output will fall with an increase environmental regulations. However if the regulation affects variable costs (e.g. regulations that affect input price), then both marginal costs and average costs will change. The direction of change will be positive (negative) when the change in average costs due to the regulation is greater (lower) than its effect on marginal costs. Examples of such regulations include; nutrient management, and mandatory record keeping, which are all similar to an increase in an input price[4]. When the regulations are aggregated, the direction of the effect will depend on how the aggregated regulations affect average costs, technology and/or whether they behave like an increase in input price. In the wake of all such possibilities, we cannot readily tell the sign.

The effect of environmental regulations on the hog output of large HFOs is given by:

$$\frac{\partial q_l}{\partial E} = \frac{(n_s p' - ac_{q_s}^s)(mc_E^s - mc_E^l) + q_s p'(ac_E^s - mc_E^s) + (n_s p' - mc_{q_s}^s)(mc_E^l - ac_E^s)}{mc_{q_l}^l (mc_{q_s}^s + ac_{q_s}^s)} \quad (16)$$

The denominator in (16) is positive by $mc_{q_l}^l > 0$,and $mc_{q_s}^s + ac_{q_s}^s > 0$. The first term in the numerator of (16), $(n_s p' - ac_{q_s}^s)(mc_E^s - mc_E^l) < 0$, is negative with

[3] Examples of regulations that affect average costs only are: facility design, operation and construction requirements, setback requirements (e.g. HFOs may be forced to relocate their operations to conform to the requirement), are all onetime costs.
[4] A nutrient management regulation may require a change in the hog diet which will have an effect on the price of feed if certain nutrients need to be added or eliminated. Also, mandatory record keeping can be viewed as a variable cost as this involves daily monitoring of the hogs. If one has to take a census of hogs weekly or every other week, then the cost of monitoring is an ongoing cost.

$n_s p' < 0, -ac^s_{q_s} < 0, (mc^s_E - mc^l_E) > 0$. The expression, $(mc^s_E - mc^l_E) > 0$,is positive following the efficiency assumption we made earlier, that is, large HFOs are assumed to be more efficient than small HFOs. The second term, $q_s p'(ac^s_E - mc^s_E)$, can either be positive or negative depending on how the change in average costs due to environmental regulations compares to the change in marginal costs due to environmental regulations as discussed in (15). It is positive (negative) when $ac^s_E < mc^s_E$ ($ac^s_E > mc^s_E$) with $q_s > 0, p' < 0$. The first part of the third term, $(n_s p' - mc^s_{q_s}) < 0$, with $n_s p' < 0$, and $-mc^s_{q_s} < 0$. However, we cannot readily sign the second part of the third expression, $(mc^l_E - ac^s_E)$. As explained earlier, some regulations affect average costs more (less) than they affect marginal costs. The sign of $(mc^l_E - ac^s_E)$ depends on the type of regulation. If the regulation does not affect marginal costs, then $mc^l_E - ac^s_E < 0$, and if the regulation affects the marginal costs of large HFOs more than the average costs of small HFOs , then $mc^l_E - ac^s_E > 0$. The effect of environmental regulations on large HFOs is negative if and only if, $mc^l_E > ac^s_E$, and $ac^s_E > mc^s_E$,and positive if and only if $mc^l_E < ac^s_E$, $ac^s_E < mc^s_E$ and $(n_s p' - mc^s_{q_s})(mc^l_E - ac^s_E) + q_s p'(ac^s_E - mc^s_E) > (n_s p' - ac^s_{q_s})(mc^s_E - mc^l_E)$.

The effect of environmental regulations on the number of small HFOs is given by:

$$\frac{\partial n_s}{\partial E} = \frac{n_s p' ac^s_{q_s}(mc^s_E - mc^l_E) + n_s p' mc^l_{q_l}(mc^s_E - ac^s_E) + n_l p' mc^s_{q_s}(mc^l_E - ac^s_E) + mc^l_{q_l}(mc^s_{q_s} ac^s_E - ac^s_{q_s} mc^s_E)}{q_s p' mc^l_{q_l}(mc^s_{q_s} + ac^s_{q_s})}$$

(17).

The denominator of (17) is negative by (14). The first term in the numerator of (17) is negative by $n_s p' ac^s_{q_s} < 0$ and $(mc^s_E - mc^l_E) > 0$, as established earlier. The second term is positive (negative) when $ac_E^s > mc_E^s$ ($ac_E^s < mc_E^s$). This basically depends on the type of environmental regulation as explained earlier. The third term is positive(negative)when the change in marginal costs for large HFOs due to environmental regulations is lower(greater) than the change in the average costs for small HFOs, due to environmental regulations. (). The fourth term is positive (negative) when $mc_{q_s}^s ac_E^s > ac_{q_s}^s mc_E^s$ ($mc_{q_s}^s ac_E^s < ac_{q_s}^s mc_E^s$). In other words, the fourth term is positive (negative) when the ratio of the change in the average costs for small HFOs (due to environmental regulations) to the change in marginal costs for small HFOs (due to environmental regulations) is greater (lower) than the ratio of the increase in average costs for small HFOs due to an increase in output to increase in marginal costs due to an increase in output, i.e. ($\frac{ac_E^s}{mc_E^s} > \frac{ac_{q_s}^s}{mc_{q_s}^s}$)($\frac{ac_E^s}{mc_E^s} < \frac{ac_{q_s}^s}{mc_{q_s}^s}$). The sign of the numerator in (17) is negative when $ac_E^s < mc_E^s$, $mc_E^l > ac_E^s$ and $\frac{ac_E^s}{mc_E^s} < \frac{ac_{q_s}^s}{mc_{q_s}^s}$, and its positive when

$ac_E^s > mc_E^s, mc_E^l < ac_E^s$, $\frac{ac_E^s}{mc_E^s} > \frac{ac_{q_s}^s}{mc_{q_s}^s}$ and

$n_s p' mc_{q_l}^l (mc_E^s - ac_E^s) + n_l p' mc_{q_s}^s (mc_E^l - ac_E^s) + mc_{q_l}^l (mc_{q_s}^s ac_E^s - ac_{q_s}^s mc_E^s) > n_s p' ac_{q_s}^s (mc_E^s - mc_E^l)$.

When the numerator of (17) is positive (negative) an increase in environmental stringency has the effect of reducing (increasing) the number of small HFOs.

In order to determine the effect of environmental regulations on the industry output, we differentiate the equilibrium industry output condition, $Q^* = n_s^* q_s^* + n_l q_l^*$, with respect to E, as follows:

$\frac{\partial Q}{\partial E} = n_s\left(\frac{\partial q_s}{\partial E}\right) + q_s\left(\frac{\partial n_s}{\partial E}\right) + n_l\left(\frac{\partial q_l}{\partial E}\right)$. Utilizing (15), (16) and (17), the effect of environmental regulations on industry output is given by:

$$\frac{\partial Q}{\partial E} = \frac{n_l p'^2 (n_s - q_s)(mc_E^s - ac_E^s) + mc_{q_l}^l (mc_{q_s}^s ac_E^s - ac_{q_s}^s mc_E^s)}{p' mc_{q_l}^l (mc_{q_s}^s + ac_{q_s}^s)} \quad (18)$$

The sign of the denominator is negative from (14). The first term in the numerator is positive when $n_s > q_s$ and $mc_E^s > ac_E^s$; or $n_s < q_s$ and $mc_E^s < ac_E^s$. It is negative when $n_s > q_s$ and $mc_E^s < ac_E^s$ or $n_s < q_s$ and $mc_E^s > ac_E^s$. The sign of the second term is positive if $mc_{q_s}^s ac_E^s > ac_{q_s}^s mc_E^s$ and its negative if $mc_{q_s}^s ac_E^s < ac_{q_s}^s mc_E^s$. From this inequality we can establish the following relationship; $\frac{mc_{q_s}^s}{ac_{q_s}^s} > \frac{mc_E^s}{ac_E^s}$. In other words, the second term is positive (negative) if the ratio of the rise of marginal costs of small HFOs (due to a marginal expansion of output) to the rise in average costs of small HFOs (due to a marginal expansion of output) is greater (smaller) than the ratio of the change in marginal cost of small HFOs (i.e. due to environmental regulations) to the change of average costs of small HFOs (i.e. due to environmental regulations). The overall sign of (18) is positive when: $n_s > q_s$ and $mc_E^s < ac_E^s$ or $n_s < q_s$ and $mc_E^s > ac_E^s$; and $\frac{mc_{q_s}^s}{ac_{q_s}^s} < \frac{mc_E^s}{ac_E^s}$. The sign of (18) is negative when $n_s > q_s$ and $mc_E^s > ac_E^s$; or $n_s < q_s$ and $mc_E^s < ac_E^s$; and $\frac{mc_{q_s}^s}{ac_{q_s}^s} > \frac{mc_E^s}{ac_E^s}$.

Using (9),(15), (16) and (18) ,the effect of environmental regulations on the share of hog marketing for a representative small HFO is:

$$\frac{\partial k_s}{\partial E} = \frac{(Qp' mc_{q_l}^l - n_l q_s^2 p'^2 - n_s n_l q_s p'^2)(ac_E^s - mc_E^s) - q_s mc_{q_l}^l (mc_{q_s}^s ac_E^s - ac_{q_s}^s mc_E^s)}{Q^2 p' mc_{q_l}^l (mc_{q_s}^s + ac_{q_s}^s)} \quad (19)$$

The denominator of (19) is negative from (14) and $Q^2 > 0$. To sign the first term in the numerator of (19) we analyze its components as follows: the first component of the first term is negative, $(Qp' mc_{q_l}^l - n_l q_s^2 p'^2 - n_s n_l q_s p'^2) < 0$; and the second component of the first term, $(ac_E^s - mc_E^s)$, can be positive or negative as discussed earlier. The first term in the numerator is therefore positive (negative) when $ac_E^s < mc_E^s$ ($ac_E^s > mc_E^s$). The second term is negative (positive) if the ratio of the rise of marginal costs of small HFOs (due to a marginal expansion of output) to the rise in average costs of small HFOs (due to a marginal expansion of output) is smaller (greater) than the ratio of the change in marginal cost of small HFOs (i.e. due to environmental regulations) to the change of average costs of small HFOs (i.e. due to environmental regulations).

The sign of (19) is positive when $ac_E^s > mc_E^s$ and $\frac{mc_{q_s}^s}{ac_{q_s}^s} > \frac{mc_E^s}{ac_E^s}$ implying that environmental regulations have the effect of raising the share of hog marketing for small HFOs. The sign of (19) is negative when $ac_E^s < mc_E^s$ and $\frac{mc_{q_s}^s}{ac_{q_s}^s} < \frac{mc_E^s}{ac_E^s}$, implying that environmental regulations have the effect of reducing the share of hog marketing for small HFOs.

The effect of environmental regulations on the share of hog marketing for representative large HFO is:

$$\frac{\partial k_l}{\partial E}=\frac{Qp'[(n_s p'-mc^s_{q_s})(mc^l_E-ac^s_E)+ac^s_{q_s}(mc^l_E-mc^s_E)]+(q_sQp'^2-q_ln_sn_lp'^2)(ac^s_E-mc^s_E)-q_lmc^l_{q_l}(mc^s_{q_s}ac^s_E-ac^s_{q_s}mc^s_E)}{Q^2p'mc^l_{q_l}(mc^s_{q_s}+ac^s_{q_s})}$$
(20).

The denominator in (20) is negative by (14) and $Q^2>0$. The first term in the numerator, $Qp'[(n_s p'-mc^s_{q_s})(mc^l_E-ac^s_E)+ac^s_{q_s}(mc^l_E-mc^s_E)]$, can either be positive or negative. Breaking down the first term into two components, $Qp'ac^s_{q_s}(mc^l_E-mc^s_E)>0$ is positive and $Qp'(n_s p'-mc^s_{q_s})(mc^l_E-ac^s_E)$ is positive when $mc^l_E>ac^s_E$ and negative when $mc^l_E<ac^s_E$. The first term is therefore positive when $mc^l_E>ac^s_E$ and negative when $mc^l_E<ac^s_E$, and $(n_s p'-mc^s_{q_s})(mc^l_E-ac^s_E)>ac^s_{q_s}(mc^l_E-mc^s_E)$ in absolute terms. The second term is positive when $q_sQ>q_ln_sn_l$ and $ac^s_E>mc^s_E$ or $q_sQ<q_ln_sn_l$ and $ac^s_E<mc^s_E$, and its negative when $q_sQ<q_ln_sn_l$ and $ac^s_E>mc^s_E$ or $q_sQ>q_ln_sn_l$ and $ac^s_E<mc^s_E$. The third term can also be either positive or negative, as established earlier..The sign of (20) is positive when the following conditions hold: $mc^l_E<ac^s_E$;(b) $q_sQ<q_ln_sn_l$;and $ac^s_E>mc^s_E$ or $q_sQ>q_ln_sn_l$; $ac^s_E<mc^s_E$;and $\frac{mc^s_{q_s}}{ac^s_{q_s}}<\frac{mc^s_E}{ac^s_E}$. This implies that environmental regulations have the effect of increasing the share of hog marketing for large HFOs. The sign of (20) is positive when the following conditions hold: (a) $mc^l_E>ac^s_E$,(b) $q_sQ>q_ln_sn_l$ and $ac^s_E>mc^s_E$ or $q_sQ<q_ln_sn_l$ and $ac^s_E<mc^s_E$, and (c) $\frac{mc^s_{q_s}}{ac^s_{q_s}}>\frac{mc^s_E}{ac^s_E}$. This implies that environmental regulations have the effect of reducing the share of hog marketing for large HFOs.

4. Summary and conclusions

We have shown how the output for each size of HFO, the number of HFOs , the industry output and the share of marketing for each HFO size change with environmental stringency both in the short-run and long-run. Results in the short-run are mainly driven by changes in marginal costs due to environmental regulations, while long-run results are driven by both changes in marginal and average costs due to environmental regulations. In the short-run, only environmental regulations that affect variable costs are captured, whereas, in the long-run, environmental regulations that affect fixed costs are also captured. The short-run analysis provides a benchmark case in this study.

In the short-run, the effect of environmental regulations on the output for a representative small HFO is to reduce output. This follows the empirical results in Metcalfe (2001) and Herath, Weersink, and Carpentier (2005).

While our theoretical result on the effect of environmental regulations on the output of large HFOs is inconclusive empirical evidence by Metcalfe (2001), Kuo, 2005 shows that environmental regulations have no effect the output of large HFOs. The industry hog output declines with an increase in environmental regulations. The market share of a representative small or large HFO can either increase or decrease depending on the direction of the effect of environmental regulations on the outputs of small and large HFOs; and the industry output.

Long-run results differ significantly from their short-run counterparts. Our prime focus is how environmental regulations affect the structure of hog farms in the long-run. In contrast to our short-run findings, long-run the effects of environmental regulations on the output for each HFO size, the number of HFOs, industry output and the share of hog marketing for each HFO size, are inconclusive. The type of regulation becomes important in the determination of the direction of change due to environmental regulations. Different types of regulations pose different effects on average costs and marginal costs. A regulation that affects fixed costs will in turn affect average costs while it will not have any major effect on marginal costs. On the other hand, a regulation that affects variable costs will affect both average and marginal costs, although we may not be able to tell apriori which one is affected more. Even though we could not readily sign the change in the shares of marketing for each HFO size, results do shed light on the variables that affect the shares of hog marketing in equilibrium.

In the long-run, the shares of marketing depend on the change in average and marginal costs due to environmental regulations, industry output, changes in average and marginal costs due to an increase in output and the number of hog farms. These variables provide an important input in empirical analysis. Results on changes in shares of hog marketing, the focus of the study, imply that environmental regulations will result in one of three possible scenarios: (1) a more competitive industry in which small hog operations are not adversely affected which will allow more small operations to enter rather than exit the industry; (2) a more concentrated hog industry in which large operations survive while small operations exit the industry; (3) no change in the structure of the industry where both sizes of operations are not significantly affected by environmental stringency. The empirical investigation of the effects of environmental regulations on HFOs in the long-run is the focus of our future work.

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______ Concentrated Animal feeding Operations Final Rule Making: Date Extension, July 2007.

______ Summary of the Second Circuit's Decision in the CAFO Litigation

Appendix A.

Table 1 compares the stringency of regulations of HFOs at the state-level. 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 more stringent at the state level than the associated federal standard.

Table 1: 2008 State and Federal Regulations on Hog Animal Feeding Operations

State	WMP	FDA	COPs	MRK	OAPs	Zoning	HDS	HSR	RWS	NMPs	CSP	ALSB	MAS	2008 index
IA	1	1	1	1	1	0	1	0	1	1	1	2	2	13
NC	1	1	1	1	1	1	1	0	1	1	1	2	1	14

MN	1	1	1	1	1	1	1	1	1	1	1	1	1	13
IL	1	1	1	1	1	0	1	1	1	1	1	2	2	14
NE	1	1	1	1	1	1	1	0	1	1	1	1	1	12
IN	1	1	1	1	1	0	1	0	1	1	1	1	2	13
MO	1	1	1	1	1	0	1	0	1	1	1	2	1	12
OK	1	1	1	1	1	0	1	0	1	1	1	2	2	13
OH	1	1	1	1	1	0	1	0	1	1	1	1	1	12
KS	1	1	1	1	1	1	1	0	1	1	1	2	1	13
FED	1	0	0	1	1	0	1	0	1	1	1	1	1	9

Source: State websites, 2=extensive regulation enforced, 1=regulation is enforced, 0=regulation is not enforced