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# Essays on Industrial Organization and Environmental Economics

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# ESSAYS ON INDUSTRIAL ORGANIZATION AND ENVIRONMENTAL ECONOMICS

By

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## Essays on Industrial Organization and Environmental Economics

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This dissertation studies environmental regulation issues in the hog production industry as well as forces behind the reorganization of the industry during the past two decades. Federal and State-level environmental regulations imposed on U.S. hog production during the year 2003 are examined in Chapter 1. Based on the number of regulations passed by the Federal government and states, the 2003 regulatory index is constructed. The regulatory stringency index suggests that state-level regulations vary across states and have increased over the years. In addition, state-level regulations are more stringent than federal regulations.

Chapter 2 develops an empirically implementable theoretical model which allows us to investigate the long-run effects of environmental regulations on the U.S. hog industry. Hog feeding operations (HFOs) are divided into large feeding operations (LHFOs) and small feeding operations (SHFOs). The impact of the presence of a large number of LHFOs on the entry and exit of CHFOs is also examined. Results of this study suggest that: Increased state-level regulation stringency significantly lowers the output of SHFOs; increased state-level regulation stringency significantly lowers the output of LHFOs; increased state-level regulation stringency significantly lowers the number of SHFOs; SHFO output rises significantly in states that have a greater number of LHFOs; LHFO output rises significantly in states that have a greater number of LHFOs; the number of SHFOs significantly increases in states that have a greater numbers of LHFOs;

regulation increases the average SHFO size; and regulation decreases the average LHFO size.

Chapter 3 examines the importance of input availability, market attractiveness, agglomeration economies and environmental regulations on the reorganization of U.S. hog production for a panel of 22 U.S. hog producing states which include, Northern states, Southern states and Midwest states for the period 1994-2006. Results from this study suggest that: Hog production in a state is positively affected by hog production in a nearby state, confirming the presence of agglomeration economies; Environmental regulations and high corn price have negative effects on state-level U.S. hog production; High hog prices, and favorable labor cost, and land values attract hog production; and transportation cost has no effect on hog production.

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## 1.1. Introduction

During the late 1990s, the U.S. Department of Agriculture (USDA) and the U.S. Environmental Protection Agency (EPA) came up with a plan to address pollution from hog feeding operations (Metcalfe, 2000). Federal legislation before 1998, gave states the primary responsibility in regulating hog feeding operations. Several lagoon spills in Iowa, North Carolina, the contamination of the city of Milwaukee's drinking water, and the link between dairy operations and poor water quality in Erath County in Texas, triggered more federal involvement in the regulation of pollution from animal feeding operations. The largest volume spill in Iowa occurred in 1995 when a malfunctioning lagoon at SNB Farms in Webster City spilled 1.5 million gallons of manure into the South Fork of the Iowa River. In 1996, 586 753 fish were killed in one lagoon spill in the North Buffalo Creek (NRDC)[1]. The recent structural changes in the U.S. hog industry such as the increase in large farms and decrease in small farms are believed to be a result of regulations on pollution from hog production.

The objective of the first chapter is to examine the Federal and State-level environmental regulations imposed on U.S. hog production in the year 2003. Based on the number of regulations passed by the Federal government and states, the 2003 regulatory index is constructed. A summary of the Federal regulations demonstrates that these regulations are a minimum requirement for states since states may have passed more regulations than the federal government standards since 2003.

[1] NRDC refers to Natural Resources Defense Council.

In this chapter, we examine state-level regulations for the top 10 hog producing states. These states account for about 86% of U.S. hog production. A close examination of the regulations provides evidence that regulation stringency varies across states. On analyzing the changes in state-level regulation stringency for the years 1994, 1998, 2000 and 2003, there is evidence that states that had more stringent regulations in one year changed their regulation policies the least and that states that had the least stringent regulations changed their regulation policies the most. State-level environmental regulation for the years 1994, 1998, 2000, and the current regulation shows that environmental stringency continued to increase over the years.

**1.2. Environmental Regulations on Hog Farms in the U.S.: A Summary of Federal Regulations.**

Agricultural pollution from animal feeding operations (AFOs) is a major environmental concern in the high hog production regions of the United States. According to Environmental Protection Agency (EPA), an AFO under the federal law is defined as an animal feeding operation that confines and feeds animals for a total of forty-five days or more during any twelve-month period and such an operation must be preventing vegetative forage growth from surviving the normal growing season over a portion of the confined area. Regulations on hog farms in the U.S. have taken several forms. These regulations have to do with: waste management; construction and operation of hog facilities; location of hog farms in relation to rivers, schools, family housing among others; mandatory record keeping; official inspections before and after facility operation; and field application of manure. Metcalfe (2000) groups the waste management regulations into three main groups: regulations controlling the construction of the facility and waste management system; regulation imposing administrative and managerial restrictions; and regulations controlling the location and method of field application. It is important to note that the foregoing regulations vary state by state.

Most of the environmental regulations on AFOs are related to water pollution and are passed through the Clean Water Act (CWA). The basis of the CWA was enacted in 1948, and was called the Federal Water Pollution Control Act. The Federal Water Pollution Control Act became to be known as the CWA after it went through reorganization and expansion in 1972. The 1972 amendments to the Federal Water Pollution Control Act gave birth to the National Pollutant Discharge Elimination System (NPDES) permit program. The NDPES federal regulation has become the blue print of the state regulations today. The U.S. EPA coordinates with states, the regulated community and the public in developing and implementing the NPDES permit program based on the statutory requirements contained in the CWA and the regulatory requirements contained in the NPDES regulations. The EPA acts as the overseer of the NPDES permit programs as it often requires changes over time. The NPDES regulates the discharge of manure or processed water into rivers and other water sources. Anyone who wants to discharge pollutants must first obtain an NPDES permit, failure of which renders any discharge illegal.

The CWA provides the statutory basis for the NPDES permit program and the basic structure for regulating the discharge of pollutants from point sources to waters of the United States. Potential pollutants which are part of the regulations include manure, litter, process wastewater[2] and overflows[3]. The 1972 CWA was mainly concerned about

[2] Process wastewater means spillage or overflow from AFO facilities such as watering systems, flushing pens, manure pits, washing of animals among others.

[3] Overflow is the discharge of manure or process wastewater due to the inability of a storage structure to contain the material, see Centner (2006).

surface water protection. The Effluent Limitations Guidelines (ELG) and the New Source Performance Standards (NSPS) which were adopted in 1974 and 1976 respectively, constituted a two step process designed to achieve water surface protection objectives set in 1972.

The ELG dealt with design and operating criteria through industry specific water quality protection rules. The 1972 CWA gives the EPA authority to set effluent limits on an industry-wide (technology-based) basis and on a water-quality basis that ensure protection of the receiving water. The NSPS focused on coming up with definitions for AFOs which constitute a point source. Such AFOs are known today as concentrated animal feeding operations (CAFOs). AFOs classified as CAFOs are regarded as point sources while other AFOs are not regulated under the Act's permitting system.

The EPA uses the three tier system to categorize CAFOs. Under this system hog CAFOs are defined as large, medium or small based on the number of animal units in the operation. The NPDES permit requirements for CAFOs are tailored for all confined animals and manure, litter and process wastewater generated by animals or the production of the animals. The EPA distinguishes between production areas and application areas. Production areas for CAFOs are defined by the federal regulations to include animal confinement areas, manure storage areas, raw material storage areas and wastewater containment areas.

In the late 1990s the EPA through a court order agreed to make revisions to the 1972 CWA rules. New rules defining environmental regulations for CAFOs were released in December 2002. The new rules are referred to as the 2003 CWA Revisions and they took effect between July, 2007 and February, 2009, becoming the first major revision of the 1972 CWA. Under the new rules, large hog producers are required to obtain a permit whether or not they have had any discharges in the past. The production area requirements for CAFOs under federal regulations apply to large hog CAFOs that have operations with 2500 hogs or more weighing 55 pounds or more, and 10, 000 hogs or more each weighing less than 55 pounds. In addition there must be no discharge of manure, litter or process wastewater from the production area unless certain conditions are met. If the discharge was caused by rainfall or if the CAFO complies with the inspection, monitoring, record-keeping, and mortality disposal and other provisions, such a discharge will be exempted from the federal regulation. In addition if the production area is designed, operated, and maintained to contain all of the manure, litter, and process waste water, including storm water plus run off from the 25-year, 24 hour rainfall event or a 100 year, 24 hour storm in an operation constructed after April 14, 2003, the discharge will be exempted under the federal regulations.

Under the 2003 CWA revisions, new storage structures must be designed and maintained to contain the run-off from a 100 year, 24 hour storm event which is more stringent than the 1972 CWA requirement. The CAFO regulations require an NPDES permit for any discharge of waste on lands under the control of a CAFO. Requirements under land application areas include; manure management plans, land application setbacks and buffer requirements, transfer of manure or wastewater off a farm, and maintenance of records for land application. Under the 2003 regulations, AFOs are required to develop and implement a Nutrient Management Plan (NMP) which must at a minimum include Best Management Practices (BMP). A NMP analyzes manure annually for nitrogen and phosphorous content. In addition, land application areas are also required to be analyzed every five years for phosphorus content, to check for excess nutrient build-up in relation to what crops can utilize. BMPs are measures that have been found to be the most effective, practical means of preventing or reducing pollution from nonpoint sources, (Copeland, 2008). BMPs include observing setbacks from streams, vegetated buffers, determination of application rates to reduce the transport of nitrogen and phosphorus to streams and rivers, daily and weekly inspections, maintenance of depth markers in lagoons and on-site record keeping.

Large CAFOs are required to implement land application setbacks[4] and buffers or alternative conservation practices on lands in which they apply manure. The federal regulations prohibit large CAFOs from applying manure, litter or process water closer than 100 feet to any down gradient surface waters, sinkholes, agricultural wellheads and open tile intake structures (Henry, 2003). Alternatively, instead of the 100 foot setback, CAFO owners may use a 35 foot wide vegetative buffer[5] where applications of manure, litter, or process wastewater are not allowed. For each land application site, information about setbacks and buffers must be included in the NMP and may be required in the permit application.

As of December 2006, the EPA requires that the following minimum records must be maintained:

i. Results from manure, litter, and process water and soil sampling.

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[4] Setback: a specified distance from surface waters or potential conduits to surface waters where manure, litter, and process wastewater many not be land applied.

[5] The EPA defines a vegetative buffer as a narrow, permanent strip of dense perennial vegetation established parallel to the contours of and perpendicular to the dominant slope of the field for the purposes of slowing water runoff, enhancing water infiltration, and minimizing the risk of any potential nutrients or pollutants from leaving the field and reaching surface waters.

ii. Test methods used to sample and analyze soil and manure, litter, or process wastewater.

iii. Dates manure, litter or process wastewater is applied to each field.

iv. Weather conditions at the time of application and 24 hours before and after the time of application.

v. Explanation of the basis for determining manure application rates.

vi. Calculations showing the total nitrogen and phosphorus to be applied to each field, including sources other than manure, litter, or process water.

vii. Total amount of nitrogen and phosphorus actually applied to each field, including documentation of calculations for the total amount applied.

viii. Methods used to apply the manure, litter, or process water.

ix. Dates of manure application equipment inspection.

x. Expected crop yields.

States were required to implement the 2003 rules by February 2005. However the 2003 rules were challenged in court and this delayed their implementation nationwide. While some states implemented the 2003 revisions sooner, they were not required to adopt them before February 2009. The 2003 CAFO rule was challenged by organizations from environmental and farm groups in *Waterkeeper Alliance,Inc vs Environmental Protection Agency* for containing provisions that were objectionable to environmental and farm groups. The objections were centered on: deficiencies in the NPDES permits; the absence of a review of permits by the permitting authority; and lack of public participation[6].

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[6] Details on the proceedings of the challenge are documented in "Clarifying NPDES Requirements for Concentrated Animal Feeding Operations" by Centner (2006).

The *Waterkeeper Alliance Inc* challenged the NPDES permit system for incorporating qualitative measures such as BMPs which are non numerical. Instead the *Waterkeeper Alliance Inc* argued that NPDES permits should also require NMPs in the permit applications. The new 2003 rule did not require permitting authorities to review NMPs and meant that NMPs that do not meet the statutory effluent limitations and standards could be easily overlooked. The *Waterkeeper Alliance Inc* argued that the failure for the new 2003 rule to make NMPs available to the public meant that the applicable effluent limitations were not known by the public making it tough for them to make judgments on whether they are deviating from a plan's requirement. The EPA, following the Second Circuit Court decision of 2005 in *Waterkeeper Alliance,Inc vs Environmental Protection Agency*, is required to update the 2003 CAFO rule to reflect the changes suggested by the court[7]. The revised 2003 rules were implemented starting from July 31, 2007 to February 27, 2009[8].

The following section provides a summary of state specific environmental regulations on hog farms and how they compare to the federal level regulations summarized in Section 1.2. A detailed description of state-specific regulations is provided in Appendix A.

### 1.3. Environmental Stringency Construction: State-level Regulations versus Federal-level Regulations

The summaries of Federal-level and state-level environmental regulations provided in Section 1.2 and Appendix A allow us to construct the current general environmental stringency index. The last environmental stringency index on AFOs was constructed through 2000 regulations by Herath, Weersink, and Carpentier (2005b). In addition we

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[7] For further details on *Waterkeeper Alliance,Inc vs Environmental Protection Agency* see "EPA's Summary of the Second Circuit's Decision in the CAFO Litigation."

[8] For more details regarding the postponement in the implementation of the 2003 rules see EPA Concentrated Animal feeding Operations Final Rulemaking: Date Extension, 2007.

construct a setback environmental stringency on AFOs. A detailed state by state documentation of state level environmental regulations is provided in the previous section.

The variation of state-level environmental regulation stringency on HFOs stems from the legislation imposed at the state-level, since some states choose to place more stringent restrictions on HFOs than others. Several regulations are required of all operations by the federal government (FED): 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). In addition, all of the top 10 states enforce: facility design approval (FDA); and construction and operation permits (COPs).

However, variation in regulation exists within these ten states. For example, the states of NC, MN, NE, and KS have zoning requirements, while only MN and IL regulate hydrogen sulfide (HSR). 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: 2003-2009 State and Federal Regulations on HFOs**

| State | WMP | FDA | COPs | MRK | OAPs | Zoning | HDS | HSR | RWS | NMPs | CSP | ALSB | MAS | Total |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 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

The listing of environmental regulations in Table 1 allows for state-level regulatory stringency comparisons and ranking according to regulation stringency. To create a stringency index, we sum the number of regulations imposed in the state and by the Federal government (Metcalfe, 2000). From a comparison based on the number of regulations imposed, the states of NC and IL have the most stringent legislation, while the states of IA, MN, IN, OK, and KS have the second highest stringency index value. The states of NE and MO rank third and OH are the lowest on the stringency ladder among the top 10 hog producing states. The FED has the weakest regulations as compared to the top hog producing states. Evident from the regulations above (Table 1), individual states have tighter environmental regulations than the FED.

Table 2 shows the variation of setback requirements across states and how these compare to the federal setback requirements. Setback requirements are divided into AFO location setbacks (LS), dry manure surface application setbacks (DMS), liquid manure surface application setbacks (LSMS) and liquid manure direct injection setbacks (LIMS). The federal government requires 1000 feet on LS's. The states of MN, NE, IN, and OH enforce the federal location setbacks. The location setback requirements for the remaining states are 1875 feet, 2500 feet, 3000 feet, 4000 feet, 1mile, and 3 miles for the states of IA, NC, MO, IL, KS ,and OK, respectively.

**Table 2: 2003-2009 State and Federal setback requirements for HFOs**

| State | LS | DMS | LSMS | LIMS |
|---|---|---|---|---|
| **IA** | 1875 | 800 | 800 | 800 |
| **NC** | 2500 | 300 | 300 | 300 |
| **MN** | 1000 | 300 | 300 | 300 |
| **IL** | 1mile | 300 | 1 mile | 1mile |
| **NE** | 1000 | 300 | 300 | 300 |
| **IN** | 1000 | 500 | 500 | 500 |
| **MO** | 3000 | 300 | 300 | 300 |
| **OK** | 3miles | 300 | 300 | 300 |
| **OH** | 1000 | 300 | 300 | 300 |
| **KS** | 4000 | 300 | 300 | 300 |
| **FED** | 1000 | 300 | 300 | 300 |

Source: State websites. The rest of the values except those denoted as miles are measured in feet

The federal government does not distinguish between, dry and liquid manure, and surface and direct injection manure application, on its setback requirements. The federal setback requirement for any type of manure application is 300 feet. At the state-level, only the state of IL distinguishes between dry manure setbacks, and liquid manure setbacks. None of the remaining nine states of the ten states considered here distinguish between the surface application and direct injection of liquid manure setbacks. The states of IN, IA and IL enforce manure application setbacks that are more stringent to the 300 feet requirement.

### 1.4. State-level Environmental Regulations 1994, 1998, 2000 and 2003

The environmental regulation stringency indices for the years 1994, 1998, 2000, and 2003 environmental regulations are provided in Table 3.

**Table 3: 1994, 1998, 2000 and 2003 State-level Environmental Legislation**

| State | 1994 | 1998 | 2000 | 2003 |
|---|---|---|---|---|
| IL | 2 | 8 | 9 | 14 |
| IN | 4 | 6 | 6 | 13 |
| IA | 4 | 9 | 10 | 13 |
| KS | 4 | 9 | 9 | 13 |
| MN | 8 | 9 | 9 | 13 |
| MO | 6 | 7 | 8 | 12 |
| NE | 3 | 7 | 9 | 12 |
| NC | 1 | 8 | 9 | 14 |
| OH | 5 | 7 | 9 | 12 |
| OK | 4 | 6 | 9 | 13 |

Source: Metcalfe (2000), Herath, Weersink, and Carpentier (2005b) and author's estimates

The 1994 and 1998 regulation stringency indices were constructed by Metcalfe (2000). Herath, Weersink, and Carpentier (2005b) constructed the 2000 environmental regulations. The 2000 regulations in Table 3 are a modified version of the regulations reported in Herath, Weersink, and Carpentier (2005b).

We modified their regulation stringency index to match the methodology used by Metcalfe (2000) so that we can compare the regulations in 1994, 1998, 2000, and 2003. To update the 2000 index constructed by Herath, Weersink, and Carpentier (2005b), we tracked the changes in individual regulations between 1998 and 2000 as reported in Metcalfe (2000) and Herath, Weersink, and Carpentier (2005b), respectively. Comparing the two indices, we determined if a state adopted a new regulation after 1998. If a new regulation was added as reflected in 2000, we added the regulation to the 1998 index to construct the 2000 index. In this study we construct the 2003 regulations following Metcalfe (2000). The 2003 regulations differ from their 1994, 1998, and 2000 counterparts in that they incorporate the 2003 revisions to the Clean Water Act regulations governing animal feeding operations which most states adopted as soon as they were announced. The rankings of states according to regulatory stringency for the years 1994, 1998, 2000 and 2003 are provided in Table 4.

**Table 4: State-level Regulation stringency ranking**

| 1994 Rank | 1994 states | 1998 rank | 1998 states | 2000 rank | 2000 states | 2003 rank | 2003 states |
|---|---|---|---|---|---|---|---|
| 1 | MN | 1 | KS, IA, MN | 1 | IA | 1 | IL, NC |
| 2 | MO | 4 | IL, NC | 2 | IL, KS, MN, NE, NC, OH, OK | 3 | IN, IA,KS, MN,OK |
| 3 | OH | 6 | MO, NE, OH | 9 | MO | 8 | MO, NE, OH |
| 4 | IN, IA,KS, OK | 9 | IN, OK | 10 | IN | | |
| 8 | NE | | | | | | |
| 9 | IL | | | | | | |
| 10 | NC | | | | | | |

## 1.5. Summary and Conclusions.

Examination of the regulation stringency indices for the years 1994, 1998, 2000 and 2003 demonstrates that state-level regulation stringency increased over the years. State-level regulations on hog production have become more stringent since 1994. Between the years

1994 and 1998 the greatest increase in the number of regulations was in the states of Illinois, Iowa, Kansas, and North Carolina. The states of Indiana, Minnesota, Missouri, Ohio, and Oklahoma changed their regulations the least (Metcalfe, 2000). Minnesota and Missouri were the most stringent states in 1994 but did not implement many new polices between 1994 and 1998, and became less stringent than states like Iowa, and Kansas.

Between the years 1998 and 2000, increases in the number of regulations were greatest in Oklahoma, Nebraska and Ohio. The states of Ohio and Oklahoma were among the states that changed their regulations the least between 1994 and 1998. The states of Indiana, Kansas, and Minnesota did not change their regulations between 1998 and 2000. A close examination of regulations imposed between 2000 and 2003, shows that increases in the number of regulations were the greatest in Illinois, Indiana, and North Carolina. The states that changed their regulation policies the least between 2000 and 2003 were Iowa, Nebraska and Ohio.

The states of Illinois and North Carolina which had the least stringent regulations in the year 1994, ranked second in the years 1998 and 2000 and first in the year 2003 among the top 10 hog producing states. The state with the most stringent regulations in 1994, Minnesota, ranked second for the years 2000 and 2003. The state of Missouri which was ranked second in 1994 currently has the least stringent regulations along with the states of Nebraska and Ohio.

# Chapter 2: Environmental Regulation and the Structure of U.S. Hog Farms

## 2.1: Introduction

Over the past two decades, the U.S. hog industry has been the subject of significant changes in operation size, organizational structure, and technological base. Associated with the structural changes in the industry is the rapid increase in the level of environmental regulations by the Federal government and individual states. The regulations are believed to have contributed to the changing landscape of hog production by speeding up the exit of small hog farms.

Prompting the regulations is the environmental damage associated with hog production. Hog production causes water pollution and deterioration of soil quality by contaminating water and soil with nutrients such as nitrogen and phosphate. These nutrients are bad for the soil when applied in excessive amounts or when manure leaks from waste storage lagoons. Excess nitrogen and phosphate have also been blamed for causing stunted growth in plants as well as causing accelerated eutrophication[9] of water systems (Ni et al. 2002). 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). Recently, an increase in livestock production has been found to be associated with an increase in infant mortality (Sneeringer, 2009). In a moist atmosphere

[9] 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.

hydrogen sulfite can turn into sulfuric acid which can be detrimental to concrete and metal (Ayoub et al. 2004).

To address the environmental damage, 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, many states, facing pressure from environmental groups, have adopted more stringent regulations than the federal standards. In addition to regulations required by the federal government, some states require facility design approval (FDA); construction and operation permits (COPs); zoning requirements; and hydrogen sulfide regulations. Regulations on hog production vary from state to state mainly due to 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. States may use different judgments because linking observations of particular management practices associated with confined hog feeding operations to changes in water quality is problematic. Third, the characteristics of the states that have to deal with the pollution vary. Differences within states in farming practices, land forms, climate and hydrologic characteristics may require different environmental laws (Sullivan, Vasavada and Smith 2000).[10]

How such regulations affect AFOs prompted several economists and environmentalists to examine: (1) how the increase in environmental stringency affected U.S. hog production; and (2) the determinants of exit behavior of U.S hog farms. Hog production has consistently been found to be negatively affected by environmental regulation (Metcalfe 2001; Roe, Irwin and Sharp 2002; and Herath, Weersink, and Carpentier 2005b). Metcalfe (2001) also found that environmental stringency only affected small HFOs (SHFO) and had no effect on large HFOs (LHFO). In a study addressing the determinants of exit behavior of small hog farms and whether large farms are displacing small farms in the U.S hog industry Kuo (2005) finds that technological improvement, unemployment rate, and hog price affect the exit behavior of small hog farms. The study also finds that state-level policies such as environmental regulation and incumbent large hog farms have no effect on the exit of small hog farms.

As important as the foregoing studies are in providing insights on the economic impact of environmental regulations on the structure of the industry, none offered an economic framework that links the empirical findings to an explicit theory of long-run industry equilibrium and environmental regulations. Our aim in this article is to develop such a framework.

Specifically, we develop an empirically implementable theoretical model which allows us to investigate the long-run effects of environmental regulations on the U.S. hog

[10] 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.

industry. Issues such as whether regulation favors small or large firms, increases the average firm-size, and reduces the number of firms are examined. In addition, we examine whether incumbent large farms crowd out small firms. All these issues have implications for the long-run equilibrium of the industry via entry and exit.

There are several reasons why environmental regulations may not be size-neutral. One reason is that regulation compliance may impact entry and exit conditions through raising the sunk costs associated with entry, generating cost differentials between entrants and incumbents, or slowing down the process of entry and exit (Heyes 2009). Heyes (2009) summarized the literature on the effect of regulation on competition. Studies in other industries have shown that regulation compliance is associated with changes in the scale of production and increase in average firm size (Pittman 1981; Pashigian 1984; Kohn 1988), and reduction in the number of establishments (Pashigian 1984).

Another reason is potential compliance asymmetries, i.e., differences in compliance costs per unit of output between small and large firms. Such asymmetries are possible when regulations are equally applied and enforced across small and large firms (Pashigan 1984; Bartel and Thomas 1987). Previous studies examining this question have found mixed results. In some studies, environmental regulations have been found to favor large incumbent firms at the expense of small firms (Pitman 1981; Pashigian, 1984; Bartel and Thomas 1987; Kohn 1988; Heyes 2009). Empirical findings from other studies (Ringleb and Wiggins 1990; Becker and Henderson 1997) did not support the conclusion that environmental regulations favors large firms at the expense of small firms. Ringleb and Wiggins (1990) posited that larger firms in hazardous industries might attempt to shield assets to protect themselves from liabilities associated with environmental regulations. Their findings on small firm entry from 1967-1980 suggest that an increase in the number of small corporations in hazardous sectors was a result of such divesture.

Enforcement asymmetries which result when regulations are not equally enforced on small versus large firms are also important (Pashigan 1984). As with compliance asymmetries, enforcement assymmetries favor large versus small firms. Regulation has also been found to discourage the formation of small firms (Dean, Brown, and Stango 2000).

Results of our study suggest that:

1. Increased state-level regulation stringency significantly lowers the output of SHFOs.
2. Increased state-level regulation stringency significantly lowers the output of LHFOs.
3. Increased state-level regulation stringency significantly lowers the number of SHFOs.
4. SHFO output rises significantly in states that have a greater number of LHFOs.
5. LHFO output rises significantly in states that have a greater number of LHFOs.
6. The number of SHFOs significantly increases in states that have a greater numbers of LHFOs.
7. Regulation increases the average SHFO size.
8. Regulation decreases the average LHFO size.

Results on the impact of regulation on the output of SHFOs conform to earlier findings in the hog industry (Metcalfe, 2001), and other industries (Pitman, 1981;

Pashigian, 1984; Bartel and Thomas, 1987; Kohn, 1988). The result that regulation has a negative impact on the number of SHFOs is consistent with the findings by earlier studies in other industries (Pitman, 1981; Pashigian, 1984; Bartel and Thomas, 1987; Kohn, 1988). Recall that results by Ringleb and Wiggins (1990) and Becker and Henderson (1997) do not support our findings pertaining to SHFOs. The negative effect on the output of large operations is likely due to divesture and supports the findings by Ringleb and Wiggins (1990). Our results provide evidence against any crowding-out effect, where incumbent LHFOs force SHFOs out of the U.S. hog industry. The result that regulation increases the average size of small farms is consistent with findings by Pittman (1981), Pashigian (1984) and Kohn (1988). The finding that regulation decreases the average size of large farms is consistent with Ringleb and Wiggins (1990). In a nutshell our results suggest that regulation compliance cost has led to the exit of small hog farms which helps explain the changing structure of the U.S. hog industry.

The rest of the study will be organized as follows, Section 2.2 provides the background of the U.S. hog industry, Section 2.3 provides a review of relevant past literature, Section 2.4 provides the theoretical model and conclusions based on the theoretical model, Section 2.5 provides the empirical model and analysis, and Section 2.6 provides the summary and conclusions.

## 2.2. Background of the U.S Hog Industry

According to the MINDBRANCH website, the U.S. hog and pork industry comprises establishments primarily engaged in raising hogs and pigs. The industry is made up of establishments engaged in farming activities such as breeding, farrowing, and the raising of weanling pigs, feeder pigs, or market size hogs. The hog and pig industry ends at the point when the livestock is sold or transferred off the farm. It is important to note that the production and packaging of processed meats is not part of this industry. How do pigs and hogs differ? The name pig embraces hogs, the only difference being that a hog is a domesticated pig that weighs more than 120 pounds. Hogs and pigs have cloven hooves, short legs and a snout used for digging. From now on, we will refer to the hog and pig industry as the hog industry. The U.S. hog industry consisted of about 3 million farms during the 1950s. According to a USDA report by Key and McBride(2007), the number of hog farms fell by more than 70% between 1992 and 2004 from over 240, 000 to about 70, 000. Figure 1 shows these dynamics.

**Figure 1: Number of U.S Hog operations and Hog inventory**

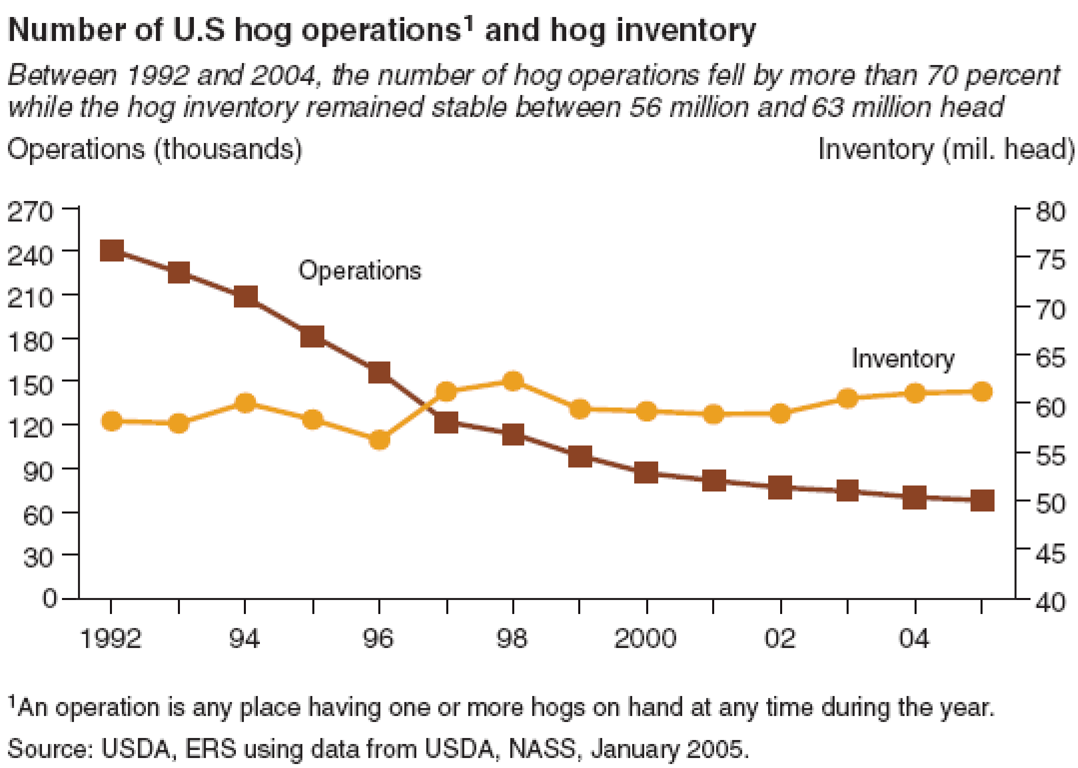


Figure 1 above shows that hog inventory remained stable despite the drastic reduction in the number of hog farms. It is important to note that while the number of hog farms experienced a huge decline between 1992 and 2004, the overall number of farms in the U.S remained stable during the same period (Key and McBride, 2007). In other words, the general farm numbers encompassing all the different farm practices in the U.S remained fairly unchanged over the years. In 2007 the U.S. hog and pig farming industry comprised of about 65,000 farms with combined annual revenue of $14 billion. This represents a reduction of about 5000 farms between 2004 and 2007. This is, however, a huge drop when compared to about 3 million operations in this industry during the 1950s. The top 10 hog producing states in 2004 are documented in Table 5 below.

**Table 5: 2004 top 10 Hog producing states**

| Rank | State | Value ($1,000) | % of Total U.S. |
|---|---|---|---|
| 1. | Iowa | 3,801,018 | 26.49% |
| 2. | North Carolina | 2,078,800 | 14.49% |
| 3. | Minnesota | 1,724,512 | 12.02% |
| 4. | Illinois | 1,027,628 | 7.16% |
| 5. | Nebraska | 761,953 | 5.31% |
| 6. | Indiana | 738,470 | 5.15% |
| 7. | Missouri | 623,260 | 4.34% |
| 8. | Oklahoma | 615,411 | 4.29% |
| 9. | Ohio | 402,719 | 2.81% |
| 10. | Kansas | 379,048 | 2.64% |

Source: http://www.cattlenetwork.com

Table 5 above shows the top 10 hog producing states in the U.S. in the year 2004. The ranking above is based on the value of the production. It is interesting though to note that the states in the 2004 ranking are exactly the same states in the 2007 ranking as shown in Table 6. However some states swapped positions between 2004 and 2007 such as Nebraska, Indiana, Ohio and Kansas. In 2004 the top three hog producing states, Iowa, North Carolina and Minnesota accounted for about 53% of the total value of hog production in the U.S. In 2007 the U.S. produced 65, 909, 000 hogs. The top three hog producing states accounted for about 55% of the U.S. total hog inventories in 2007. Table 6 below summarizes the U.S. hog industry based on the top 10 producing states, inventories and their percentage contribution to hog industry.

**Table 6: 2007 top 10 hog producing states**

| Rank | State | Total state inventory | % of Total U.S. |
|---|---|---|---|
| 1 | Iowa | 18,700,000 | 28.37% |
| 2 | North Carolina | 10,000,000 | 15.17% |
| 3 | Minnesota | 7,300,000 | 11.08% |
| 4 | Illinois | 4,300,000 | 6.52% |
| 5 | Indiana | 3,500,000 | 5.31% |
| 6 | Nebraska | 3,200,000 | 4.86% |
| 7 | Missouri | 3,050,000 | 4.63% |
| 8 | Oklahoma | 2,330,000 | 3.54% |
| 9 | Kansas | 1,860,000 | 2.82% |
| 10 | Ohio | 1,830,000 | 2.78% |

Source: http://www.cattlenetwork.com

The changes in the number of operations from 3 million in the 1950s to about 65000 operations in 2007 may reflect a lot of structural changes in this industry over the years. The changes in animal production saw an expansion in concentrated animal feeding operations (CAFOs), a rise in the issues associated with large numbers of animals in confined areas, Centner (2006). The changing structure of the U.S. hog production industry towards more concentrated large hog farms has created concerns over the danger such big animal feeding operations (AFOs) are likely to pose to the waters of the country. The issues associated with large confined animal feeding operations include; water contamination, air pollution, health effects, concern about antibiotics, animal welfare and loss of resources.[11] The foregoing concerns are related to the production of animals and could be solved if environmentally friendly production and management practices are

[11] For a detailed discussion of these environmental issues see Centner (2006).

voluntarily exercised by the owners of the operations. However, Centner (2006), noted that this measure has failed to achieve the desired water quality and this has led to the need for governmental regulatory controls in order to address pollutant problems.

### 2.3: Literature Review

This section will review the relevant literature to the current study.

#### 2.3.1. Relevant literature on regulation and market structure

**Pittman (1981)** in a study based on a study of 30 integrated paper mills in Wisconsin and Michigan concluded that abatement requirements increase the minimum efficient size of plants which in turn increase the barriers to entry.

**Kartz and Rosen (1983)** analyzed the effects of taxation as a cost shifter using the conjectural variations model of oligopoly. The study demonstrates the way in which the incidence of a tax depends upon the pattern of firm interaction. The authors found an interesting result that a shift in the cost function (increase in cost) can lead to higher profits. They conclude that the notion that oligopolists act as they were competitive or monopolists is likely to provide misleading results, since it is possible for oligopolists that a tax can lead to higher profits, while this result never arise in competitive or monopolistic markets. Their result supports the heavily criticized econometric result by Krzyzaniak and Musgrave (1963), which concluded that a tax can lead to higher profits under oligopoly.

**Pashigan (1984)** examined the effects of environmental regulation on changes in the number of plants in pollution-intensive industries and concluded that regulation reduced the number of firms per industry and raised the average plant size. This study also finds that regulation placed a greater burden on small plants than on large plants.

**Bartel and Thomas (1987)** documented the competitive advantages which arise from the asymmetrical distributions of OSHA and EPA regulatory impact among different types of firms. They concluded that regulation favors large firms over small firms because large firms may acquire a form of relative competitive advantage over small firms. Their study also finds that in some cases comparative advantage obtained from differential regulatory costs outweighed the costs of compliance.

**Kohn (1988)** examined the impact of pollution abatement costs on market structure based on a general equilibrium model. The study identified two effects which push towards larger firms and higher concentration. Firstly, the input effect which is based on the idea that compliance costs contribute to fixed costs and shift the U-shaped average cost curve to the right. This increases the scale at which average cost is minimized. Secondly, the output effect which occur when the percentage reduction in emissions due to abatement increases or decreases the level of output of the polluting firm.

**Litchenberg, Parker and Zilberman (1988)** developed a method for estimating marginal costs of environmental regulations affecting agriculture, in the short-run, when the direct costs of environmental and resource policies vary among regions. Their results indicate that, redistribution of income among producers becomes the dominant effect of pesticide policies when supply elasticities are higher and demand elasticities are lower, with changes in supply elasticity having a greater impact than changes in demand elasticity. Results also show that for crops with significant export markets, foreign consumers may bear much of the cost of restrictive policies in the short run. The authors do infer long run results, that higher production costs will provide an incentive for entry by foreign producers undermining U.S. competitiveness, without explicitly incorporating them in the analysis

**Bartik (1988)** examined the effect of state environmental regulations on the location of manufacturing plants. The study separates the effect of state air pollution regulations from that of state water pollution regulations. The author used state spending on water pollution control, state spending on air pollution control, average air and water compliance costs in state, and particulate regulations. Results found no statistically significant effects of environmental regulation on business location.

**Bartik (1989)** examined how the characteristics of American states affect small business start-ups. Among these characteristics was environmental stringency which was proxied by the number assigned to strictness of state environmental regulations, as of 1983, by the Conservation Foundation. Results show that environmental regulations were found to have a positive and significant effect on small businesses starts.

**Ringleb and Wiggins (1990)** analyzed the application of liability to large-scale, long- term hazards. They argued that larger firms in hazardous industries might attempt to shield assets to protect themselves from liabilities associated with environmental regulations. They also hypothesized that incumbents would divest themselves of hazardous activities. Their results on small firm entry from 1967-1980 suggest that an increase in the number of small corporations in hazardous sectors was a result of such divesture.

**Shy (1995)** defines market structure as a description of the firm's behavior in a given industry or market. Four notable items defining a firm's behavior are said to include: (1) the actions available to each firm such as price setting, quantity setting, and setting production capacity; (2) the number of firms in the industry and whether free entry and exit is possible or not; (3) firms' expectations about the actions available to competing firms, and the response of the firms in the industry to each firm's action; and (4) firms' expectation about the number of firms and potential entry.

**Sunding (1996)** developed a method of measuring the marginal welfare cost of environmental regulations affecting agriculture. The author extends the work by Litchenberg, Parker and Zilberman(1988) by explicitly considering temporal as well as spatial diversity when measuring marginal welfare costs of nonuniform environmental regulations (i.e. pesticide application reduction requirement) affecting agriculture. The work facilitates the design of season and region specific environmental regulations. The ability of the method developed by the author can be used to measure the marginal costs of regulating agricultural production at a disaggregated level and can thus be paired with earth science data to gain a better picture of marginal costs and benefits of localized environmental regulation.

**Hamilton and Sunding (1997)** examined 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 main results indicate that increasing concentration in the food processing sector leads to a decrease in market power and when there is an outward shift in the farm supply curve, concentration can only increase when there is a decrease in market power.

**Becker and Henderson (1997)** examined the unintended effects of air quality regulation on decisions of major polluters, using plant data for the years 1963 to 1992. They found an increase in the number of small firms in the four high polluting industries they examined which included industrial organic chemicals, plastic products, metal containers and wood furniture.

**Dean, Brown, and Stango (2000)** estimated the effects of environmental regulations on the formation of small manufacturing establishments across 170 manufacturing industries for the years 1967 to 1980. Their results suggested that greater environmental regulations intensity is associated with fewer small business formations. Results also found that regulation had no effect on the formation of large establishments. They concluded that environmental regulations put small entrants at a unit cost disadvantage.

**Lahiri and Ono (2007)** analyzed the effects of an increase in emission tax on a symmetric oligopoly. Their study allows for firms to reduce emissions using abatement technologies. Their results suggested that aggregate output decreases with an increase in emission tax while the emissions tax has an ambiguous effect on output per firm. Output per firm was found to increase (decrease) provided the inverse demand function is concave (convex).

**Heyes (2009)** surveyed theoretical and empirical research on the effects of regulation on the vigor of competition in product markets. The study concludes that environmental regulations can advantage large firms over small firms, discourage entry directly, provide instruments with which incumbents can discourage entry strategically, and provide the basis of predatory behavior by incumbents.

**Millimet, Roy and Sengupta (2009)** surveyed the literature on the economic effects of environmental regulation on several aspects of market structure including entry, exit, and size distribution of firms and market concentration. They found that existing literature focuses on the private costs of environmental regulation incurred by firms and the benefits of environmental quality enjoyed by society, and missing in the literature is the potential for firms to benefit from environmental regulation through an increase in product demand by “green” consumers.

**2.3.2. Environmental regulations and stringency literature in the hog industry.**

**Hubbell and Welsh (1998)** investigated geographic concentration in the hog industry, using a measure based on Theil’s entropy index for the top 20 hog producing states for the period 1974-1996. Results showed that hog production is becoming more geographically concentrated at the national level and within states. The study also found that changes in the hog industry have led to a non-uniform interregional distribution of hogs.

**Fleming, Babcock, and Wang (1998)** investigated the cost of delivering manure nutrients from Iowa swine production for 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). The study addressed three major questions concerning swine manure management: (1) Should manure nutrients be conserved and applied to crops? (2) What is the impact of a policy requiring all manure applications to be incorporated? (3) What is the impact of a policy requiring manure applications to be based on phosphate? The results of the study suggest that (1) manure nutrient returns are maximized where high nutrient using crops are grown close to a medium sized swine facility that uses nutrient conserving methods to store manure (2) incorporating manure increases production returns while improving air quality and (3) basing manure applications on phosphate levels rather than nitrogen increases the value of manure nutrients as applied nutrients tend to match crop requirements, the profit maximizing number of hogs and profits are greater under a phosphate standard than under a nitrogen standard. While the costs under a phosphate standard are higher, the net value of manure for low hog numbers (a characteristic of Iowa) is enhanced by a adoption of 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. The study also provides a discussion of the state legislation used to regulate animal manure management and how the regulation varies across states. 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. The cost of this environmental input incurred by hog operations through utilization of state water was the main concern of the study. The amount of state spending on water quality[12] and a qualitative stringency measure constructed through examination of state manure management regulations imposed on AFOs for the years 1994 and 1998. The following stringency rating, 1(low), 2(average), and 3(high), was used for each state. Results show that there are significant environmental compliance costs for small hog feeding operations. Large operations did not appear to be influenced by the level of state environmental stringency.

**Roe, Irwin and Sharpe (2002)** addressed the factors behind the reorganization of the hog production in a cross-section of counties for the years 1992 and 1997. They concluded that the presence of other swine has a positive effect on the inventory of hogs in a particular county for the year, 1997, and hog production in one county was negatively correlated with hog production in a nearby county between 1992 and 1997. Regulation had a negative effect on the location of hog farms.

**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. The author’s recommendation to regulators is to revise existing regulations by moving them toward more meaningful provisions that

[12] Spending on water quality is defined as the amount of state monies used for managing water quality programs and for enforcement of water quality regulations.

give greater deference to efficiency criteria and to increase resources into enforcement efforts. The work warns regulators that increasing the number of regulations may serve only to amplify benefits from noncompliance.

**Agapoff and Cattaneo (2003)** addressed the effectiveness of 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. The authors found the willingness of crop operators to accept manure on their farms as a nutrient source to be a very important factor affecting the cost of large farms meeting a nutrient standard. The higher the willingness to accept manure (WTAM), the higher the number of large farms that will be able to meet the N-standard without increasing production costs, while the number of EQIP will also drop significantly. A high WTAM was found to have very little effect on small farms and to decrease EQIP funding thus making available funds for other conservation issues and making funds available for a large number of producers.

**Herath, Weersink, and Carpentier (2005a)** 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. The authors examined the association of such patterns with the changes in slaughtering/processing capacity, population density, and stringency in environmental regulations. Entropy measures were used to compare concentration nationally as well as within and across the eight major production regions. 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 (2005b)** 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. The study uses a state specific time series measure of stringency. A Gini coefficient ranging from 0 (equal distribution of livestock inventories among the states) to 1 (concentration of livestock inventories in one state) was used to measure the degree of geographical concentration. The Gini coefficient for hogs increased from 0.72 in 1975 to 0.77 in 2000 indicating increasing geographical concentration in this industry. Their findings also 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)** addressed the determinants of the exit behavior of small hog farms and whether large farms are displacing small farms in the U.S hog industry. The study finds that technological improvement, unemployment rate, and hog price affect the exit behavior of small hog farms. The study also finds that state-level policies such as environmental regulation and incumbent large hog farms have no effect on the exit of small hog farms.

**Weersink and Raymond (2006)** investigated the regional characteristics where 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. Findings also suggest a positive relationship between spills in a region and the number of complaints with an implication that complaints can be used by regulators as a tool to identify problem areas.

### 2.3.3. Environmental regulations and stringency literature in other livestock industries.

**Huang, Magleby and Christensen (2005)** examined the economic impacts of the EPA's manure application regulations on medium and large dairy farms in the U.S. southwestern region. The authors found that new EPA restrictions on land application of manure by CAFOs could harm the net returns of medium and large dairy farms with lagoon systems in the southwestern region of the country, and that higher net incomes by other types of dairy farms can only be achieved under these restrictions if they are able to reduce feed costs by better utilizing manure and expanding homegrown feed production.

**Schuk and Birchall (2001)** developed a manure BMP adoption model to examine whether or not state level manure management regulations influence manure BMP adoption rates among beef CAFOs in South Dakota. The CAFO size was measured by herd size and acreage and regional nutrient demand was measured by regional crop production. The study found relatively small influences of regional crop coverage and state level regulations on the manure handling practices by CAFOs, while herd size is found to play a larger role in promoting the adoption of manure storage BMPs.

**Osei and Lakshminarayan (1996),** investigated the factors previously thought to affect the location of dairy farms as well as the environmental policy effects on dairy farm location. Results indicated environmental determinants tend to deter the location of dairy farms. Investigation of the influence of environmental stringency was a key factor in this analysis. Environmental stringency is based on four state level indicators namely air quality, ground water quality, soil conservation and an aggregate environmental policy stringency index. The measures were obtained from data provided by the Fund for Renewable Energy and the Environment (FREE). The data rates states according to their commitment to environmental protection.

**Murat (2004)** generated an environmental index for each state using the 1998 National Survey of Animal Confinement Policies. The survey gathered information on 48 states in the U.S. on their policies and implementation of environmental regulations of the livestock industry. The environmental stringency proxy is generated as an unweighted sum of the affirmative responses to twenty-nine regulatory stringency survey questions. The index the author used varies from 1(lowest environmental stringency) to 21(highest environmental stringency).

**Lester and Lombard (1990)** provided both a review and a critique of environmental policy literature that existed prior to the 1990s. They developed an intergovernmental framework which they suggest to be a better way for studying state environmental policy implementation during the 1990s.

While the foregoing studies are important in providing insights on the economic impact of environmental regulations on the hog industry, none addressed the effect of regulation on the long-run equilibrium of the industry. The long-run impact of environmental regulations on the entry and exit 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.[13] In this study, we answer the following question: What is the effect of environmental regulations on the long-run equilibrium of the U.S hog industry allowing for the entry and exit of hog farms?

Specifically, this study seeks to investigate the implications of state-level environmental regulations on the entry and exit of small hog farms in the U.S hog industry. 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 the long-run.

**2.4: Theoretical framework**

We present a general profit maximization model for a perfectly competitive industry with heterogeneous firms which will be used to analyze the impact of environmental regulations on HFOs in the long-run. Prior studies assumed that the hog industry is perfectly competitive industry (Metcalfe, 2001; Roe, Irwin and Sharp, 2002; Kuo, 2005). The model is an adaptation of the framework developed by Hamilton (1999), which addressed demand shifts in an oligopolistic industry.

**2.4.1. Model of an Industry with Heterogeneous Firm Size**

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 SHFOs and LHFOs , respectively. We further assume that hog farms in each HFO size category are

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[13] 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.

identical, that is they have the same cost structure and are all of the same size. Costs of production for a single HFO of size $k$, for $k = s, l$, are given by $c^k = c^k(q^k, E)$, where $q^k$ is the level of hog output for a HFO of size $k$, and, $E$ represents environmental regulations imposed on HFOs. We introduce $E$ as a cost shifter in the same manner as in Katz and Rosen (1983), Litchenberg, Parker and Zilberman (1988), and Sunding (1996). We model the effect of regulation on the firm and industry, assuming the industry is in the long-run equilibrium to begin with.

The properties of the cost functions are:

i. $c_E^k = \dfrac{\partial c^k(q^k, E)}{\partial E} > 0$, the cost function is a non-decreasing function of the levels of environmental regulations.

ii. $mc^k = c_{q^k}^k = \dfrac{\partial c^k(q^k, E)}{\partial q^k} > 0$, cost is increasing in output.

iii. $mc_{q^i}^k = c_{q^k q^k}^k = \dfrac{\partial^2 c^k(q^k, E)}{\partial (q^k)^2} \geq 0$, the marginal expansion of output raises the marginal cost of each HFO of size $k$.

iv. $mc_E^k = c_{q^k E}^k = \dfrac{\partial^2 c^k(q^k, E)}{\partial q^k \partial E} \geq 0$, the marginal cost of a HFO of size $k$ is a non-decreasing function of the levels of environmental regulations.

We assume that a representative LHFO is (weakly) more efficient than a representative SHFO (Rhodes 1995; Kuo 2005) due to economies of scale, and that the following condition holds:

(1) $$\frac{\partial c^s(q^s, E)}{\partial q^s}\Big|_{q^s = q^l} \geq \frac{\partial c^l(q^l, E)}{\partial q^l}\Big|_{q^s = q^l}$$

Condition (1) states that, when evaluated at the same output level, the marginal cost of a SHFO is at least as much as the marginal cost of a LHFO. Specifically, the marginal cost for a SHFO equals that of a LHFO only at the point where profits are maximized and the marginal cost for a representative SHFO is greater than that of a representative LHFO everywhere else. The efficiency assumption implies that the marginal cost function for a representative LHFO is more elastic than that of a representative SHFO. Empirically this condition was found to be 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 for large farms.

In order to maintain the identity of low cost LHFOs and high cost SHFOs for a marginal expansion in output we impose the following condition:

$$(2) \qquad \frac{\partial^2 c^s(q^s, E)}{\partial (q^s)^2}\bigg|_{q^s=q^l} \geq \frac{\partial^2 c^l(q^l, E)}{\partial (q^l)^2}\bigg|_{q^s=q^l}.$$ [14]

Condition (2) states that the marginal expansion of output does not increase the marginal cost function of LHFOs by more than that of SHFOs. 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

[14] This condition eliminates the ambiguity in the definition of low cost firms by ruling out situations in which high and low cost firms switch identity in response to small changes in output, Hamilton (1999).

and $p$ is the hog price. The demand curve is downward sloping, $\frac{\partial p}{\partial Q} < 0$. The representative HFO of size $k$ 's objective is:

$$(3) \qquad \max_{q^k} \pi^k = pq^k - c^k(q^k, E)$$

Differentiating equation (3) with respect to $q^k$ and setting equal to zero yields the first-order conditions for a SHFO and a LHFO,

$$(4) \qquad p = c^s_{q^s}(q^s, E), \text{ and}$$

$$(5) \qquad p = c^l_{q^l}(q^l, E), \text{ respectively.}$$

The sufficient second order condition of an HFO of size $k$ is,

$$(6) \qquad -c^k_{q^k q^k} < 0.$$

In the long-run, short-run profits or losses will induce HFOs to enter or exit the industry until profits are driven to zero. In this study, we treat the number of LHFOs as constant, so that only the number of SHFOs is determined in equilibrium. There is evidence that LHFOs have not been exiting the hog industry and that it takes a long time for a new large HFO to enter or exit the industry (Gillespie and Fulton 2001; McBride and Key 2003).[15] In contrast, there is evidence that SHFOs have been frequently entering and exiting the hog industry (McBride and Key, 2003).[16] Deriving the long-run equilibrium by allowing both SHFOs and LHFOs to enter and exit the industry in the long-run is not technically feasible as the coefficient matrix would be singular and not invertible. Among the reasons why the coefficient matrix is not invertible is that the two

[15] It takes a long-time to come up with a highly mechanized farm; (2) when such a large mechanized farm enters the industry, evidence from industry does support the fact that such farms rarely exit the industry.
[16] Entry by small scale firms has been argued to be more common than the entry of large firms in most industries, Geroski (1995).

HFO sizes both face the same price in equilibrium and it is not possible to solve for a single price that satisfies the two different long-run equilibria, one for LHFOs and the other for SHFOs. That is, we cannot have a single price satisfying two different minimum points of two average cost curves relating to the two different HFO sizes. For these reasons, in our model we assume that only SHFOs enter and exit the industry.

SHFOs enter until profit is driven to zero and the long-run equilibrium for the number of SHFOs, $n^{s^*}$ is determined by:

$$\pi^{s^*} = pq^{s^*} - c^s(q^{s^*}, E) = 0 \text{ or } pq^{s^*} = c^s(q^{s^*}, E), \tag{7}$$

where $q^{s^*}$ is the optimal output for small HFOs.

The equilibrium number of SHFOs is determined simultaneously by the optimal output for each HFO in Equations (4) and (5), and the entry condition in Equation (7).

### 2.4.2. Measuring the Effects of Increased Environmental Regulation

The comparative statics effects of an environmental regulation cost shift are calculated by totally differentiating the first-order conditions in (4) and (5), and the entry condition (7). The resulting equations are combined and presented in matrix form as

$$\begin{bmatrix} \theta^s & n^l p' & q^s p' \\ n^s p' & \theta^l & q^s p' \\ n^s q^s p' & n^l q^s p' & q^{s^2} p' \end{bmatrix} \begin{bmatrix} dq^s \\ dq^l \\ dn^s \end{bmatrix} = \begin{bmatrix} mc_E^s \\ mc_E^l \\ c_E^s \end{bmatrix} dE, \tag{8}$$

where $\theta^s = n^s p' - mc^s_{q^s}$, $\theta^l = n^l p' - mc^l_{q^l}$, and the other elements are as defined earlier.

Calculating the determinant of the coefficient matrix, $\Omega$, and using the definitions of $\theta^s$ and $\theta^l$, we have:

$$\det(\Omega) = p' q^{s^2} mc^l_{q^l} mc^s_{q^s} < 0, \tag{9}$$

which is negative since $p'<0$, $q^s>0$, $mc^l_{q^l}>0$ ,and $mc^s_{q^s}>0$.

The effects of environmental regulations on the hog output of a representative SHFO, output of a representative LHFO, and the number of SHFOs are:

(10) $$\frac{\partial q^s}{\partial E}=\frac{c^s_E-q^s mc^s_E}{q^s mc^s_{q^s}},$$

(11) $$\frac{\partial q^l}{\partial E}=\frac{c^s_E-q^s mc^l_E}{q^s mc^l_{q^l}},$$

(12) $$\frac{\partial n^s}{\partial E}=\frac{n^l p' mc^s_{q^s}(q^s mc^l_E-c^s_E)+n^s p' mc^l_{q^l}(q^s mc^s_E-c^s_E)+mc^l_{q^l}mc^s_{q^s}c^s_E}{p' q^{s^2} mc^l_{q^l}mc^s_{q^s}},$$

The signs of the denominators in Equations (10) and (11) are positive while the denominator in (12) is negative by (9). The signs of (10) - (12) are all ambiguous. The result in (10) is positive and negative when $c^s_E>q^s mc^s_E$ and $q^s mc^s_E>c^s_E$, respectively. The result in (11) is positive and negative when $c^s_E>q^s mc^l_E$ and $q^s mc^l_E>c^s_E$, respectively. The sign of (12) is negative when $q^s mc^l_E>c^s_E$, $q^s mc^s_E>c^s_E$ and the absolute value of the first two expressions in the numerator, $n^s p' mc^s_{q^s}(q^s mc^l_E-c^s_E)+n^s p' mc^l_{q^l}(q^s mc^s_E-c^s_E)$ is greater than the value of the last term in the numerator, $mc^l_{q^l}mc^s_{q^s}c^s_E$. The result in (12) is positive when $c^s_E>q^s mc^l_E$, and $c^s_E>q^s mc^s_E$.[17]

[17] Notice that the conditions under which (12) is positive and negative documented here are not exhaustive, that is we can have situations where $c^s_E>q^s mc^l_E$, and $q^s mc^s_E>c^s_E$; and $q^s mc^l_E>c^s_E$, and $c^s_E>q^s mc^s_E$ which will change the signing suggested here. However, this does not change the intuition behind the ambiguity of (12).

### 2.4.1. Discussion of Results from the Economic Model

Central to the ambiguous effects of regulation in (10)-(12) include the cost of regulation, its size bias, its input biases, and whether the underlying pre-and post-regulation technology is homothetic or non-homothetic. The effects of a regulation induced cost shift are the opposite of a technological change induced cost shift on the long-run equilibrium of a perfectly competitive industry, a question addressed in Perrin (1997).[18] For simplicity, we define the cost of regulation as the upward shift in marginal or average cost due to regulation. The regulation input bias affects the magnitude of the cost of regulation. Regulation input bias will result when there are shifts in the optimal input shares used in hog production due to regulation.

Because the cost of regulation could be a result of a shift in average cost or both marginal-and average cost, we cannot rule out the possibility of the farm-size (size) bias of regulation. Farm-size bias results when the shift in the marginal cost curve is different from the shift in the average cost curve at the original output-level. This is analogous to the firm-size bias in technology induced cost shifts. In the context of our study, a positive (negative) farm-size bias results when the shift in the average cost curve is greater (lower) than the shift in the marginal cost curve. A positive (negative) size bias implies that regulation will increase (decrease) the size of a representative HFO. Positive farm-size bias results if the regulation causes a representative HFO to acquire additional capital to conform to regulation, leading to an increase in its scale of production. On the other hand, a negative farm-size bias results if a representative HFO phases out some hog production practices by getting rid of equipment, reducing its scale of production. The

[18] Perrin (1997) approximated the nature of technological change in terms of the rate of technological change, the size of technological change, and the input bias of technological change.

absence of farm-size bias results when the marginal-and average cost curves shift by the same magnitude.

The signs of (10)-(12) primarily depend on how the change in the marginal costs of output for LHFOs and SHFOs ( $mc^k_{q^k}$ ) compare to the SHFO marginal cost of regulation ( $c^s_E$ ). The changes in SHFO and LHFO marginal costs are scaled by the SHFO output (i.e. $q^s mc^k_E$ ).[19] Equation (10) measures the change in output from an individual small farm after a change in environmental regulation stringency. The difference between the SHFO cost of regulation and the change in output-scaled SHFO marginal cost in (10) amounts to a difference between the shifts in the marginal-and average cost curves due to regulation. Because the cost of regulation reflects shifts in both marginal and average cost curves, the difference between the marginal cost curve shift reflected in the cost of regulation and the output-scaled shift in marginal cost, gives the net or overall shift in SHFO marginal cost. The sign of (10) is positive (negative) with positive (negative) regulation farm-size bias.

Equation (11) measures the change in output by a single large firm after a change in the stringency of environmental regulations. The sign of (11) depends on how the shift in the output scaled LHFO marginal cost curve due to regulation compares to the SHFO cost of regulation. When the SHFO cost of regulation is greater (lower) than the output scaled change in LHFO marginal cost due to regulation, the result in (11) is positive (negative). Intuitively, since in equilibrium the marginal costs of SHFOs and LHFOs are the same, the direction of change is depends on whether there is positive or negative size

[19] We refer to $q^k mc^k_E$ as the output scaled change in marginal cost due to regulation.

bias do play an important role. In addition to size bias, input bias of regulation also plays an important role.

Equation (12) determines the effect of environmental regulation on the number of small firms in the industry. The result in (12) incorporates the conditions required in the signing of both (10) and (11).[20] When positive (negative) profits arise in the adjustment process from the initial equilibrium to the final equilibrium, profits attract (deter) the entry of new HFOs, which has implications on both the equilibrium number of HFOs and the equilibrium output.

The nature of the HFO's cost function (technology) is important in determining the signs of (10)-(12). Our study does not separate the contributions of the nature of regulation from the nature of technology in (10)-(12). The manner in which the total cost function is affected by regulation depends on whether the underlying technology associated with the cost function before and after the regulation induced shift is homothetic or non-homothetic. With homothetic technology, the pre-regulation cost function for a representative HFO of size $k$ takes the form, $C^{k^0}(q^k, E) = \xi^0(q^k)c^{k^0}(1, E)$, where $\xi^0(q^k)$ is some increasing function of output (Fare and Mitchell, 1992). If the post-regulation technology is also homothetic the cost function for a representative HFO of size $k$ is given by $C^{k^1}(q^k, E) = \xi^1(q^k)c^{k^1}(1, E)$. If the pre- and post-regulation homotheticity components are equal, $\xi^0(q^k) = \xi^1(q^k)$, regulation shifts the total cost curve without changing its slope at every output level. This effect is independent of whether the pre-and post-regulation unit costs $c^{k^0}(1, E)$ and $c^{k^1}(1, E)$ are equal or not. In this case, the marginal cost curve does not shift but the average increases

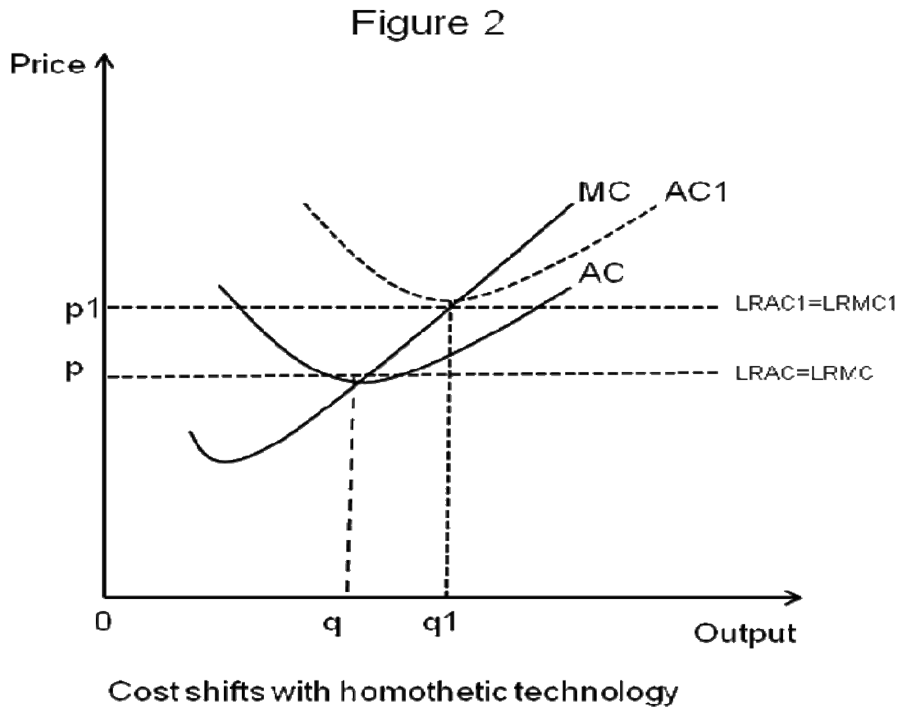
[20] Signing (12) combines the conditions required in signing (10) and (11).

at every point. This is illustrated in Figure 2 where we observe a shift only in the average cost curve and a movement along the original marginal cost curve due to environmental regulation. Since, in Figure 2, we have positive shift in the average cost curve and no shift in the marginal cost curve, the cost of regulation is explained by the shift in average cost and we observe a positive farm-size bias.

The result in Figure 2 assumes a constant-returns-to-scale (CRS) production function. Binger and Hoffman (1998), show that a perfectly competitive long-run equilibrium is only possible for a CRS production function or a U-shaped long-run average cost production function. Assuming a CRS or a U-shaped long-run average cost production function is sufficient for the existence of the long-run competitive equilibrium.[21] With a CRS production function, in Figure 2, regulation causes the average cost curve to shift from AC to AC1. The marginal cost curve does not shift since the slope of the total cost curve did not change at every point. The resulting effect is to increase both the long-run equilibrium output for an individual HFO and the long-run equilibrium price faced by the individual HFO from q to q1 and p to p1, respectively. The cost of regulation is approximated as the vertical distance between the minimum point of the pre-regulation average cost curve, AC, and the minimum point of the new average cost curve, AC1. The regulation input bias is intertwined in the cost of regulation as alluded to earlier. Since the average cost curve has shifted by more than the marginal cost curve, we observe a positive size bias in this case.

[21] Binger and Hoffman (1998), p.324-328, provide the justification on why a perfectly competitive long-run equilibrium exists with CRS production function and a U-shaped long-run average cost production functions. They also show why the long-run competitive equilibrium is non-existent with increasing-and decreasing returns to scale production functions.

**Figure 2: Regulation shifts the cost function without changing its slope**




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 increases or no farm-size bias. As explained earlier, when 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. Figure 3 illustrates the case where the regulation induced shift in the average cost curve is equal to the shift in the marginal cost curve.

**Figure 2: Marginal cost shift equals average cost shift**

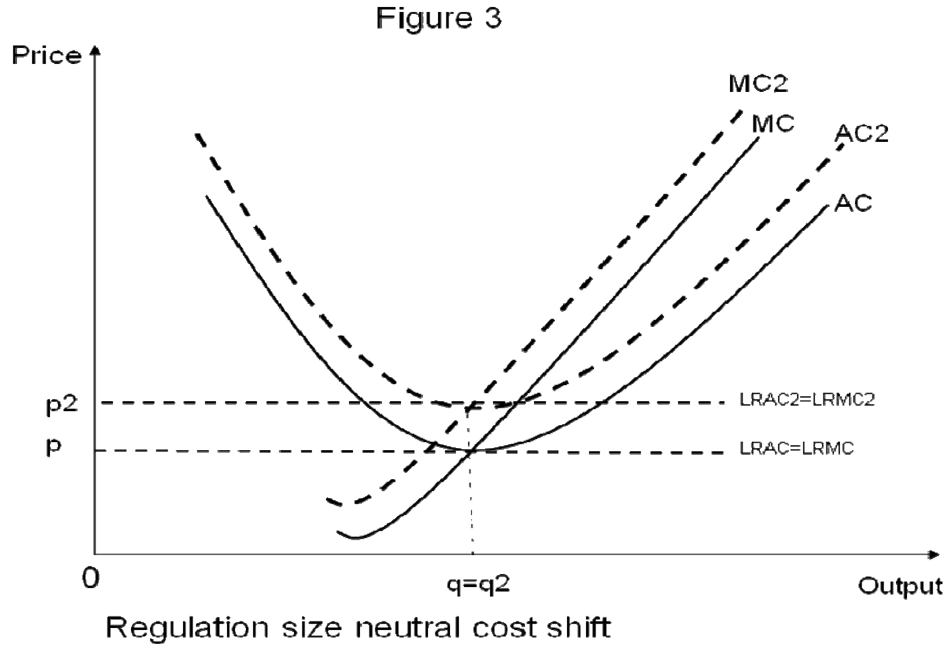
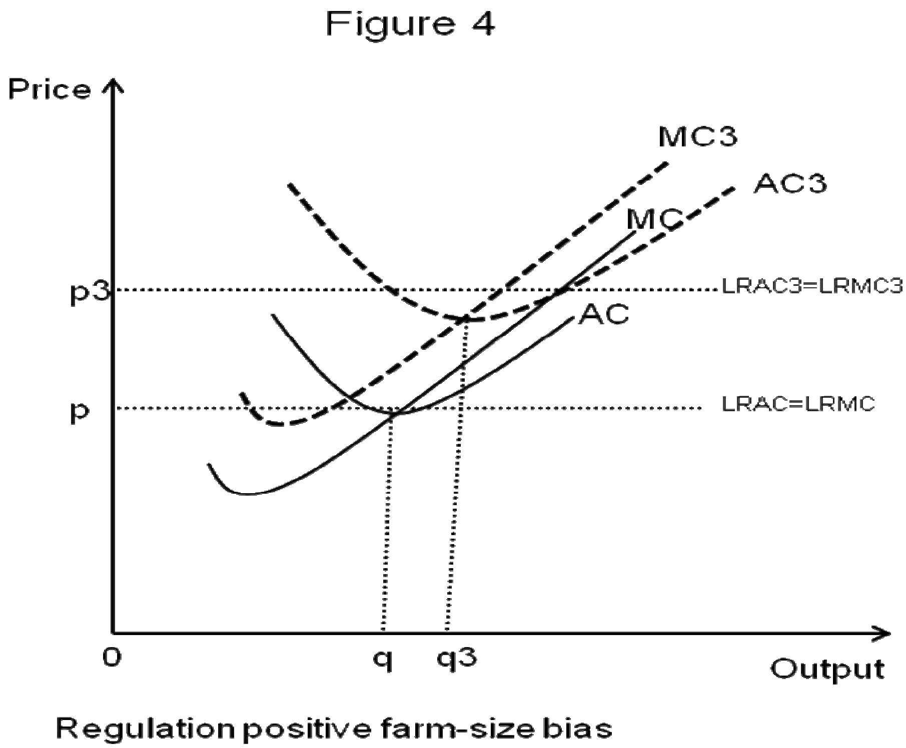



Figure 4 illustrates the case where the regulation induced shift in the average cost curve is greater than the shift in the marginal cost curve. Recall that the effect of regulation on an HFO is the direct opposite of the effect of neutral technological change on the firm. The most commonly documented perfectly competitive long-run equilibrium supply shift in economics textbooks is the technological change induced shift.[22] Regulation causes marginal-and average cost curves to shift from MC to MC3 and 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.

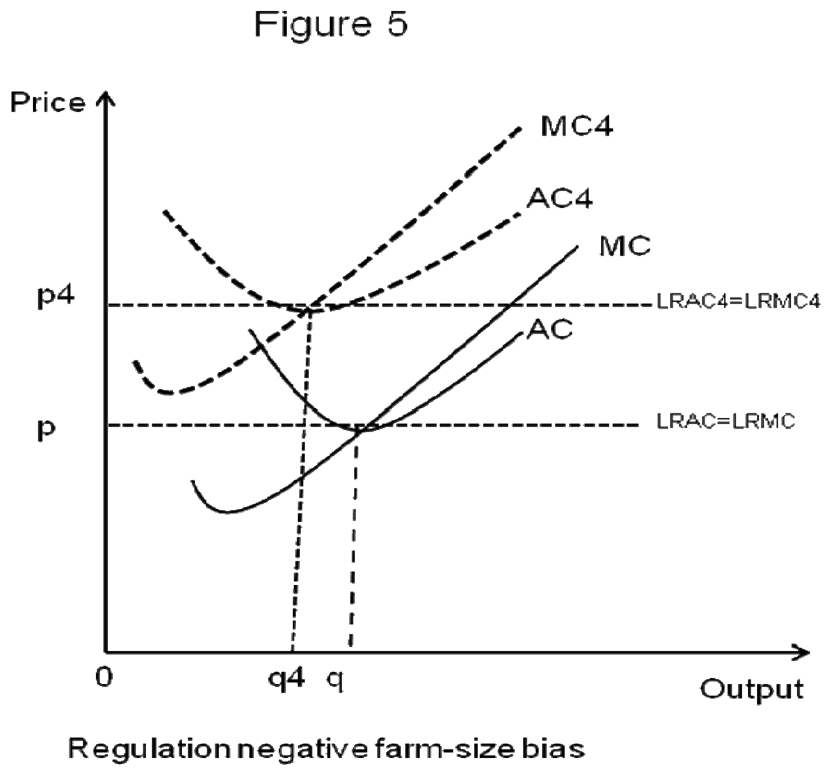
[22] In the case of new technology adoption both marginal-and average cost curves shift down leading to reduction in price and an increase in output.

**Figure 3: Average cost shifts more than the Marginal cost**




On the other hand, when marginal cost shifts upward more than average cost, output decreases from q to q4. Under this case, regulation will decrease HFO size. This case is shown in Figure 5.

**Figure 4: Marginal cost shifts more than the Average cost**




### 2.4.4. Impact of Environmental Regulation on Industry Output and Price

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: $\frac{\partial Q}{\partial E} = n^s \left( \frac{\partial q^s}{\partial E} \right) + q^s \left( \frac{\partial n^s}{\partial E} \right) + n^l \left( \frac{\partial q^l}{\partial E} \right)$. Using (10)-(12), the effect of environmental regulations on the U.S hog industry is given by

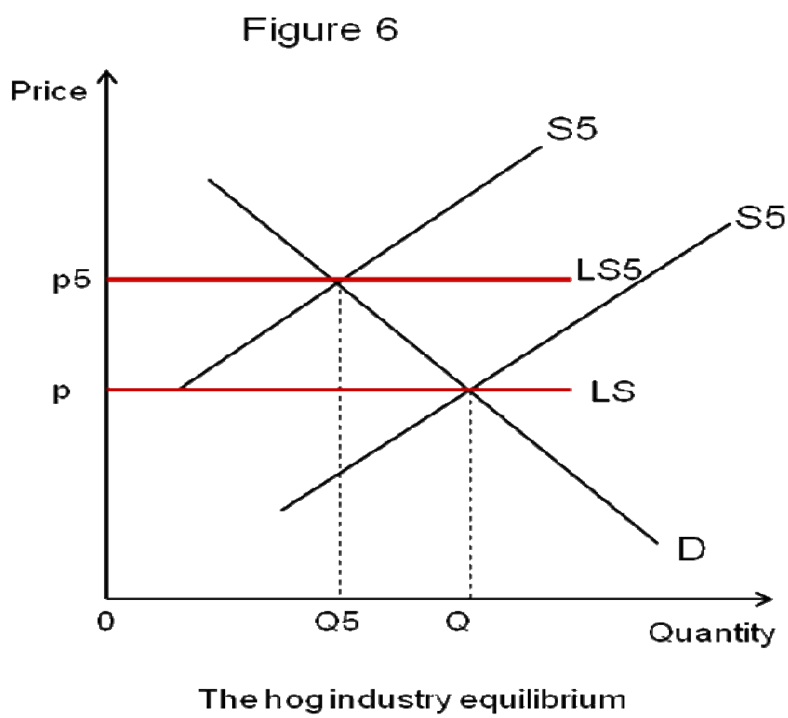
$$\frac{\partial Q}{\partial E} = \frac{c_E^s}{p' q^s} \prec 0. \tag{13}$$

Totally differentiating the inverse demand function, $p = p(Q)$, with respect to $E$ and utilizing (13) gives the change in equilibrium price due to environmental regulations shown in (14) below

$$(14) \qquad \frac{\partial p}{\partial E} = \frac{c_E^s}{q^s} \succ 0 .$$

Equations (13) and (14) show that an increase in environmental regulation has the effect of decreasing hog industry output and increasing hog industry price in the long-run. This result is shown graphically in Figure 6. Regulation affects the hog industry long-run price and output through its effects on SHFOs.[23] The introduction of regulation shifts the marginal-and average cost curves from MC and AC to MC5 and AC5, respectively. At the market-level hog price increases from p to p5 and hog output falls from Q to Q5.

**Figure 5: Effect of regulation on the hog industry equilibrium**




Our theoretical framework finds that output for a representative HFO and the number of SHFOs can either increase or decrease with environmental regulation depending on the associated shifts in the marginal and average cost curves. Results also suggest that in the long-run, regulation causes hog price and hog output to increase and

[23] Recall that in this study we only have a long-run condition for SHFOs.

decrease, respectively. These results confirm the findings by Lahiri and Ono (2007) based on a symmetric oligopoly that an emissions tax leads to a decrease in aggregate output but has an ambiguous effect on output per firm. The decrease in industry output is consistent with negative regulation farm-size bias for both HFO sizes associated with a decrease in the number of SHFOs with regulation. On the other hand, in the presence of positive regulation farm-size bias, this is consistent with the number of SHFOs declining significantly with regulation.

### 2.4.5. Impact of LHFOs on Industry Equilibrium

Given that the number of LHFOs is treated as exogenous and fixed in our model, we can examine how the number of LHFOs affects the hog industry long-run equilibrium. This allows us to be able to determine whether any crowding-out effect exists in the hog industry (i.e. whether the presence of a large of number of incumbent LHFOs has a negative effect on the entry and exit of SHFOs) or not. In other words we would like to know if the presence of a large number of LHFOs has the effect of forcing SHFOs out of the hog industry or not. To examine the effect of $n^l$ on $q^s$, $q^l$ and $n^s$, we totally differentiate (4), (5) and (7) with respect to $n^l$. Presenting the resulting expressions in matrix form we have:

$$\begin{bmatrix} \theta^s & n^l p' & q^s p' \\ n^s p' & \theta^l & q^s p' \\ n^s q^s p' & n^l q^s p' & {q^s}^2 p' \end{bmatrix} \begin{bmatrix} dq^s \\ dq^l \\ dn^s \end{bmatrix} = \begin{bmatrix} -p' q_l \\ -p' q_l \\ -p' q_l \end{bmatrix} dn_l , \tag{15}$$

where $\theta^s = n^s p' - mc^s_{q^s}$, and $\theta^l = n^l p' - mc^l_{q^l}$. The determinant of the coefficient matrix, $\Omega$, is the same as in (9), and it is given by $\det(\Omega) = p' {q^s}^2 mc^l_{q^l} mc^s_{q^s} < 0$.

The effect of the number of LHFOs on the output of SHFOs and LHFOs is given by

(16) $$\frac{\partial q^s}{\partial n^l} = \frac{p' q^l (q^s - 1)}{q^s mc^s_{q^s}} \prec 0 \text{, and}$$

(17) $$\frac{\partial q^l}{\partial n^l} = \frac{p' q^l (q^s - 1)}{q^s mc^l_{q^l}} \prec 0 \text{ , respectively.}$$

The results in (16) and (17) suggest that the presence of a large number of LHFOs has a negative effect on the output of SHFOs and LHFOs. This is because when LHFOs gain more market share, given that demand for hogs stays the same, we expect the industry equilibrium to adjust so that SHFOs will produce lower output in the long run.

The effect of the number of LHFOs on the number of SHFOs is given by

(18) $$\frac{\partial n^s}{\partial n^l} = \frac{p' q^l (1 - q^s)(n^l mc^s_{q^s} + n^s mc^l_{q^l}) - q^l mc^s_{q^s} mc^l_{q^l}}{{q^s}^2 mc^l_{q^l} mc^s_{q^s}}$$

The sign of (18) is ambiguous. The first expression in the numerator of (18) is positive by $1 < q^s$ and $p'$; and the second term in the numerator is negative. The sign in (18) is positive (negative) if the value of the first term, $p' q^l (1 - q^s)(n^l mc^s_{q^s} + n^s mc^l_{q^l})$, in the numerator is greater (lower) than the value of the second term, $p' q^l mc^s_{q^s} mc^l_{q^l}$. This result suggests that the presence of a large number of LHFOs can either attract or deter the entry of SHFOs in equilibrium.

The construction and implementation of the empirical model which addresses the long-run implications of environmental regulations in the U.S hog industry as well as checking whether or not crowding-out effect exists in this industry is presented next.

## 2.5. Empirical Model and Analysis

To develop the empirical model and test the results in (10)-(12), we focus on the long-run equilibrium outcomes from the first-order conditions in (4) and (5) and the long-run condition in (7).

### 2.5.1. Empirical Model Development

We assume that a representative HFO uses only three inputs: corn, labor and transportation, so that the cost function faced by a representative firm of size $k$ , , for $k = s,l$ , is as follows:

(19) $$c^k = c^k(q^{k^*}, feed, labor, trans, Envir),$$

where $feed$ , $labor$ , and $trans$, refer to price of corn, price of labor and price of transportation services, respectively. Input markets are competitive and both SHFOs and LHFOs face the same input prices. $Envir$ refers to the environmental stringency variable.

Due to the lack of farm level data and the assumption that hog farms in each HFO size category are homogenous we investigate the problem by aggregating firms within each HFO size group. After incorporating the industry demand function we rewrite (4), (5) and (7) as a system of three equations and aggregating firms within each HFO size group, we have:

(20) $$p(Q) = mc^s(Q^{s^*}, feed, labor, trans, Envir)$$

(21) $$p(Q) = mc^l(Q^{l^*}, feed, labor, trans, Envir)$$

(22) $$p(Q) = ac^s(Q^{s^*}, feed, labor, trans, Envir) \text{, where}$$

$ac^s$ refers to the SHFO average cost.

We can simultaneously solve the system of equations (20)-(22) to determine $N^{s^*}, Q^{s^*}$, and $Q^{l^*}$. Since the number of LHFOs is given, it enters as an exogenous variable in equilibrium. Rearranging the system in (20)-(22), the equilibrium solution in implicit form is given by:

(23) $$Q^{s^*} = f(p, feed, labor, trans, Nlarge, Envir)$$

(24) $$Q^{l^*} = f(p, feed, labor, trans, Nlarge, Envir)$$

(25) $$N^{s^*} = f(p, feed, labor, trans, Nlarge, Envir)$$

Equations (23) and (24) represent the long-run supply functions for small and LHFOs, respectively. Equation (25) shows the factors affecting the number of SHFOs in equilibrium. It is important to know that price is endogenous in equilibrium as it gives us information about the demand function. That is, the long-run equilibrium is defined by the intersection between the long-run supply function and the demand curve. In our model, we assume that the environmental regulation cost shifter does not have any effect on the demand schedule, so any change in equilibrium involves shifts in the supply curve and a movement along the demand curve. The econometric model which is based on our theoretical model is presented below.

### 2.5.2 .Econometric Model for Estimation

In addition to the information derived from the theory in (23)-(25), in our estimation we include dummy variables to capture the effects of different time periods and state-level characteristics. The econometric model to be estimated is given below:

(26) $$Q_{kt}^{s} = \beta_0 + \beta_1 p_{kt} + \beta_2 feed_{kt} + \beta_3 labor_{kt} + \beta_4 trans_{kt} + \beta_5 N\text{large}_{kt} + \beta_6 Envir_{kt} + \beta_k K + \beta_t T + \varepsilon_{1kt}$$

(27) $$Q_{kt}^{d} = \gamma_0 + \gamma_1 p_{kt} + \gamma_2 feed_{kt} + \gamma_3 labor_{kt} + \gamma_4 trans_{kt} + \gamma_5 N\text{large}_{kt} + \gamma_6 Envir_{kt} + \gamma_k K + \gamma_t T + \mu_{kt}$$

(28) $$Nsmall_{kt} = \theta_0 + \theta_1 p_{kt} + \theta_2 feed_{kt} + \theta_3 labor_{kt} + \theta_4 trans_{kt} + \theta_5 N\text{large}_{kt} + \theta_6 Envir_{kt} + \theta_k K + \theta_t T + \upsilon_{kt}$$

Where *k* = state, *t* = year (1994-2006). The $\beta's$, $\gamma's$, and $\theta's$ are parameters to be estimated while, $\varepsilon$, $\mu$, and $\upsilon$, represent the error terms. The variable $K$ is a dummy variable representing state-level unobserved characteristics and the variable $T$ is a dummy variable representing the effects of different time periods. We allow for unobserved effects as they may have effects on the coefficients of the continuous variables in the model. If they do have statistically significant effects, there is no reason to ignore them.

Hog price and environmental regulations compliance costs (*Envir*) are endogenous in the system of equations (26)-(28). The endogeneity of environmental compliance costs was first noted by Metcalfe (2001) and later adopted by Herath, Weersink, and Carpentier (2005b). We use price of beef, median household income, and population density as instrumental variables for the hog price. Gross state farm product and median household income are used as instrumental variables for environmental stringency. Herath, Weersink, and Carpentier (2005b) used median household income as an instrumental variable for environmental stringency. The reduced forms of hog price and environmental compliance (stringency) cost regression equations provide the first stage estimations. The first stage estimations are represented in (29) and (30) below:

(29) $$p_{it} = \lambda_1 feed_{kt} + \lambda_2 labor_{kt} + \lambda_3 trans_{kt} + \lambda_4 Nl\arg e_{kt} + \lambda_6 pbeef_{kt} + \lambda_7 pd_{kt} + \lambda_8 income_{kt} + \lambda_k K + \lambda_t T + \omega_{kt}$$

(30) $$Envir_{it} = \alpha_1 feed_{kt} + \alpha_2 labor_{kt} + \alpha_3 trans_{kt} + \alpha_4 Nl\arg e_{kt} + \alpha_5 gsfar_{kt} + \alpha_6 pbeef_{kt} + \alpha_7 pd_{kt} + \alpha_8 income_{kt} + \alpha_k K + \alpha_t T + \eta_{kt}$$

where *pbeef* , *income* , *gsfar*, and *pd* refer to price of beef, median household income, gross farm product, and population density, respectively.

The predicted values from (29) and (30) are used in place of $p_{it}$ and $Envir_{it}$ in the system of equations in (26)-(28) which represent the second stage estimation. The system of equations in (26)-(28) is estimated using the seemingly unrelated regressions (SUR) econometric procedure. All model specifications are in log-log form except for the time variable and the fixed effects variables.

### 2.5.3. Description of Data and Variables

The study uses data for the top ten hog producing states for the years 1994 through 2006. The states which constitute the top ten hog producing states include: Iowa (IA), North Carolina (NC), Minnesota (MN), Illinois (IL), Nebraska (NE), Indiana (IN), Missouri (MO), Oklahoma (OK), Ohio (OH), and Kansas (KS). Our choice to consider the ten major hog producing states was motivated by the fact that these states account for about 85% of the total U.S. hog production.

**Dependent variables**

Based on our theoretical model, our empirical model uses three dependent variables. These variables include: **the state-level total hog inventory for SHFOs**; **the state-level total hog inventory for LHFOs**; and **the state-level number of SHFOs**. The variables are described in detail below.

**The state level total hog production inventories for SHFOs and LHFOs** are designed to measure the aggregate supply of hogs from SHFOs and LHFOs, respectively. In this study SHFOs are defined as operations that raise 1-999 head and LHFOs are defined as operations that raise 1000 head and above. These two variables are solutions to the aggregate form of the first-order conditions in equation (4). Roe, Irwin and Sharpe (2002) used hog inventories as the depended variable to study the spatial structure of the U.S hog industry. Metcalfe (2001) used the percentage share of total U.S. hog inventory to study the effect of environmental regulations on hog production for 18 U.S. major hog producing states.

The **Number of hog operations** is designed to measure the equilibrium number of SHFOs in the U.S hog industry. The endogeneity of this variable stems from the determination of the number of small farms by the zero profit condition in equation (7), in our theoretical model. However, in this analysis, the number of large farms is treated as an exogenous variable for several reasons. The following reasons are behind our treatment of this variable as exogenous: (1) it takes a long-time to come up with a highly mechanized farm; (2) when such a large mechanized farm enters the industry, evidence from industry does support the fact that such farms rarely exit the industry; and (3) if we were to make both the number of large farms and the number of small farms endogenous, we will not get an analytical solution to the theoretical model.

**Explanatory variables**

The **Environmental stringency** variable measures the number of state-level environmental regulations on HFOs. Data on state-level environmental stringency indices is not readily available. For each state, we make use of a 1994-2006 time series qualitative environmental stringency data in this study. Several studies have used qualitative environmental stringency indices to study environmental stringency issues in the U.S hog industry (Metcalfe, 2000; Metcalfe, 2001; Roe, Irwin and Sharp, 2002; Herath, Weersink, and Carpentier, 2005b). For the period 1994 - 2002, we make use of the qualitative environmental stringency indices for 1994-1999 and 2000-2002 constructed by Metcalfe (2000), and Herath, Weersink, and Carpentier (2005b), respectively.

To complete the 1994-2006 time series, we construct environmental stringency indices for the years 2003 -2006 using the methodology employed by Metcalfe (2000).[24] The 2003-2006 stringency values incorporate the 2003 revisions to the Clean Water Act regulations governing animal feeding operations which most states adopted as soon as they were announced. We argue that hog farmers are forward looking (Metcalfe 2001), hence the 2003-2006 stringency values are the same. In addition, we update the stringency indices constructed by Herath, Weersink, and Carpentier (2005b) to match the methodology used by Metcalfe (2000). Table 7 documents the 1994-2006 environmental stringency data for the top ten U.S. hog producing states.

[24] The construction of the 2003-2006 environmental stringency values is documented in appendix C.

**Table 7: State-level Environmental Stringency 1994-2006 Time Series Data**

| State | 1994 | 1995 | 1996 | 1997 | 1998 | 1999 | 2000 | 2001 | 2002 | 2003 | 2004 | 2005 | 2006 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Illinois | 2 | 2 | 2 | 2 | 8 | 8 | 9 | 9 | 9 | 14 | 14 | 14 | 14 |
| Indiana | 4 | 4 | 4 | 4 | 6 | 6 | 6 | 6 | 6 | 13 | 13 | 13 | 13 |
| Iowa | 4 | 4 | 4 | 4 | 9 | 9 | 10 | 10 | 10 | 13 | 13 | 13 | 13 |
| Kansas | 4 | 4 | 4 | 4 | 9 | 9 | 9 | 9 | 9 | 13 | 13 | 13 | 13 |
| Minnesota | 8 | 8 | 8 | 8 | 9 | 9 | 9 | 9 | 9 | 13 | 13 | 13 | 13 |
| Missouri | 6 | 6 | 6 | 6 | 7 | 7 | 8 | 8 | 8 | 12 | 12 | 12 | 12 |
| Nebraska | 3 | 3 | 3 | 3 | 7 | 7 | 9 | 9 | 9 | 12 | 12 | 12 | 12 |
| North Carolina | 1 | 1 | 1 | 1 | 8 | 8 | 9 | 9 | 9 | 14 | 14 | 14 | 14 |
| Ohio | 5 | 5 | 5 | 5 | 7 | 7 | 9 | 9 | 9 | 12 | 12 | 12 | 12 |
| Oklahoma | 4 | 4 | 4 | 4 | 6 | 6 | 9 | 9 | 9 | 13 | 13 | 13 | 13 |

Source: Metcalfe (2000), Herath, Weersink, and Carpentier (2005) and author's estimates (2003-2006)

The indices reported for 1994-1999 match the indices reported in Metcalfe (2000). To update the 2000 index constructed by Herath, Weersink, and Carpentier (2005b), we tracked the changes in individual regulations between 1998 and 2000 as reported in Metcalfe (2000) and Herath, Weersink, and Carpentier (2005b), respectively. Comparing the two indices, we determined if a state adopted a new regulation after 1998. If a new regulation was added as reflected in 2000, we added the regulation to the 1998 index to construct the 2000 index. Both studies constructed their indices in a similar way except that that Herath, Weersink, and Carpentier (2005b) did not build on Metcalfe (2000) to calculate their initial index. Without reconciling the ways in which the indices were constructed, the time series would not make sense. The time series data shows that environmental regulations have been increasing over the years.

The environmental stringency variable is endogenous because regulations may increase in states that are experiencing increasing hog production while states with low environmental regulations may realize increased hog production (Metcalfe 2001). Our theoretical results shown in equations (16)-(18) suggest that the effect of environmental stringency on the output of SHFOs, LHFOs, and the number of SHFOs are ambiguous. A positive (negative) sign on the environmental stringency variable on regressions involving the outputs of LHFOs and SHFOs suggests that environmental stringency has the effect of increasing (decreasing) the output of LHFOs and SHFOs. A positive (negative) coefficient on the environmental stringency variable on the regression which uses the number of SHFOs as the dependent variable suggests that environmental regulations have the effect of increasing (decreasing) the number of SHFOs in the U.S hog industry.

The **hog output price** variable is endogenous in our model as it is associated with the demand side of the industry. Metcalfe (2001) used the hog price predicted values to address the endogeneity of hog output price. By the monotonicity property of the supply function, we expect a positive sign on hog output price in the supply equations. In the number of SHFOs equation a positive sign is expected on the hog price variable if an increase in the price of hogs attracts new entrants. This sign will also depend on whether the increase in the hog price is short-term or long-term. A short-term increase may not increase entrants, but if the price increase is long-term, then the number of SHFOs should increase.

The **Corn price** variable is designed to measure the cost of hog feed input. Corn is an input in hog production which constitutes a greater percentage of hog feed. Several studies used corn price as an input to study the effect of environmental regulations on hog production (Metcalfe, 2001; Roe, Irwin and Sharp, 2002). Other studies addressing the livestock industry also used corn as an input. We expect hog supply to decrease with an increase in the price of feed corn. Specifically, production costs increase with a higher price of corn, reducing the quantity of hogs supplied. The corn price has an ambiguous effect on the number of SHFOs. When the price of corn goes up, some SHFOs may exit the industry reducing the number of small operations. Higher corn prices also increase the price of hogs, leading to positive profits which will attract new entry by SHFOs. Entry by new SHFOs will drive the price down to a new equilibrium price higher than the original price or back to the original equilibrium price. If the equilibrium price reverts back to the original equilibrium price then there will be an effect on the number of SHFOs only in the short-run and not in the long-run. However, if the increase in the price of corn leads to a higher new equilibrium price in the long-run we expect the number of small firms to decrease in the long-run.

**Farm labor** measures the cost of labor used in hog production. We use the average hourly state-level hourly wages as a proxy for farm labor wages. Metcalfe (2001), and Herath, Weersink, and Carpentier (2005b) also used farm labor wages to capture the cost of farm labor input. A negative sign is expected on farm-labor wages on regressions involving the supply of SHFOs and LHFOs. We expect the increase in farm labor wages to either have no effect or to negatively affect the number of SHFOs, depending on whether the wage increase is short term or long-term. Some SHFOs may exit the industry if the rise in wages greatly affects their profits making it difficult to continue operating. If the reaction of SHFOs to increased farm labor wages is a shift from labor to capital inputs (i.e, machinery), the number of small operations may not be affected. Long-run impacts will be similar to those described for corn prices.

**Transportation cost** measures the cost of transporting several commodities used in hog production. Energy price is a popular proxy for transportation cost in livestock industry studies as well as meatpacking industry studies. Azzam (1997), Metcalfe (2001), and Herath, Weersink, and Carpentier (2005b) used energy price as a proxy for transportation cost in studies related to the livestock industry. The supply function is decreasing in input prices; hence, we expect a negative sign on the transportation cost variable. The effect of transportation cost on the number of SHFOs is either to decrease or have no effect the number of SHFOs. The sign on the transportation cost variable will depend in part on whether the increase in transportation cost is short term or long-term. If the increase in the price of transportation is long-term, some SHFOs may shut down and exit the industry. However, if the price increase is short-term, the number of SHFOs may not be affected in the long-run.

The **Number of LHFOs** variable is treated as exogenous in our model. This variable is designed to test whether any crowding-out effect exists in the hog industry. When the number of LHFOs increases, SHFOs may be squeezed out of the industry. Alternatively, the increase in the number of LHFOs may attract more entry by SHFOs into the industry, due to agglomeration economies (i.e. the benefit HFOs enjoy from locating close to each other.). The overall direction of change will help partially explain the dynamics of different size HFOs over the years. Our theoretical model derives the effect of environmental regulations on the outputs for SHFOs and LHFOs and the number of SHFOs. Analytical results, as shown in equations (16) and (17), suggest that the number of LHFOs has a negative effect on the outputs of SHFOs and LHFOs.

However, the result on the effect of the number of LHFOs on the number of SHFOs in (18) is inconclusive. Based on the theoretical predictions, we expect the signs on the number of LHFOs variable to be negative in the regressions involving the outputs for SHFOs and LHFOs, while the impact on the number of SHFOs is ambiguous. Table 8 provides the source and variable description for the data used in the empirical analysis and Table 9 shows the summary statistics for the data.

**Table 8: Variable Definition and Data Sources**

| **Definition of variables** | **Source** |
|---|---|
| Small hog farms total inventory | USDA-NASS |
| Large hog farms total inventory | USDA-NASS |
| Number of small hog farms | USDA-NASS |
| Number of large hog farms | USDA-NASS |
| Hog price: Dollars/Cwt(100 weight) | NASS Agricultural Prices Summaries- USDA |
| Corn price: Dollars/Bushel | NASS Agricultural Prices Summaries- USDA |
| Transportation cost: cents per gallon: | Energy Information Administration |
| Environmental Stringency | 1993-2002: Metcalfe(2000) and Herath, Weersink, and Carpentier (2005)<br>2003-2006 indices: author's estimates |
| Farm labor: Dollars/Hour | Farm labor-NASS-USDA |
| Cattle all beef price: Dollars/Cwt | NASS Agricultural Prices Summaries- USDA |
| Income: personal per capita income/Dollars | Almanac of the 50 States Information Publications |
| Population density(pd): persons per square mile | Almanac of the 50 States Information Publications |
| GSPFARM in million dollars; gross state farm product: includes agricultural services, forestry and fisheries | Almanac of the 50 States Information Publications |

**Table 9: Descriptive Statistics**

| Variable | Mean | Standard Deviation | Minimum | Maximum |
|---|---|---|---|---|
| **LHFO inventory** | 39985 | 35640 | 4454.5 | 154630 |
| **SHFO inventory** | 9712.2 | 11715 | 665 | 75400 |
| **Number of LHFOs** | 1058.5 | 1022.2 | 60 | 4400 |
| **Number of SHFOs** | 4780 | 3734.6 | 935 | 25100 |
| **Hog price** | 42.19 | 4.28 | 33.52 | 54.48 |
| **Corn price** | 2.34 | 0.47 | 1.64 | 3.99 |
| **Transport** | 101.16 | 31.17 | 59.8 | 179.7 |
| **Labor** | 8.2 | 0.79 | 6.6 | 10 |
| **Population density** | 112.5 | 84.22 | 21.1 | 280.3 |
| **Environ stringency** | 8.41 | 3.71 | 1 | 14 |
| **Cattle price** | 69.17 | 7.83 | 49.8 | 91.7 |
| **Per capita income** | 27191.73 | 2549.95 | 21311.4 | 33264.7 |
| **Gspfarm** | 2839.09 | 1339.66 | 355.9 | 6333.8 |

All dollar values are in year 2000 dollars. The Consumer Price Index was used to convert all nominal values to real terms.

### 2.5.4. Empirical Results

Empirical results in Tables 10-12 are based on Zellner's Seemingly Unrelated Regressions estimation procedure of the three equation system, (26)-(28). The Breusch-Pagan (B-P) LM test for diagonal covariance matrix rejects the hypothesis that the off diagonal elements of the covariance matrix are all zero. The B-P LM test result justifies our use of the SUR estimation procedure rather than estimating the individual equations by ordinary least squares. We failed to reject the null hypothesis that the slopes of the cost parameters in (26) and (28) are equal. We test for this restriction based on the long-run equilibrium condition for SHFOs, $p = mc^s = ac^s$. In addition, since the long-run equilibrium price is determined by SHFOs, we also test whether or not the following restriction holds $p = mc^s = mc^l = ac^s$. The null hypothesis that the slopes of cost parameters in the three regression equations are the same was not rejected. We failed to reject the null hypothesis that the supply function for SHFOs is homogenous of degree zero in output price and input prices. On the other hand, the null hypothesis that the supply function for LHFOs is homogenous of degree zero in output price and input prices was rejected.

Results in Table 10 present the unrestricted SUR, Table 11 results are based on a SUR model with cross-equation restrictions on the equality of cost parameter slopes imposed on (26) and (28) and the homogeneity restriction imposed on (26), and results in Table 12 are based on a SUR model with cross-equation restrictions on the equality of cost parameter slopes imposed on (26)-(28) and the homogeneity restriction imposed on (26).

The unrestricted SUR results in Table 10 suggest that environmental regulations had a negative and statistically significant effect on the supply of both LHFOs and SHFOs, and the number of SHFOs. These results suggest that environmental regulations significantly contributed to the changing structure of the U.S hog industry during the period, 1994- 2006. Specifically, regulation played an important role in the reduction of the number of SHFOs in the U.S hog industry. In addition, regulation forced both LHFOs and SHFOs to reduce hog supplies.

The coefficients on the effect of the number of LHFOs on the supply of SHFOs and LHFOs, and the number of SHFOs are all positive and statistically significant. These results suggest that HFOs benefit with the increase of LHFOs through spillover effects such as transmission of new methods of hog production and facility management. Empirical results also provide evidence against any crowding-out effect as the increase in the number of large hog operations has a positive and statistically significant effect on the number of incumbent small hog feeding operations, a result that is consistent with Kuo

(2005). The trend in the reduction of the number of SHFOs was not due to the increase in the number of LHFOs.

The coefficients on hog price do have the expected positive sign for regressions involving the supply of SHFOs and the number of SHFOs. However, the coefficient on hog price in the regression involving the supply of LHFOs is negative and statistically significant. While the coefficients on transportation cost, corn price and labor do have the expected negative signs for the regression involving LHFOs hog supply, only coefficients on transportation cost and labor have the expected negative signs while the coefficient on corn price is positive but insignificant in the SHFO hog supply regression. Only the coefficient on labor has the expected sign in the regression that uses the number of SHFOs as the dependent variable. While the coefficients on transportation cost and corn price have unexpected positive signs, they are statistically insignificant in the number of SHFO regression.

**Table 10: Regression results using fixed effects and the time variable**

| | Ln(OSHFO) | | Ln(OLHFO) | | Ln(NSHFO) | |
|---|---|---|---|---|---|---|
| **Variable** | **Coefficient** | **T-stat** | **Coefficient** | **T-Stat** | **Coefficient** | **T-Stat** |
| **CONSTANT** | 6.003 | 4.403*** | 8.28 | 8.477*** | 5.961 | 5.105*** |
| **Ln(Hog Price)** | 0.614 | 1.612 | -0.452 | -1.656* | 0.009 | 0.002 |
| **Ln(Corn Price)** | 0.007 | 0.847 | -0.103 | -1.574 | 0.005 | 0.751 |
| **Ln(Labor)** | -0.691 | -1.762* | -0.287 | -1.02 | -0.957 | -2.847*** |
| **Ln(Transcost)** | -0.197 | -0.764 | -0.021 | -0.116 | 0.117 | 0.532 |
| **Ln(NLHFOs)** | 0.629 | 6.343*** | 0.728 | 10.238*** | 0.692 | 8.14*** |
| **Ln(Stringency)** | -0.181 | -1.926* | -0.331 | -4.907*** | -0.23 | -2.854*** |
| **T** | -0.006 | -2.21** | 0.008 | 3.817*** | -0.008 | -3.237*** |
| **IL** | -0.395 | -2.757*** | -0.443 | -4.316*** | -0.004 | -0.371 |
| **IN** | -0.485 | -2.882*** | -0.485 | -4.019*** | 0.007 | 0.52 |
| **KS** | -0.778 | -2.606*** | -0.154 | -0.72 | 0.343 | 1.341 |
| **MN** | -0.293 | -2.399** | -0.218 | -2.484*** | 0.148 | 1.415 |
| **MO** | -0.513 | -2.307** | -0.006 | -0.428 | 0.329 | 1.729* |
| **NE** | -0.235 | -1.345 | -0.454 | -3.629*** | 0.164 | 1.098 |
| **NC** | -2.63 | -22.285*** | 0.365 | 4.315*** | -1.051 | -10.404*** |
| **OH** | -0.241 | -1.042 | -0.943 | -5.688*** | 0.862 | 4.351*** |
| **OK** | -1.321 | -3.75*** | 0.523 | 2.075** | 1.02 | 3.382*** |
| **R-Square** | | 0.985 | | 0.985 | | 0.969 |

Note for Table 10: The dependent variables are: log of SHFOs output (Ln (OSHFO)); log of LHFOs output (Ln (OLHFO)); and log of the number of SHFOs (Ln (NSHFO)). P-values are indicated as ***0.01, **0.05 and *0.10.

The state-level fixed effects dummy variables are for nine states excluding the state of Iowa. The time-effects are for the 13 years from 1994-2006. Both the fixed effects and time effects are assumed to be exogenous to the model.

The restricted SUR results in Table 11 provide the same conclusions as results in Table 10 for the key parameters we are interested in. That is, the coefficients on the environmental stringency variable are all negative and statistically significant. The sign of the hog price variable is unexpected in the LHFO hog supply regression and has the expected sign in the other two regressions. The coefficients on the transportation, corn, and labor price variables are as predicted in the LHFO supply estimation. The imposed restrictions had an effect on the cost parameters in the SHFO hog supply and number of

SHFOs regressions. The coefficient on labor is negative and statistically significant, while the coefficients on corn price and transportation cost are positive and statistically insignificant in the HFO hog supply and number of SHFOs regressions. The number coefficient on the number of LHFOs remains positive and highly statistically significant in all the three regressions.

**Table 11: SUR Regression results with restrictions on the cost parameters of equations 1 and 3 and homogeneity restriction on equation 1**

| | Ln(OSHFO) | | Ln(OLHFO) | | Ln(NSHFO) | |
|---|---|---|---|---|---|---|
| **Variable** | **Coefficient** | **T-stat** | **Coefficient** | **T-Stat** | **Coefficient** | **T-Stat** |
| **CONSTANT** | 5.758 | 5.952*** | 8.361 | 8.636*** | 4.574 | 5.023*** |
| **Ln(Hog Price)** | 0.28 | 0.859 | -0.441 | -1.624 | 0.134 | 0.421 |
| **Ln(Corn Price)** | 0.091 | 1.244 | -0.105 | -1.619 | 0.091 | 1.244 |
| **Ln(Labor)** | -0.471 | -3.307*** | -0.321 | -1.154 | -0.471 | -3.307*** |
| **Ln(Transcost)** | 0.099 | 0.474 | -0.035 | 0.195 | 0.099 | 0.474 |
| **Ln(NLHFOs)** | 0.609 | 6.281*** | 0.73 | 10.321*** | 0.682 | 8.045*** |
| **Ln(Stringency)** | -0.155 | -1.763* | -0.334 | -4.981*** | -0.198 | -2.522*** |
| **T** | -0.096 | -4.255*** | 0.081 | 3.94*** | -0.088 | -3.988*** |
| **IL** | -0.444 | -3.218*** | -0.44 | -4.314*** | -0.052 | 0.428 |
| **IN** | -0.529 | -3.228*** | -0.483 | -4.022*** | 0.07 | 0.49 |
| **KS** | -0.853 | -2.924*** | -0.15 | 0.704 | 0.334 | 1.305 |
| **MN** | -0.352 | -3.117*** | -0.213 | -2.447*** | 0.113 | 1.132 |
| **MO** | -0.555 | -2.557*** | -0.068 | 0.43 | 0.376 | 1.967** |
| **NE** | -0.245 | -1.421 | -0.455 | -3.655*** | 0.188 | 1.249 |
| **NC** | -2.602 | -24.342*** | 0.36 | 4.291*** | -0.984 | -10.467*** |
| **OH** | -0.284 | -1.252 | -0.941 | -5.71 | 0.87 | 4.372*** |
| **OK** | -1.389 | -4.017*** | 0.526 | 2.096** | 1.044 | 3.445*** |
| **R-Square** | | 0.985 | | 0.986 | | 0.968 |

Note for Table 11: The dependent variables are: log of SHFOs output (Ln (OSHFO)); log of LHFOs output (Ln (OLHFO)); and log of the number of SHFOs (Ln (NSHFO)). P-values are indicated as ***0.01, **0.05 and *0.10.

The restricted SUR results in Table 12 also suggest that environmental regulations had a negative and statistically significant effect on the supply of both LHFOs and SHFOs, and the number of SHFOs. The coefficients on the effect of the number of LHFOs on the supply of SHFOs and LHFOs and number of SHFOs remain positive and statistically significant.

The coefficients on hog price do have the expected positive sign for regressions involving the supply of SHFOs and the number of SHFOs. However, the coefficient on hog price in the regression involving the supply of LHFOs is negative and statistically significant. The coefficients on corn price and labor do have the expected negative signs. While the coefficient on transportation cost has an unexpected positive sign, it is highly statistically insignificant.

**Table 12: SUR Regression results with restrictions on cost parameters of all equations and a homogeneity restriction for equation 1**

| | Ln(OSHFO) | | Ln(OLHFO) | | Ln(NSHFO) | |
|---|---|---|---|---|---|---|
| **Variable** | **Coefficient** | **T-stat** | **Coefficient** | **T-Stat** | **Coefficient** | **T-Stat** |
| **CONSTANT** | 5.654 | 6.239*** | 8.667 | 10.1*** | 4.424 | 5.062*** |
| **Ln(Hog Price)** | 0.435 | 1.973* | -0.566 | -2.773*** | 0.296 | 1.377 |
| **Ln(Corn Price)** | -0.022 | -0.487 | -0.022 | -0.487 | -0.022 | -0.487 |
| **Ln(Labor)** | -0.43 | -3.722*** | -0.43 | -3.722*** | -0.43 | -3.722*** |
| **Ln(Transcost)** | 0.016 | 0.131 | 0.016 | 0.131 | 0.016 | 0.131 |
| **Ln(NLHFOs)** | 0.6 | 6.383*** | 0.739 | 10.751*** | 0.674 | 8.195*** |
| **Ln(Stringency)** | -0.201 | -2.399*** | -0.305 | -4.649*** | -0.242 | -3.221*** |
| **T** | -0.085 | -5.397*** | 0.076 | 5.154*** | -0.077 | -5.115*** |
| **IL** | -0.443 | -3.396*** | -0.439 | -4.543*** | -0.048 | -0.423 |
| **IN** | -0.534 | -3.414*** | -0.478 | -4.14*** | 0.069 | 0.505 |
| **KS** | -0.859 | -3.067*** | -0.143 | -0.693 | 0.332 | 1.353 |
| **MN** | -0.35 | -3.286*** | -0.208 | -2.649*** | 0.116 | 1.245 |
| **MO** | -0.558 | -2.674*** | -0.072 | -0.465 | 0.377 | 2.052** |
| **NE** | -0.265 | -1.57 | -0.444 | -3.551*** | 0.171 | 1.157 |
| **NC** | -2.6 | -24.546*** | 0.347 | 4.243*** | -0.98 | -10.445*** |
| **OH** | -0.295 | -1.344 | -0.934 | -5.751*** | 0.863 | 4.473*** |
| **OK** | -1.397 | -4.191*** | 0.528 | 2.141** | 1.042 | 3.558*** |
| **R-Square** | | 0.985 | | 0.986 | | 0.968 |

Note for Table 12: The dependent variables are: log of SHFOs output (Ln (OSHFO)); log of LHFOs output (Ln (OLHFO)); and log of the number of SHFOs (Ln (NSHFO)). P-values are indicated as ***0.01, **0.05 and *0.10.

It is important to note that the restrictions imposed on results in Tables 11 and12 do not change the conclusions regarding the effect of regulation on the long-run equilibrium of the U.S. hog industry. We can use our empirical results to estimate the effect of regulation on average farm-size as reflected by the changes in the scale of hog production. This will help explain whether there exist positive or negative regulation farm-size biases for the two HFO sizes.

**2.5.5. Regulation and Average Farm-size**

We use results in Tables 10-12 to approximate the effect of regulation on average farm-size or scale of hog production. The change in the number of head per unit for SHFOs due to regulation is given by:

$$\frac{\partial}{\partial E}\left(\frac{Q^s}{N^s}\right) = \frac{N^s}{Q^s}\frac{\partial}{\partial E}(\partial \ln Q^s - \partial \ln N^s)$$

$$(31) \qquad = \frac{N^s}{Q^s}\frac{\partial}{E\partial \ln E}(\partial \ln Q^s - \partial \ln N^s)$$

Using the result in (31), the effect of regulation on the output for a representative SHFO is given by the product of $\frac{N^s}{Q^s E}$ and 0.049, 0.043, and 0.041 based on results reported in Tables 10, 11, and 12, respectively.

Making use of (27), the change in the number of head per unit for LHFOs due to regulation is given by:

$$\ln\left(\frac{Q^l}{N^l}\right) = (\ln Q^l - \gamma_5 \ln N^l) = \gamma_0 + \gamma_1 p_{kt} + \gamma_2 feed_{kt} + \gamma_3 labor_{kt} + \gamma_4 trans_{kt} + \gamma_6 E + \gamma_k K + \gamma_t T + \mu_{kt}$$

(32)
$$\frac{\partial}{\partial E}\left(\frac{Q^l}{N^l}\right) = \frac{N^l}{Q^l}\frac{\partial}{E\partial \ln E}(\partial \ln Q^l - \gamma_5 \partial \ln N^l)$$
$$= \frac{N^l}{Q^l E}\gamma_6$$

Using the result in (32), the effect of regulation on a representative LHFO is negative since $\gamma_6$ is estimated to be -0.331, -0.334, and -0.305, based on results reported in Tables 10, 11, and 12, respectively. With the variables evaluated at their respective means, these impacts are given in Table 13.

**Table 13: Effect of regulation on an average HFO**

| Results used | Effect on a SHFO | Effect on a LHFO |
|---|---|---|
| **Table 10** | 0.003 | -0.001 |
| **Table 11** | 0.003 | -0.001 |
| **Table 12** | 0.002 | -0.001 |

Note for Table 13: Results are in thousand head.

These results show that positive and negative farm-size biases exist for SHFOs and LHFOs, respectively. This result suggests that regulation increases the average SHFO farm size and reduces the average LHFO farm size. In other words, the scale of hog production for SHFOs increases while that of LHFOs decreases.

### 2.6: Summary and Conclusions

The primary objective of this study is to examine the effect of environmental regulations on the entry and exit of small U.S hog farms. To address this question we develop a theoretical model that addresses supply shifts due to environmental regulation compliance costs in a perfectly competitive hog industry in the long-run. Theoretical results on the long-run effects of regulation on the output of SHFOs, large-HFOs and the number of SHFOs are inconclusive.

Among the factors important in the determination of the direction of change in the endogenous variables due to regulation include the nature of regulation and technology. Embedded in the cost of regulation are important regulation characteristics which include: regulation farm-size bias and regulation input bias. Positive (negative) regulation farm-size bias occurs when the regulation induced shift in the average cost curve is greater (lower) than the shift in the marginal cost curve. How the shift in marginal cost curve compares to the shift in the average cost curve is central to the ambiguity of our theoretical results.

Whether the pre-and post-regulation increase shifts both the marginal-and average cost curves or not could be a result of the nature of the pre-and post-regulation underlying technology. This is another way the shifts in the marginal-and average cost curves may differ. When the pre-and post-regulation increase underlying technologies are homothetic, regulation shifts only the average cost curve. In this case, the shift in average cost is greater than the shift in marginal cost (zero). On the other hand, regulation may shift both marginal-and average cost curves. The direction of change will depend on how the shift in the marginal cost curve compares to the shift in the average cost curve. In addition, the importance of the different HFO size technologies is important in determining the direction of change of our theoretical results. Because of the complexity of the various regulation induced effects, the overall impact is an empirical question.

Prior studies argue that incumbent HFOs may pose as an entry barrier to potential entrants. In the U.S. hog industry, the question is whether incumbent LHFOs act as an entry deterrent and whether their presence leads to the exit of SHFOs. Theory also suggested that the presence of a large number of LHFOs have a negative effect on the outputs of SHFOs and LHFOs, and the effect on the number of SHFOs is ambiguous. Based on the theoretical model, we developed an empirical model to help explain how regulation affected the entry and exit of U.S. hog farms for the period 1994-2006.

Empirical results suggest that environmental regulations had a negative and statistically significant effect on hog supply for both SHFOs and LHFOs, and the number of SHFOs. These results suggest that environmental regulations significantly affected the entry and exit of U.S. hog farms thereby contributing to the changing structure of the U.S hog industry during the period, 1994- 2006. Specifically, regulation played an important role in the exit of the number of SHFOs in the U.S hog industry in the last two decades. In addition, regulation compliance cost forced both SHFOs and LHFOs to reduce hog supplies.

The coefficients on the effect of the presence of a large number of LHFOs in a state on the supply of SHFOs, LHFOs, and the number of SHFOs are all positive and statistically significant. These results suggest that all HFO size categories benefit from the existence of a large number of LHFOs in a state ruling out the argument that incumbent LHFOs pose a threat to SHFOs. HFOs may benefit from incumbent LHFOs through learning from LHFOs in areas such as technological improvements. LHFOs are likely to bear the risk of adopting new technology and SHFOs are likely to wait and adopt only the successful technologies through learning. SHFOs will save the cost of the risk associated with adoption of technologies that are not cost effective. In addition, the presence of agglomeration economies where HFOs benefit from locating next to other HFOs could be behind this result.

Therefore, the trend in the reduction of the number of SHFOs was not due to the existence of a large number of LHFOs. The existence of a large number of LHFOs serves as an entry attraction for SHFOs. State-level policies targeted at saving family farms should take into account the fact that improving the cooperation between SHFOs and LHFOs does benefit SHFOs. Encouraging cooperation between SHFOs and LHFOs will help save family farms. We can infer from our results that, policies aimed at discouraging LHFOs can be detrimental to the survival of SHFOs henceforth, the survival of the hog industry.

Based on our empirical results, we examined how regulation affects the average farm-size of the two HFO size categories. Results suggest that regulation increases and decreases the average farm-size for a representative SHFO and LHFO, respectively. This suggests that the output of an individual SHFO increases with regulation. In other words, the scale of hog production by an individual SHFO increases implying that the average size of an incumbent SHFO increases with regulation.  This could be due to SHFOs acquiring better machinery to cope with regulation compliance. This could be a result of obsolete technology that LHFOs had acquired earlier which can still have an effect of altering SHFO scale of production. On the other hand, the output for an individual LHFO decreases with regulation. This result implies that the average size of an incumbent LHFO decreases with regulation.

In conclusion, environmental regulations are responsible for the exit of SHFO in the hog industry. Since regulation, leads to an increase in the average size of incumbent SHFOs, this could act as an entry barrier for potential SHFO entrants. If this is true, policies to save SHFOs should be targeted on SHFOs and not LHFOs as explained earlier. Regulation is also responsible for the reduction in the supply of hogs by SHFOs and LHFOs.

# Chapter 3: The Reorganization of U.S. Hog Production during the past two decades: What were the driving forces?

## 3.1. Introduction

This essay examines the importance of input availability, market attractiveness, agglomeration economies and environmental regulations on the reorganization of U.S. hog production for a panel of 22 U.S. hog producing states for the period 1994-2006. Results from this study suggest that:

1. Hog production in a state is positively affected by hog production in a nearby state, confirming the presence of agglomeration economies.
2. Environmental regulations and high corn prices have negative effects on state-level U.S. hog production.
3. High hog prices, favorable labor cost, and low land values attract hog production.
4. Transportation cost has no effect on hog production.

Based on these results, we conclude that agglomeration economies, regulation, market attractiveness and factors of production were important in shaping the reorganization of the U.S. hog industry for the period 1994-2006. The result on agglomeration economies contrasts the result by Roe, Irwin and Sharp (2002). They found a negative and statistically insignificant result based on two data points, 1992 and 1997. However, our result on agglomeration economies is consistent with their result based only on 1997 data. The result on regulation confirms the result that regulation slows down hog production (Metcalfe, 2001; Roe, Irwin and Sharp, 2002; Kuo, 2005; and Herath, Weersink, and Carpentier, 2005b).

The U.S. hog production industry has been the subject of structural changes, increase in environmental regulations, and geographical concentration during the past two decades. The industry, once dominated by small family farm operations, has evolved toward large specialized operations characterized by low costs (McBride and Key, 2003). The U.S. hog industry consisted of about 3 million farms during the 1950s. Of interest in this study are the factors behind the reorganization toward a more geographically concentrated industry over the last two decades.

U.S. hog production has become geographically concentrated within-and across states (Hubbell and Welsh, 1998; Herath, Weersink, and Carpentier, 2005a) during the past two decades. Hubbell and Welsh (1998) provided one of the earliest studies to formally address geographical concentration in the hog industry. Based on Theil's entropy index, showed that hog production is becoming more geographically concentrated at the national level and within states. Recently, Herath, Weersink, and Carpentier (2005a), making use of the Gini coefficient to measure concentration, confirmed the finding that hog production is becoming more concentrated within states. The changes associated with the hog industry becoming more geographically concentrated have led to a non-uniform interregional distribution of hogs (Hubbell and Welsh, 1998).

The geographical concentration of hog farms can have several lasting effects. Specifically, the changes in the hog production industry could: affect communities with changes in hog production levels; affect local supply and demand for key inputs and output; alter the economic base of communities; change the utilization of industry-specific infrastructure and services; and concentrate nutrients from animal manure in fewer locations causing adverse environmental consequences (Roe, Irwin, and Sharp, 2002).

The reorganization of an industry has been found to be affected by several factors including those internal to the firm; factors external to the firm but internal to the industry; and factors external to both the firm and the industry. Eberts and McMillen (1999) noted that firm-internal scale economies, industry internal scale economies (external economies to the firm), urbanization economies (external to both the firm and the industry), transportation costs, and regulatory stringency are important factors affecting firm location. The U.S. hog industry is not unique, such factors were found to be important to the U.S. hog industry by Roe, Irwin, and Sharp (2002) for the year 1997 and between the years1992 and 1997. These factors are more than likely to have played an important role in the reorganization of U.S. hog production within and across states witnessed over the past two decades.

This study addresses the importance of selected factors internal to the firm (factors of production), forces external to the firm but internal to the industry (the attractiveness of the market; agglomeration economies), and environmental regulation on the reorganization of U.S. hog production over time. Easy access to factors of production plays an important role on a farmer's decision on whether or not to operate a hog operation facility in a particular state. The variation of input costs may lead to variations in input use through time. Because such fluctuations are inevitable, the cost of the factors of production will pose a great challenge to existing and potential hog producers.

Because one of the main reasons why farmers engage in hog production is to make a profit, the attractiveness of the market plays an important role in determining whether to engage in hog production in a particular location or not. High market prices will more than likely attract more farmers to engage in hog production.

Agglomeration economies are economies external to the farm but internal to the hog production sector. In this study, agglomeration economies are defined in the context of localization economies as all the benefits that accrue to hog production in one state as a result of hog production in a nearby state. Such spillovers are likely to arise because the presence of other hog feeding operations facilitates a local, industry-specific infrastructure of service individuals and information, which enhances the performance of each operation through reduced transaction costs and improved diffusion of production, financial and marketing information (Eberts and McMillen, 1999).

Roe, Irwin and Sharp (2002) addressed the factors behind the reorganization of the hog production in a cross-section of counties for the years 1992 and 1997. They concluded that the presence of other swine farms has a positive effect on the inventory of hogs in a particular county based on a cross-section of counties and only 1997 data. They also found hog production in one county to be negatively correlated with hog production in a nearby county using the change in hog production between 1992 and 1997 as the dependent variable.

The other factor affecting the location of firms considered in this study is environmental regulation. Environmental regulations in the hog industry were introduced by the Federal government through the Clean Water Act of 1972. Most of the existing regulations, which vary across states, are enforced at the state-level (Metcalfe, 2000; and Centner, 2006). The variation in state-level policies regulating nonpoint-source pollution is mainly due to 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 (Sullivan, Vasavada and Smith, 2000).

Centner and Mullen (2002) argued that reductions in pollution could be a result of more effective enforcement of the existing regulations, rather than additional regulation. State-level environmental regulation stringency, as measured by the number of regulations, has been increasing over the years (Metcalfe, 2000). Environmental regulations are costly to the hog industry through regulation compliance costs (Metcalfe, 2001). Such regulations are believed to have contributed to several changes in the industry including changes in operation size, organizational structure, and technological base during the past decade (McBride and Key, 2003).

Several studies found evidence that environmental regulations have slowed down U.S. hog production (Metcalfe, 2001; Roe, Irwin and Sharp, 2002; Kuo, 2005; and Herath, Weersink, and Carpentier, 2005b).

Metcalfe (2001) concluded that regulation has a negative effect on hog production. His study also finds regulation affects small hog operations and has no effect on large farms. The result that regulation has a negative effect on hog production was confirmed by subsequent studies (Roe, Irwin and Sharpe, 2002; Herath, Weersink, and Carpentier, 2005b; Kuo, 2005). Kuo (2005) examined the determinants of small hog operation exits.

While the U.S. hog industry has received wide research attention in recent years, the importance of agglomeration economies on U.S. hog production has received limited attention. To the best of our knowledge, only a single study by Roe, Irwin and Sharp (2002) addressed the importance of agglomeration economies on U.S. hog production. Accounting for agglomeration economies by making use of the spatial lag serves two distinct purposes; firstly, it corrects spatial autocorrelation through the dependent variable and secondly, this variable captures whether agglomeration economies are present or not.

Because the spatial lag captures the existence or absence of spatial autocorrelation, studies that did not account for agglomeration economies in this manner did not control for spatial autocorrelation. If positive or negative spatial autocorrelation exists in the hog industry, results of such studies are likely to be unbiased but inefficient (Anselin, 1988).

The study by Roe, Irwin and Sharp (2002) is, however, limited in that it addresses the importance of agglomeration economies and regulation over a single year, 1997, and between two years, 1992 and 1997. Their finding that agglomeration economies existed in the hog industry in the year 1997 and that such economies did not exist between 1992 and 1997, suggests that agglomeration economies are not important over time. Their study captures the initial wave of the effects. The period of the 90s marks the beginning of the rush to tighten regulations in the U.S. hog industry. Sorting out the true effects as they exist and whether they have persisted or changed over time is important to fully understand such effects (Dean, Brown and Stango, 2000).

Such an analysis while useful in shedding light on the importance of agglomeration economies and other forces in the U.S. hog industry may not have captured the actual yearly changes of the importance of agglomeration economies. Since their study is a county-wide cross-sectional study, we argue that it misses the variation of the importance of agglomeration economies through time. We believe that the importance of agglomeration economies and regulation in hog production is not likely to remain the same over time as such spillovers are likely to change over time due to several factors including the changes in economy, e.g., recession, depression or boom. Economic hardships may disrupt or change the institutions central to the diffusion of production, marketing and financial information forcing farmers to go out of business.

While the foregoing studies have been useful in the understanding of issues in U.S. hog production, to our knowledge, no study has investigated the importance of the factors affecting hog production accounting for agglomeration economies in the context of panel data. The current study will make use of panel data from 22 U.S. major hog producing states to address the importance of input availability, market attractiveness, agglomeration economies and environmental regulations. In addition, the current study differs from prior studies in that it incorporates the most recent environmental stringency indices as well as a more current data set. The environmental indices used in prior studies were the 1994 and 1998 indices constructed by Metcalfe (2000) and the 2000 index constructed by Herath, Weersink, and Carpentier (2005b). These indices do not take into account the 2003 changes to the Clean Water Act of 1972, which we incorporate in our index calculations.

We further argue that evidence of positive spatial autocorrelation (agglomeration economies) at county-level hog production may or may not reflect state-level spatial effects. The evidence of county-level agglomeration economies results may have mostly captured linkages between counties within the same state, rather than counties across state boundaries. A hog producer in one state might share benefits of proximity to a hog producer in another state.  Even if county-level local economies were to reflect state-level agglomeration economies, our state-level analysis captures variations of agglomeration economies over time which is missing in prior studies. The importance of agglomeration economies is likely to change through time. Such changes can only be captured by making use of panel data or time series data. The foregoing argument provides a strong reason why the importance of addressing the factors affecting state-level hog production after accounting for spatial autocorrelation (agglomeration economies) over time is worth pursuing, henceforth, the focus of the current study.

To address this problem, we make use of a simple profit maximization model for a theoretical framework. The empirical analysis is based on three alternative models; ordinary least squares (OLS), two-stage least squares-spatial lag model (2SLS-SLM) and generalized method of moments-spatial autoregressive (GMM-SAR). Results from the three alternative models are then used to determine the model that best fits the data. While the effects of the other factors can be examined using all three models, agglomeration economies can only be examined using the 2SLS-SLM model. Our study also tests for spatial autocorrelation through the error term using the GMM-SAR model. We discuss more on how we come up with the best model for the data in the next section.

The rest of the study is organized as follows: Section 2 presents literature review on spatial models; Section 3 presents the theoretical model; Section 4 presents the empirical model and data; Section 5 presents the results; and Section 6 provides the results discussion and conclusions.

### 3.2. Review of Spatial models

Cross-sectional models that assume that the dependent variable corresponding to each cross-sectional unit depends (in part) on a weighted average of that dependent variable corresponding to neighboring cross-sectional units are called spatial autoregressive models (Anselin, 1988). The weighted average itself is referred to as a spatial lag of the dependent variable. According to Ord (1975) and Anselin (1988), the spatially lagged dependent variable is usually correlated with the error term rendering the ordinary least squares estimator inconsistent.

The standard spatial autoregressive model, popularly known as the spatial lag model (SLM) is defined as follows:

$$(33) \qquad \begin{array}{l} y = \lambda W y + X\beta + \mu \\ \varepsilon \sim N(0, \sigma^2 I_n) \end{array}, \; |\lambda| < 1,$$

where $y$ is the n x 1 vector of observations on the dependent variable, $X$ is the n x k matrix of observations on k exogenous variables, $W$ is an n x n spatial weighting matrix of known constants, $\beta$ is the k x 1 vector of regression parameters, $\lambda$ is a scalar autoregressive parameter , and $\mu$ is the n x 1 vector of disturbances.

An alternative way is to use the spatial autoregressive (SAR) model, which operates through the spatial error structure. This model is applied if the researcher believes that the spatial dependence stems from omitted variables that are related to each other over space. The model is defined as follows:

$$(34) \qquad \begin{array}{l} y = X\beta + \mu \\ \mu = \rho W \mu + \varepsilon \quad , |\rho| < 1 \quad , \\ \varepsilon \sim N(0, \sigma^2 I_n) \end{array}$$

where $\mu$ is the n x 1 vector of disturbances and $\varepsilon$ is the n x 1 vector of innovations. The other parameters are as defined in the model in (33). In the SAR model, the parameters of interest are $\rho$ and $\sigma^2$. In addition to the (quasi) maximum likelihood and the moments estimator of $\rho$ suggested by Ord (1975), Kelijian and Prucha (1999) proposed a “generalized” moments (GMM) approach for the estimation of the spatial autoregressive parameter, $\rho$ , which they proved to be as efficient as the popularly used standard maximum likelihood estimator.

The models in (33) and (34) are special cases of the more general model referred to as a spatial autoregressive model with autoregressive disturbances by Kelijian and Prucha (1998) as defined below:

$$(35) \quad \begin{aligned} y &= \lambda Wy + X\beta + \mu \\ \mu &= \rho M\mu + \varepsilon \\ \varepsilon &\sim N(0,\sigma^2 I_n) \end{aligned} \quad ,$$

where $y$ is the n x 1 vector of observations on the dependent variable, $X$ is the n x k matrix of observations on k exogenous variables, $W$ and $M$ are n x n spatial weighting matrices of known constants, $\beta$ is the k x 1 vector of regression parameters, $\lambda$ and $\rho$ are scalar autoregressive parameters , $\mu$ is the n x 1 vector of disturbances, and $\varepsilon$ is a nx1 vector of innovations. By setting $\rho = 0$, the model in (35) reduces to the model represented in (33), and setting $\lambda = 0$ yields the model in (34). In the more general model, the lack of spatial correlation results when $\lambda = \rho = 0$.

Kelijian and Prucha (1998) proposed a generalized spatial two-stage least squares (GS2SLS) procedure for estimating the spatial autoregressive model with autoregressive disturbances. Their model allowed for the possibility that the spatial weight matrix associated with the error term and that associated with the dependent variable is the same, that is, $M = W$. The generalized spatial two-stage least squares approach is a three-step procedure. In the first step the regression model in (35) is estimated by two-stage least squares (2SLS) using some instruments.

The instrument matrices used are a subset of the linearly independent columns of, $(X, WX, W^2X, ..., MX, MWX, MW^2X)$ ,where the subset contains the linearly independent columns of $(XM, X)$. In the second step the autoregressive parameter ρ is estimated by generalized method of moments (GMM) procedure suggested by Kelijian and Prucha (1995). According to Kelijian and Prucha, the GMM estimation procedure yields a consistent estimator of ρ, whether or not the weight matrices for the dependent variable and the error term are equal. Finally, the regression model in (35) is re-estimated by 2SLS after transforming the model using the Cochrane-Orcutt type transformation to account for the spatial correlation as follows:

First equation (35) is rewritten as follows:

$$(36) \qquad \begin{aligned} y &= Z\delta + \mu \\ \mu &= \rho W\mu + \varepsilon \end{aligned},$$

where $Z = (X, Wy)$ and $\delta = (\beta', \lambda)'$. A Cochrane-Orcutt type transformation to this model yields:

$$(37) \qquad y^* = Z^*\delta + \varepsilon,$$

where $y^* = y - \rho Wy$ and $Z^* = Z - \rho WZ$. In general, the foregoing spatial models, (33), (34), and (35) are the popularly used models in spatial econometrics today.

**3.3. Theoretical Model**

We present a simple profit maximization model for our theoretical framework. Hog production is assumed to utilize land, feed, labor, transportation, and the environment as inputs. The production function associated with hog production is therefore given by: $y = f(C, L, N, T, E)$, where $y$, $C$, $L$, $N$, $T$ and $E$ represent the quantity of output, the quantity of corn feed, the quantity of land, the transportation input and the quantity of the environmental input, respectively. The environment is treated as an input in this model because hog producers incur a cost to utilize the environment in disposing of hog waste including manure.

The production of hogs is costly, and the total cost of production is given by $V = w_C C + w_L L + w_N N + w_T T + w_E E$ where, $V$ , $w_C$, $w_L$, $w_N$, $w_T$ and $w_E$ represent total cost, hog price, price of feed, price of labor, price of land, transportation cost and environmental cost, respectively. The firm's profit maximization problem in each state is given by:

$$\max_{C,L,N,T,E} \pi = py - w_C C - w_L L - w_N N - w_T T - w_E E \quad (38)$$

Solving the problem above yields the following first order conditions:

$$\begin{aligned} pf_C - v_{w_C} &= 0 \\ pf_L - v_{w_L} &= 0 \\ pf_N - v_{w_N} &= 0 \\ pf_E - v_{w_E} &= 0 \\ pf_T - v_{w_T} &= 0 \end{aligned} \quad (39)$$

Solving the above system of first-order conditions provides the following input or factor demand functions:

$$\begin{aligned} C^* &= C(p, w_C, w_L, w_N, w_T, w_E) \\ L^* &= L(p, w_C, w_L, w_N, w_T, w_E) \\ N^* &= N(p, w_C, w_L, w_N, w_T, w_E) \\ T^* &= T(p, w_C, w_L, w_N, w_T, w_E) \\ E^* &= E(p, w_C, w_L, w_N, w_T, w_E) \end{aligned} \quad (40)$$

By plugging in the input demand functions back into the profit function yields the indirect profit function given by:

$$\pi^* = \pi(p, w_C, w_L, w_N, w_T, w_E) \quad (41)$$

The usual properties of the profit function are assumed to hold. The profit function is assumed to be homogenous of degree one in output and input prices. The partial derivative of the indirect profit function with respect to the output price, $\frac{\partial \pi^*}{\partial p} = y > 0$. This inequality satisfies the property that the profit function is non-decreasing in output price. The partial derivatives of the indirect profit function with respect to input prices are negative by the envelope theorem, that is, $\frac{\partial \pi^*}{\partial w_i} = -i^* < 0$, for $i = C, L, N, T$ and $E$.

By Hotelling's Lemma, we can derive the optimal hog supply function for hogs from the indirect profit function given in (41), i.e. $\frac{\partial \pi^*}{\partial p} = y^*$. The hog supply function is a function of the output price and all input prices. We can write the hog supply function as follows:

(42) $$y^* = y(p, w_C, w_L, w_N, w_T, w_E).$$

The effect of environmental costs on hog production will be captured by how environmental stringency affects hog supply. Given that we model environmental regulations as an input in the production of hogs, it follows that the comparative statics results of this effect on profit and the optimal hog supply are given by $\frac{\partial \pi^*}{\partial w_E} < 0$, and $\frac{\partial y^*}{\partial w_E} < 0$, respectively. This stems from one of the properties of the profit and supply functions that they are non-increasing in input prices. In Section 4 we present an empirical model that estimates the optimal supply function. Given the above comparative static results, theory predicts that the effect of environmental regulations on hog production is negative.

### 3.4. Empirical Model

In this study we analyze the effect of environmental regulations on hog production for a panel consisting of 22 major hog producing states in the U.S. For an empirical framework we estimate models based on pooled OLS, the 2SLS-SLM in (1) using the two-stage least squares procedure developed by Kelijian and Prucha (1998), and the GMM-SAR model in (2) using the generalized method of moments (GMM) developed by Kelijian and Prucha (1999). We estimate and compare results for the Midwest, Northern-and Southern hog producing states to those based on all the 22 states.

If the 2SLS-SLM and the GMM-SAR models show that spatial autocorrelation through both the dependent variable and the error term exist, we will turn to the GS2SLS model which captures both spatial measures in a single model. If results show that spatial autocorrelation exists only through the dependent variable, then the 2SLS-SLM model will be the best model for the data and the GMM-SAR model will be the best model for the data if results show that spatial autocorrelation exists only through the error term.

If both spatial autocorrelation parameters, one through the dependent variable and the other through the error term, are not statistically significant, then the OLS model estimates will be reliable. Our strategy is to first check for the importance of all possible spatial autocorrelation sources to come up with the model that best explains the data.

Since the dimensions of the components of the spatial models in (1), (2) and (3) are for cross-sectional data, we redefine their components to suit the panel data model as follows: the dependent variable, y, is the nt x 1 vector of observations on hog output; $X$

is the nt x k matrix of observations on k exogenous variables; $W$ is an nt x nt spatial weighting matrix of known constants, $\beta$ is the k x 1 vector of regression parameters, $\lambda$ is a scalar autoregressive parameter , $\mu$ is the nt x 1 vector of disturbances, and $\varepsilon$ is the nt x 1 vector of innovations. For the spatial weighting matrix, we use a standardized first-order spatial contiguity matrix. We assign a "1" for states that share a common border and a "0" for states that do not share a common border. Notice that a state cannot be its own neighbor, henceforth; the elements on the main diagonal of the first-order contiguity matrix are all set to zero. The spatial weight matrix is standardized by normalizing so that row sums add to unity (LeSage, 1997). Several studies including Pan and LeSage (1995) and LeSage (1997), have used the first-order contiguity matrix in spatial econometrics.

The menu of spatial models considered in this study is given below:

$$(33') \quad \begin{aligned} &y = \lambda W y + X\beta + \mu \\ &\mu \sim N(0, \sigma^2 I_{nt}) \end{aligned} \quad , |\lambda| < 1,$$

$$(34') \quad \begin{aligned} &y = X\beta + \mu \\ &\mu = \rho W \mu + \varepsilon \quad , |\rho| < 1 \quad , \\ &\varepsilon \sim N(0, \sigma^2 I_{nt}) \end{aligned}$$

$$(37') \qquad y^* = Z^* \delta + \varepsilon ,$$

where models in (33'), (34') and (37') are panel data versions for models in (39), (40) and (43), respectively.

The dependent and independent variables used in this study are defined next. The dependent variable, y, is the **state level percentage share of U.S. total hog production**. The state level percentage share of U.S. total hog production is used to capture state-level hog supply as in Metcalfe (2001). Roe, Irwin and Sharpe used the logarithm of U.S. hog production as the dependent variable which is not far from what we use here.

The specific independent variables contained in the X matrix include: hog output price; the cost of factors of production variables, corn price, farm labor, transportation cost, land price; and the environmental input cost (index).

The **hog output price** is endogenous in our model as it is associated with the demand side of the industry. We make use of the predicted values for hog output price to take care of the endogeneity problem as in Metcalfe (2001). A positive sign is expected since the higher the price of hogs, the more hog suppliers are willing to supply hogs.

**Corn price** reflects the cost of the corn input in hog production which constitutes a greater percentage of hog feed. Several studies used corn price as an input to study the effect of environmental regulations on hog production (Metcalfe, 2001; Roe, Irwin and Sharp, 2002). We expect a negative sign on this variable since the higher the corn feed input price the lower the number of hogs hog producers are willing to supply.

To capture the cost of **farm labor** in hog production, we use farm labor wages. Specifically we use the average hourly state-level wages as a proxy for farm labor wages. Metcalfe (2001), and Herath, Weersink, and Carpentier (2005b) also used farm labor wages to capture the cost of farm labor input. A negative sign on this variable is expected, that is, the higher the farm labor cost, the lower the number of hogs hog producers are willing to supply.

**Land price** captures the cost of land input in hog production. We use farm land price to capture land input cost in the same manner as in Metcalfe (2001), and Herath, Weersink, and Carpentier (2005b). We expect the coefficient on the land price variable to be negative. A negative sign shows that hog farmers supply fewer hogs as the price of land input goes up.

**Transportation cost** reflects the cost of transport input in hog production. We capture transportation cost using the price of unleaded gas. Energy price is a popular proxy for transportation cost in studies in livestock industry studies as well as meatpacking industry studies, e.g. Azzam (1997). Metcalfe (2001) and Herath, Weersink, and Carpentier (2005b) used the price of gas as a proxy for transportation cost in hog related studies. A negative sign is expected for this variable since it is a cost of an input in the hog production process.

For the **environmental index** variable, we make use of a time series of qualitative environmental stringency indices constructed in the same manner as in Metcalfe (2000). Qualitative environmental stringency indices have been widely used in hog industry studies (Metcalfe, 2001; Roe, Irwin, and Sharp, 2002; Herath, Weersink, and Carpentier, 2005b). Specifically, we construct the indices for the years 2003 to 2006, and we combine these with indices constructed in prior studies (Metcalfe ,2000; and Herath, Weersink, and Carpentier, 2005b), to complete the 1994-2006 time series for each of the top 10 hog producing states.[25]

Because stringency indices used in prior studies are based on different measures and judgments, we make use of the method employed by Herath, Weersink, and Carpentier (2005b), to go around the problem of different stringency indices that exist in the literature. The methodology uses the ratio of the state value divided by the mean of the state's regulation stringency for the period in the sample. If the value of this ratio is greater than 1, equals 1 and is less than 1, that state has above average, average and

[25] Environmental stringency indices based on Metcalfe (2000), Herath, Weersink, and Carpentier (2005b), and those constructed in this study are documented in Table A-1 in Appendix A. The construction of the 2003-2006 stringency indices is presented in Table A-2 in Appendix A.

below average stringency level, respectively. This is one way to make the different stringency measures comparable.

Environmental stringency is endogenous in our model because regulations may increase in states that are experiencing increasing hog production while states with low environmental regulations may realize increased hog production (Metcalfe, 2001). Predicted values of the environmental stringency measure are used in order to take care of this endogeneity. A negative sign is expected on this variable as suggested by theory, $\frac{\partial y^*}{\partial w_E} < 0$, as it enters the hog production as an input. Specifically, in this model the indices reflect an environmental compliance cost.

**Spatial lag** is used as a proxy for agglomeration economies. We use this variable in the same manner as in Roe, Irwin and Sharp (2002). A positive (negative) and statistically significant sign on the spatial lag variable suggests the presence (absence) of agglomeration economies in the hog industry. A positive or a negative sign is expected.

### 3.4.1. Data

The study uses data for 22 major U.S. hog producing states for the years 1994 through 2006. We also estimate regressions for the Northern producing states, Southern hog producing states and the Midwest hog producing states. Results for the Northern, Southern and Midwest producing states are of interest in this study for three reasons.[26] First, regional spatial dependence is likely to be different from the spatial dependence we observe when all the 22 states are considered. Secondly, the Midwest-and Northern states account for most of the corn production in the U.S. and corn is a major input in hog

[26] It is important to note that the Midwest and Northern hog producing states are basically the same with the exception that Northern hog producing states include Pennsylvania.

production, and thirdly, the Midwest-and Northern states include eight of the top 10 U.S. hog producing states; Illinois, Indiana, Iowa, Kansas, Michigan, Minnesota, Missouri, Nebraska, and Ohio. The top 10 U.S. hog producing states account for about 85% of total U.S. hog production. The states and regions considered in this study, data source and description, and the descriptive statistics are given in tables 14, 15, and 16, respectively.

**Table 14: Units of study**

| **Unit of study** | **States** |
|---|---|
| **22 major producing states** | Arkansas, Colorado, Georgia, Illinois, Indiana, Iowa, Kansas, Kentucky, Michigan, Minnesota, Missouri, Nebraska, North Carolina ,Ohio, Oklahoma, Pennsylvania, South Dakota, Tennessee, Texas, Utah, Virginia, and Wisconsin |
| **Midwest states** | Illinois, Indiana, Iowa, Kansas, Michigan, Minnesota, Missouri, Nebraska, Ohio, South Dakota, and Wisconsin |
| **Northern states** | Illinois, Indiana, Iowa, Kansas, Michigan, Minnesota, Missouri, Nebraska, Ohio, Pennsylvania, South Dakota, and Wisconsin |
| **Southern states** | Arkansas, Colorado, Georgia, Kentucky, North Carolina , Oklahoma, Tennessee, Texas, Utah, and Virginia |

**Table 15: Variable Definition and Data Sources**

| Definition of variables | Source |
|---|---|
| Hog farms total inventory | USDA-NASS |
| Land value: Dollars/acre | NASS Agricultural Prices Summaries- USDA |
| Hog price: Dollars/Cwt | NASS Agricultural Prices Summaries- USDA |
| Corn price: Dollars/Bushel | NASS Agricultural Prices Summaries- USDA |
| Transportation cost: cents per gallon: | Energy Information Administration |
| Environmental Stringency | 1993-2002: Metcalfe(2000) and Herath, Weersink, and Carpentier (2005)<br>2003-2006 indices: author's estimates |
| Farm labor: Dollars/Hour | Farm labor-NASS-USDA |
| Cattle all beef price: Dollars/Cwt | NASS Agricultural Prices Summaries- USDA |
| Income: personal per capita income/Dollars | Almanac of the 50 States Information Publications |
| Population density(pd): persons per square mile | Almanac of the 50 States Information Publications |

Cwt refers to 100 weight

**Table 16: Descriptive statistics**

| Variable | Mean | StdDev | Minimum | Maximum |
|---|---|---|---|---|
| Output% | 4.40 | 5.84 | 0.07 | 27.68 |
| Hog price | 42.13 | 8.72 | 27.47 | 83.51 |
| Corn price | 2.43 | 0.56 | 1.5 | 4.38 |
| Transport | 101.27 | 31.99 | 58.53 | 182.71 |
| Labor | 7.88 | 0.80 | 6.16 | 9.96 |
| Land | 1585.57 | 817.92 | 332.32 | 4185.42 |
| Population density | 110.56 | 78.05 | 9.5 | 280.3 |
| Environmental stringency | 1.00 | 0.52 | 0.2 | 2.38 |
| Cattle price | 65.49 | 10.83 | 32.76 | 96.99 |
| Per capita income | 27131.3 | 2981.53 | 20329.36 | 35334.31 |

### 3.5. Empirical Results and Discussion

Results for the 22 major hog producing states, Midwest hog producing states, Northern hog producing states, and Southern hog producing states are given in Tables 17, 18, 19 and 20, respectively.

**Table 17: Results for the 22 major hog producing states**

| | 2 SLS -S LM | | GMM-SAR | | OLS | |
|---|---|---|---|---|---|---|
| Variable | Coefficient | T-ratio | Coefficient | T-ratio | Coefficient | T-ratio |
| Constant | -73.50 | -6.44*** | -93.83 | -7.48*** | -115.83 | -9.51*** |
| Index | -58.50 | -7.75*** | -70.34 | -8.86*** | -86.77 | -10.78*** |
| Hog price | 20.04 | 3.86*** | 25.19 | 4.60*** | 33.77 | 5.89*** |
| Corn price | -33.81 | -6.68*** | -39.86 | -7.57*** | -49.14 | -8.88*** |
| Transport | -1.66 | -0.64 | -3.20 | -1.21 | -8.00 | -2.77*** |
| Labor | 31.47 | 4.08*** | 47.99 | 5.53*** | 64.21 | 7.97*** |
| Land | 7.23 | 6.43*** | 8.18 | 6.82*** | 9.22 | 7.30*** |
| Agglom | 0.57 | 10.41*** | | | | |
| Rho | | | 0.37 | 0.09 | | |

Note for Table 17: The dependent variable is the state-level percentage share of total U.S. hog production. P values are indicated as ***0.01, **0.05 and *0.10.

Table 17 provides results for the 22 major hog producing states based on three different models, namely; 2SLS-SLM, GMM-SAR and OLS. The 2SLS-SLM results show that the coefficient of **Agglom** is positive and statistically significant while the coefficient of **Rho** is positive and statistically insignificant. Based on the GMM-SAR model results, we reject the null hypothesis that spatial autocorrelation through the error term exists at the state-level. Since there is evidence of positive spatial autocorrelation, the OLS model results are unbiased but inefficient (Anselin, 1988). We therefore conclude that the model that best explains our data is the 2SLS-SLM.

Based on the 2SLS-SLM results, the coefficients on **hog price**, **corn price**, and **transport** have the expected signs. The coefficient on **hog price** suggests that hog production increased with an increase in the price of hogs. The coefficients on **corn price** and **transport** suggest that high prices of these factors of production serve to deter hog production in the 22 major hog producing states. The coefficients on **labor** and **land** have unexpected positive and statistically significant signs. The coefficient on **labor** suggests that the presence of a large pool of labor or relatively low farm labor wages serve to attract hog production. The positive coefficient on **land** suggests that land values are favorable for hog production probably due to the availability of vast farming land.

The positive and statistically significant coefficient on **Agglom** suggests that production in a state is positively affected by hog production in a nearby state, confirming the existence of agglomeration economies in the U.S. hog industry. The coefficient on **index** is negative and statistically significant. This result suggests that environmental regulation has a negative effect on hog production.

**Table 18: Midwest hog producing states**

| | 2 SLS Spatial Lag | | GMM-SAR | | OLS | |
|---|---|---|---|---|---|---|
| Variable | Coefficient | T-ratio | Coefficient | T-ratio | Coefficient | T-ratio |
| Constant | -112.83 | -6.22*** | -104.35 | -5.21*** | -154.82 | -8.67*** |
| Index | -116.10 | -9.16*** | -116.05 | -9.16*** | -149.46 | -12.48*** |
| Hog price | 21.95 | 2.48*** | 7.69 | 0.74 | 35.07 | 3.74*** |
| Corn price | -62.31 | -8.69*** | -63.27 | -8.86*** | -75.61 | -10.23*** |
| Transport | 2.10 | 0.55 | 6.27 | 1.47 | -0.79 | -0.19 |
| Labor | 62.38 | 5.33*** | 71.34 | 5.41*** | 87.27 | 7.42*** |
| Land | 10.96 | 6.51*** | 12.86 | 6.37*** | 12.75 | 6.98*** |
| Agglom | 0.35 | 5.03*** | | | | |
| Rho | | | 0.48 | 0.13 | | |

Note for Table 18: The dependent variable is the state-level percentage share of total U.S. hog production. P values are indicated as ***0.01, **0.05 and *0.10.

Results for the Midwest hog producing states also show that the best model for the data is the 2SLS-SLM. Based on 2SLS-SLM results, hog production in a state is positively affected by hog production in a nearby state and environmental regulation has a negative effect on hog production. This result suggests that agglomeration economies are important for the Midwest hog producing states. The coefficients on **hog price**, and **corn price** have the expected signs, suggesting that hog price attracts hog production while the corn input cost deters hog production in the Midwest. The coefficient on

**transport** is positive and statistically insignificant. This result suggests that transport cost has no effect on hog production in the Midwest. The coefficients on **land** and **labor** have positive and statistically significant signs suggesting that the costs of these factors of production are favorable for hog production in the Midwest. The coefficient on **index** is negative and statistically significant. This result suggests that environmental regulations have a negative effect on hog production.

**Table 19: Northern hog producing states**

| | 2 SLS Spatial Lag | | GMM-SAR | | OLS | |
|---|---|---|---|---|---|---|
| Variable | Coefficient | T-ratio | Coefficient | T-ratio | Coefficient | T-ratio |
| Constant | -95.24 | -6.21*** | -105.20 | -5.91*** | -146.93 | -8.49*** |
| Index | -86.27 | -7.84*** | -105.07 | -9.37*** | -137.83 | -12.46*** |
| Hog price | 20.02 | 2.66 | 13.76 | 1.42 | 34.37 | 3.77*** |
| Corn price | -43.19 | -6.87*** | -51.52 | -8.04*** | -68.72 | -10.22*** |
| Transport | 0.60 | 0.19 | 1.87 | 0.49 | -2.28 | -0.58 |
| Labor | 51.66 | 5.53*** | 68.67 | 6.73*** | 80.77 | 7.54*** |
| Land | 8.13 | 5.27*** | 11.57 | 6.01*** | 12.78 | 7.18*** |
| Agglom | 0.52 | 7.92*** | | | | |
| Rho | | | 0.45 | 0.12 | | |

Note for table 19: The dependent variable is the state-level percentage share of total U.S. hog production. P values are indicated as ***0.01, **0.05 and *0.10.

The 2SLS-SLM is the best model for the regressions involving the Northern U.S. hog producing states. The coefficient on **Agglom** is positive and statistically significant confirming the presence of agglomeration economies in the Northern U.S. hog producing states. The coefficients on **hog price**, and **corn price**, have the expected negative signs. The coefficients on **labor** and **land** have unexpected positive signs and are statistically significant. The coefficient on **transport** is positive and statistically insignificant. The coefficient on **index** is negative and statistically significant. Results suggest that **hog price**, **labor** and **land** serve to attract hog production in the Northern U.S. hog producing states while **corn price** and environmental regulations (index) have negative effects on hog production for Northern U.S. hog producing states.

**Table 20: Southern hog producing states**

| | 2 SLS Spatial Lag | | GMM-SAR | | OLS | |
|---|---|---|---|---|---|---|
| Variable | Coefficient | T-ratio | Coefficient | T-ratio | Coefficient | T-ratio |
| Constant | -106.48 | -4.88*** | -77.61 | -3.24*** | -130.64 | -5.35*** |
| Index | -112.30 | -9.14*** | -104.96 | -8.26*** | -136.32 | -10.42*** |
| Hog price | 19.04 | 1.71 | -1.33 | -0.11 | 20.38 | 1.60 |
| Corn price | -56.12 | -8.09*** | -51.97 | -7.61*** | -69.21 | -9.33*** |
| Transport | 2.04 | 0.47 | 7.81 | 1.62 | 3.12 | 0.63 |
| Labor | 57.30 | 4.72*** | 55.56 | 4.15*** | 75.48 | 5.66*** |
| Land | 11.81 | 5.86*** | 12.70 | 4.96*** | 14.83 | 6.70*** |
| Agglom | 0.37 | 5.34*** | | | | |
| Rho | | | 0.54 | 0.14 | | |

Note for Table 20: The dependent variable is the state-level percentage share of total U.S. hog production. P values are indicated as ***0.01, **0.05 and *0.10.

The 2SLS-SLM is the best model for regressions involving the Southern U.S. hog producing states. The coefficient on **Agglom** is positive and statistically significant confirming the presence of agglomeration economies in the Southern U.S. hog producing states. Similar to the results for the Northern states, the coefficients on **hog price**, and **corn price**, have the expected negative signs. The coefficients on **labor** and **land** have unexpected positive signs and are statistically significant. The coefficient on **transport** is positive and statistically insignificant. The coefficient on **index** is negative and statistically significant and that environmental regulation has a negative effect on hog production.

We established that the model that describes our data better for the 22 states, Midwest states, Northern states and Southern states is the 2SLS-SLM. We therefore document only the 2SLS-SLM results already reported in Tables 17-20. These results are given in Table 21 below.

**Table 21: 22 States and Regional 2SLS-SLM Results**

| | All states | | Midwest | | North | | South | |
|---|---|---|---|---|---|---|---|---|
| Variable | Coeff | T-ratio | Coeff | T-ratio | Coeff | T-ratio | Coeff | T-ratio |
| Constant | -73.50 | -6.44*** | -112.83 | -6.22*** | -95.24 | -6.21*** | -106.48 | -4.88*** |
| Index | -58.50 | -7.75*** | -116.10 | -9.16*** | -86.27 | -7.84*** | -112.30 | -9.14*** |
| Hog price | 20.04 | 3.86*** | 21.95 | 2.48*** | 20.02 | 2.66 | 19.04 | 1.71 |
| Corn price | -33.81 | -6.68*** | -62.31 | -8.69*** | -43.19 | -6.87*** | -56.12 | -8.09*** |
| Transport | -1.66 | -0.64 | 2.10 | 0.55 | 0.60 | 0.19 | 2.04 | 0.47 |
| Labor | 31.47 | 4.08*** | 62.38 | 5.33*** | 51.66 | 5.53*** | 57.30 | 4.72*** |
| Land | 7.23 | 6.43*** | 10.96 | 6.51*** | 8.13 | 5.27*** | 11.81 | 5.86*** |
| Agglom | 0.57 | 10.41*** | 0.35 | 5.03*** | 0.52 | 7.92*** | 0.37 | 5.34*** |

Note for Table 21: The dependent variable is the state-level percentage share of total U.S. hog production. P values are indicated as ***0.01, **0.05 and *0.10.

It is important to compare the regional variation of the results for the prime variables of interest. Results in Table 21 show that on average, regulation affects Midwest states the most, followed by the Southern states and the Northern states. On average, environmental regulation affects the 22 major hog producing states, the least. In a nutshell, results confirmed that regulation has a negative effect on U.S. hog production regardless of the region.

With regard to agglomeration economies, results show that agglomeration economies are strongest for the 22 major hog producing states. Agglomeration economies for Northern hog producing states are greater than agglomeration economies for the Southern hog producing states. The Southern hog producing states have greater agglomeration economies when compared to the Midwest hog producing states. This suggests that hog production in a state is more positively related to that of a neighboring state, when the 22 major producing states are considered. However, results confirmed that agglomeration economies play a major role in U.S. hog production regardless of the region being considered.

Results on the effect of the cost of factors of production on the U.S. hog production industry suggest that: transport cost has no effect on hog production; land value and labor cost have a positive effect on hog production; and the cost of corn input has a negative effect on hog production for the 22 major hog producing states, Northern hog producing states, Southern hog producing states, and the Midwest hog producing states.

**3.6. Conclusions**

This study examined the importance of input availability, market attractiveness, agglomeration economies and state-level environmental regulations on 22 major U.S. hog producing states for the period 1994-2006. The 22 major U.S. hog producing states are further broken down into Midwest, North, and South U.S. regions. The theoretical model is based on a simple profit maximization model which treats the environment as an input in hog production. To come up with the empirical model that best explains our data, models based on Pooled OLS, 2SLS-SLM and GMM-SAR were estimated.

The 2SLS-SLM results suggest that hog production in a state is positively affected by hog production in a nearby state over time. This result is true for the 22 major hog producing states, Northern hog producing states, Southern hog producing states and Midwest hog producing states. This result confirms the importance of agglomeration economies in the U.S. hog industry. This is a similar result to the county-level cross-section result based on 1997 data found by Roe, Irwin, and Sharp (2002). However, this result contrasts with the result by Roe, Irwin, and Sharp (2002) on changes in regulation between the years1992-1997. Indeed, their result may have failed to capture the changes in regulation over time.

The GMM-SAR model results show that the error spatial parameter is statistically insignificant in all the GMM-SAR based models. Based on the GMM-SAR model results, we reject the null hypothesis that spatial autocorrelation through the error term exists at the state-level, confirming the conclusion by Roe, Irwin, and Sharp (2002).The presence of agglomeration economies present in the 2SLS-SLM makes the OLS results are unbiased but inefficient, Anselin (1988). We therefore conclude that the model that best explains our data is the 2SLS-SLM.

The 2SLS-SLM results suggest that environmental regulations have a negative and statistically significant effect on U.S. hog production. This result holds for the 22 major hog producing states, Northern hog producing states, Southern producing states and the Midwest hog producing states. This confirms the robustness of this common result in studies that have addressed the effect of environmental regulations in the U.S. hog industry, Metcalfe (2001). This result suggests that tightening or increasing state-level environmental regulations is one way to implement policies designed to reduce environmental pollution emanating from the hog production industry.

An area for further investigation would be trying to answer the question: Is environmental regulation in a state influenced by regulation in nearby states? States may consider regulation in nearby state as a way to reduce the time cost of coming up with new regulations or to make their regulation more stringent than those of nearby states for political reasons.

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## Appendix A: Understanding state-level Environmental Regulations on Hog Farms in the Top 10 Hog Producing States

All the states in the U.S. are required to adopt the federal regulations passed in 1972. State governments for states which are highly dependent on animal production are trying to balance the environmental and economic implications of new regulations (Metcalfe, 2000). The EPA authorizes the NPDES permits to state governments which allow the states to do most of the permitting, administrative and enforcement aspects of the NPDES program. According to Copeland (2008), currently 45 states have been authorized to administer the NPDES permit program and Oklahoma has been authorized to issue permits for most sources but not for CAFOs. Seven of the forty five states regulate CAFOs through the NPDES program only, thirty two states administer the NPDES program in addition they also require other state permits, licenses, or authorizations such as construction and operation permits, and six states regulate CAFOs under separate non-NPDES programs.

States which are not authorized to administer the NPDES program include Alaska, Arizona, Idaho, Maine, Massachusetts, New Hampshire and New Mexico. In these states the EPA retains the responsibility to issue CAFO permits. All the top 10 hog producing states are authorized to run the NPDES program by the EPA. Under the CWA, states are allowed to impose additional requirements for permits and freedom to regulate other types of operations not covered under the NPDES. In this section we will focus on the top 10 hog producing states in the U.S.

### A.1. Illinois

The Illinois Department of Agriculture (IDA) administers the Livestock Management Facilities Act of 1996 that regulates the siting and construction of livestock production facilities across the state and includes requirements regarding facility setback distances, facility design and construction standards, waste management plans, and livestock manager certification.

To construct a livestock management facility or a livestock waste handling facility, the owner has to notify the IDA prior to construction. This is required in order to determine setbacks in compliance with setback distances and other location requirements. Livestock waste handling facilities other than earthen livestock waste lagoons are required to meet certain design standards to ensure that they are strong and the load they are capable of handling and that they are compatible with their intended use. The state regulates the siting of animal waste disposal facilities. New livestock management facilities and livestock waste handling facilities constructed after January 1, 2001 shall be subject to the additional construction requirements and siting prohibitions. These include:

i. No new non-lagoon livestock management facility or livestock waste handling facility may be constructed within the floodway of a 100-year floodplain.
ii. A new non-lagoon livestock waste handling facility constructed in a karst[27] area shall be designed to prevent seepage of the stored material into groundwater
iii. A new non-lagoon livestock waste handling facility constructed in an area where aquifer material is present within 5 feet of the bottom of the facility shall be designed

[27] Karst means an area with a land surface containing sinkholes, large springs, disrupted land drainage, and underground drainage systems associated with karstified carbonate bedrock and caves or a land surface without these features but containing a karstified carbonate bedrock unit generally overlain by less than 60 feet of unconsolidated materials. Karstified Carbonate Bedrock" means a carbonate bedrock unit (limestone or dolomite) that has a pronounced conduit or secondary porosity due to dissolution of the rock along joints, fractures, or bedding plains.

to ensure the structural integrity of the containment structure and to prevent seepage of the stored material to groundwater.

An owner or operator of a livestock waste handling facility should report to the Agency any release of livestock waste from a livestock waste handling facility or from the transport of livestock waste within 24 hours after discovery of the release. Reporting is not required in the case of a release of less than 25 gallons that is not released to the waters of the State or from a controlled and recovered release during field application. Failure to report is subject to a fine which gets larger as the number of failing to report violations increase.

The livestock management facility owner or operator has to comply with the requirements for handling, storing, and disposing of livestock wastes as set by the Illinois Environmental Protection Act concerning agriculture related pollution. The livestock management facility owner or operator of a facility of 1,000 or greater animal units but less than 5,000 animal units shall prepare and maintain a general waste management plan file at the livestock management facility. An operator of a facility with 5000 animal units and above has to have his/her waste management plan approved by the IDA before operation of the facility. Owners of livestock facilities are required to upgrade their facilities as the number of animal units change over time and also incorporate the requirements of the regulations that govern them.

The IDA inspects the construction site prior to construction, during construction, and within 10 business days following receipt of the certification of compliance. The person making any inspection shall comply with reasonable animal health protection procedures as requested by the owner, operator, or certified livestock manager. The IDA will seek an injunction in circuit court to prohibit the operation of the facility until construction and certification of the livestock waste handling facility are in compliance with the rules if in any case the owner violates any agreement of compliance. The IDA also regulates odor from animal feeding operations. Operators of livestock waste handling facilities are required to practice odor control methods during the course of manure removal and field application in accordance with the rules set by the Illinois Environmental Protection Act concerning agriculture related pollution.

The Illinois Environmental Protection Agency (IEPA) uses permit programs as one of the tools to regulate wastewater discharges to Illinois streams and lakes. Within the permit programs, facility owners and the public are provided with a discharge specific interpretation of the law and regulations. A specific set of effluent limits, a monitoring schedule, a reporting schedule and an approval of the treatment systems about to be built are also provided through the permit program. Two separate permit programs are administered by the Bureau of water which are, the NPDES permit program and the state construction/operating permit program. The NPDES permit program is ran the same way as discussed earlier. The program requires permits for the discharge of treated municipal effluent, treated industrial effluent and storm water. The conditions under which the discharge may occur and establish monitoring and reporting requirements are established within this permit program. The state of Illinois received its delegation to administer this federal permit program on October, 23, 1977. The state construction/operating permit program is based in the state Environmental Protection Act and the regulations developed by the Pollution Control Board.

**A.2. Indiana**

Indiana law defines a confined feeding operation (CFO) as any animal feeding operation engaged in the confined feeding of at least 300 cattle, or 600 swine or sheep, or 30,000 fowl, such as chickens, turkeys or other poultry. The Indiana Department of Environmental Management (IDEM) regulates confined feeding operations, as well as smaller operations which have violated water pollution rules or laws that govern confined feeding operations.

It is believed that confined feeding operations are more than likely to pose environmental concerns, including the following:

i. Manure can leak or spill from storage pits, lagoons or tanks
ii. Improper application of manure to the land can impair surface or ground water quality

The IDEM CAFO approval/permit program is based on the Confined Feeding Control Law administered through regulations adopted under the Water Pollution Control Board. The goal of these regulations is to protect water quality. Through this regulation program the IDEM ensure that waste storage structures are designed, constructed and maintained to be structurally sound and in addition that manure is handled and land applied in an environmentally acceptable manner. The IDEM permits the construction of new confined feeding operations, expansions of existing confined feeding operations, and existing animal feeding operations that must seek approval due to water quality violations. The IDEM administers the NPDES permit program required by the CWA. In December 2003, EPA released a final regulation for CAFOs. Farms of feeding facilities that are defined as point sources by the CWA and are required to obtain permit coverage. Any hog feeding operation that has 1000 animal unit capacity (2500 swine above 55 pounds) will need a NDPES permit.

**A.3. Iowa**

In Iowa, EPA delegates enforcement of the NPDES program to the Iowa Department of Natural Resources (DNR). Livestock and poultry producers need to follow state law and state regulations. The DNR issues the federal NPDES permits. Open feedlots that are greater than 1,000 animal units need to apply for the NPDES permits. Confinement feeding operations have not needed NPDES permits under federal law however the 2002 changes in federal rules meant that all confinement feeding operations with more than 1,000 animal units will be affected by the NPDES permitting requirements. The state of Iowa regulates two types of AFOs, namely; confined feeding operations and open feedlots. A confinement feeding operation confines animals to areas that are totally roofed. Confinement feeding operations in Iowa are not allowed to discharge manure to a water of the state. An open feedlot is unroofed or partially roofed with no vegetation or residue ground cover while the animals are confined. Hog operations are associated with confinement feeding operations in Iowa.

**Confinement operations**

Confinement feeding operations that plan to build, modify or expand must meet state requirements for the new construction. The size of the manure storage system needs to be determined based on the size of the proposed facility. The size of the proposed unit will be determined by calculating the animal unit capacity (ACU). The state of Iowa distinguishes between formed and unformed manure storage facilities. Formed manure storage structures usually have concrete or steel walls and floors and unformed manure storage structures or earthen basins include anaerobic lagoons, earthen aerobic structures and earthen manure storage basins. A construction permit is required prior to building, modifying or expanding all sizes of operations that use unformed storage. A construction permit will also be required prior to building, modifying, or expanding any operation that uses formed storage if the final animal unit capacity will be 1,000 animal units or more. The state of Iowa does not permit the construction permit is not required for building, modifying or expanding a confinement feeding operation with a proposed animal unit capacity from 501 to 999 animal units that uses formed storage. Pre-construction and design standards will still have to be met before construction begins.

**Manure management plans**

This applies to all animal feeding operations regardless of the size of the operation in Iowa. Iowa law requires that all manure from an animal feeding operation be disposed so that it does not cause surface or groundwater pollution

**Separation distances**

The state of Iowa also requires some separation distances to be maintained between areas of land application, protected buildings, sinkholes, wells, agricultural drainage wells, water sources, high quality water source and from public buildings. High quality water source include high quality water (HQ), high quality resource water (HQR) and protected water sources (PWS). High quality water is waters with exceptionally better quality than the levels specified in the Water Quality Standards and with exceptional recreational and ecological importance. High quality resource water are waters of substantial recreational or ecological significance which possess unusual, outstanding or unique physical, chemical, or biological characteristics which enhance the beneficial uses and warrant special protection. A protected water source is a program designed to maintain, preserve and protect outstanding natural and scenic qualities of select waters and their adjacent land areas.

i. Manure disposal is generally prohibited;

  - Within 200 feet of a well, agricultural drainage well, cistern, surface water inlet or water source including lakes, rivers, streams, ditches, etc. unless:
    - The manure is injected or is incorporated in the soil on the same date of application, or
    - Permanent vegetation covers the area within 50 feet of the designated area, and no manure is applied within the 50-foot area.
  - Within 800 feet of a high quality water resource unless:
    - The manure is injected or is incorporated in the soil on the same date of application, or
    - Permanent vegetation covers the area within 50 feet of the designated area, and no manure is applied within the 50-foot area.

ii. Regulations that apply only for confinement feeding operations include;

iii. Manure shall not be discharged directly into a water of the state or into a tile line that discharges directly to state waters.

iv. Operations using anaerobic lagoons or other earthen manure storage structures must maintain a minimum of two feet of "freeboard" at all times. In other words, the liquid level in the structure must never get within two feet of overflowing.

v. Upon closing a confinement feeding operation, the owner must remove and properly dispose of all accumulated manure from the operation's manure storage structures.

Tables 22-24 below summarize manure application setbacks in Iowa.

**Table 22: Required separation distances (in feet) to buildings or public use areas by type of manure and method of manure application**

| Buildings or Public Use Areas | Dry Manure | | Liquid Manure (except irrigated) | | |
|---|---|---|---|---|---|
| | Surface Application | | Direct Injection | Surface Application | |
| | Incorporated within 24 hours | Incorporated after 24 hrs. or not incorporated | | Incorporated within 24 hrs. | Incorporated after 24 hrs. or not incorporated |
| • residence • business • church • school • public use area | 0 | 0 | 0 | 0 | 750 ft. [1] |

Source: Iowa Department of Natural Resources 2003 revisions

**Table 23: Required separation distances (in feet) to designated areas by type of manure and method of manure application**

| Designated Areas | Dry Manure | | Liquid Manure (except irrigated) | | |
|---|---|---|---|---|---|
| | Surface Application | | Direct Injection | Surface Application | |
| | Incorporated on same date | Not incorporated | | Incorporated on same date | Not incorporated |
| • sinkhole • abandoned well • cistern • drinking water well • designated wetland • water source | 0 | 200 ft.[2] (50 ft. with buffer[3]) | 0 | 0 | 200 ft.[2] (50 ft. with buffer[3]) |
| • high quality water resource | 0 | 800 ft. [2, 4] (50 ft. with buffer[3]) | 0 | 0 | 800 ft. [2, 4] (50 ft. with buffer[3]) |
| • unplugged ag drainage well • ag drainage well surface inlet | 0 | 200 [5] | 0 | 0 | 200 [5] |

Source: Iowa Department of Natural Resources 2003 revisions

**Table 24: Required separation distances (in feet) for land application of irrigated liquid manure**

| Protected Areas | Irrigated Liquid Manure | |
|---|---|---|
| | Low Pressure (≤ 25 psi) | High Pressure (> 25 psi) |
| **Property Boundary Line** | 100 ft. [1] | 100 ft. [1] |
| **Buildings or Public Use Areas**<br>• residence • business • church<br>• school • public use area | 250 ft. [2] | 750 ft. [3] |
| **Designated Areas**<br>• sinkhole • abandoned well • designated wetlands<br>• cistern • drinking water well<br>• water source | 200 ft. (50 ft. with buffer [4]) | 200 ft. (50 ft. with buffer [4]) |
| • high quality water resource | 800 ft. [5] | 800 ft. [5] |
| • unplugged ag drainage well • ag drainage well surface inlet<br>• agricultural drainage well area (watershed) | No Irrigation Allowed [6] | No Irrigation Allowed [6] |

Source: Iowa Department of Natural Resources 2003 revisions

**Land application of manure**

i. Confinement feeding operations larger than a small animal feeding operation with 500 animal units or less must:

   - Use a certified manure applicator to apply manure, and
   - Apply manure at or below the nitrogen use level necessary to obtain optimum crop yields, and
   - Submit a manure management plan to the Iowa Department of Natural Resources(DNR) each year, and
   - Keep records of manure application

ii. Land application of manure for all confinement feeding operations

iii. Using spray irrigation for manure disposal is allowed under state statutes, provided the irrigation operations comply with separation distance and other disposal requirements of DNR rules. However, spray irrigation of manure is not allowed on land located within the drainage area of an agricultural drainage well.

**iv.** Liquid manure disposal from a confinement is also prohibited within 750 feet of certain buildings and public use areas.

### A.4. Kansas

Kansas is the only state in the top 10 hog producing a state that is authorized by the EPA to shut down o**perations that** violate water quality standards. In 1998, the Kansas legislature came up with additional regulations on swine operations. The Environmental Quality Council (EQC) Water Policy Subcommittee summarized the main elements of this law as follows;

i. Setbacks for confined feeding facilities for swine with 300 or more Animal Units from: existing habitable structures; city, county, state, or federal parks; and wildlife refuges. Setback requirements do not apply to new habitable structures or parks.

ii. Notice and publication requirements.

iii. Setbacks from water sources.

iv. Manure management plans required. Soil testing required when manure is land applied.

v. Nutrient utilization plans required if the manure or wastewater will be land applied. Land application of manure or waste water other than by incorporation into the soil during the same day is prohibited within 1,000 feet of: any habitable structure; city, county, state or federal park; or wildlife refuge. The law provides for exceptions to this provision. Requirements are established for use of an irrigation system to apply manure or wastewater from such facilities.

vi. Operator certification.

vii. Odor control plans required for facilities.

viii. Closure requirements including: a closure plan and financial assurance for closure costs is required for facilities with more than 3,725 Animal Units; closure requirements to be established by Kansas Department of Health and Environment (KDHE) for swine retention lagoons or ponds.

ix. Periodic inspection of swine facilities is required.

x. A liner is required for waste retention lagoons or ponds at swine facilities with an animal unit capacity of 3,725 or more.

xi. The KDHE may require the installation of groundwater monitoring wells and may require sampling.

xii. The KDHE may require vegetative screening (planting trees) to control odor.

xiii. The KDHE may adopt requirements governing location and construction of waste retention lagoons and ponds to protect the state's waters and soils.

xiv. Plans are required for handling of dead swine. The KDHE is authorized to adopt rules and regulations for handling of dead swine.

xv. Kansas State University is required to cooperate with KDHE, other agencies and owners and operators of swine facilities to determine best available technology and best management practices.

xvi. KDHE is authorized to establish more stringent requirements.

**A.5. Minnesota**

Currently, the State of Minnesota only regulates Hydrogen Sulfide (H2S) and Particulate Matter (PM) emissions from livestock operations. H2S is regulated through the state H2S ambient air standard. This standard is a 30-minute average of 30 parts per billion (ppb) found twice in five days, or a 30-minute average of 50 ppb found twice per year. Odor is not regulated by the State at the present time. The MPCA is responsible for enforcing H2S and PM. The MPCA utilizes a hand held unit called a Jerome Meter to screen for H2S. Jerome meters cannot be used to establish a legal violation of the standard; this requires continuous air monitoring. When H2S emissions are exceeded, the MPCA may utilize a Continuous Air Monitor (CAM) to further monitor H2S emissions in the field for an extended period of time. It should be noted that a variety of factors can affect the accuracy of CAM results. Livestock operators that are emptying liquid manure storage areas and are applying the manure are exempt from H2S standards for 21 days during a calendar year. More information is posted on the

The state of Minnesota also regulates the design, construction, operation and maintenance of liquid manure storage. Owners must submit their engineered plans and specifications to the MPCA or delegated county feedlot officer. MPCA regulates the collection, transportation, storage, processing and disposal of animal manure and livestock processing activities, and provides assistance to counties and the livestock industry. The rules apply to all aspects of livestock production areas including the location, design, construction, operation and management of feedlots, feed storage, storm water runoff, and manure handling facilities. New or modified liquid manure storage area with 1,000 or more animal units must be designed to provide a minimum of nine months storage capacity. New Feedlots are prohibited in, flood plains, within 300 feet of a sink hole, within 100 feet of a private well and within 1000 feet of a community water supply well or wells serving a school or licensed childcare center.

Regulations through the permit system

For owners with 300 animal units or more, and less than 1,000 animal units, a streamlined short-form construction permit is required for construction activities. A National Pollutant Discharge Elimination System (NPDES) permit or State Disposal System (SDS) permit is required for all feedlots with 1,000 animal units or more, or that are defined as a CAFO under the federal rule. Permits are not required for feedlots with less than 300 animal units and if the facility is located in county fairgrounds.

A description of the permits required by the state of Minnesota is as follows:

i. Five year permits are required for the construction and/or operation of an animal feedlot that has 1000 or more animal units, or is otherwise a CAFO as defined under federal regulations Title 40 section 122.23 that meets the criteria for a General NPDES/SDS permit. Such permits will last 5 years and will need to be renewed.

ii. Five year permits are also required for individual SDS if they own/operate a facility that has 1000 or more animal units that do not meet the criteria of a CAFO.

iii. Twenty four month interim permits are required for owners of facilities with less than 1,000 animal units and non-CAFOs that have an identified pollution hazard. For owners of facilities with more than 300 animal units where land application is on high phosphorus soils; on greater than 6 percent slopes in special protection areas; or in a drinking-water supply management area where the aquifer is vulnerable. Interim permits can be issued for any size facility under 1,000 animal units.

iv. Construction short-form permits are required for facilities proposing to construct or expand in the range of 300 to 999 animal units that do not have pollution hazards.

v. Prior to construction or expansion, the owner must obtain the proper permit or permit modification. Owners constructing or expanding must complete all notifications and may commence construction/expansion 30 days after notifying the MPCA and/or delegated county and all local zoning authorities. Liquid manure storage plans and specifications must be submitted with a permit application or at least 90 days before the planned start date of construction/expansion.

vi. If an owner with a pollution hazard was issued an interim permit that also authorizes construction for an expansion, the owner cannot stock the expansion until the pollution hazard is corrected.

**A.6. Missouri**

The Missouri Department of Natural Resources (MDN) is responsible for publishing rules and enforcing standards regarding animal waste in Missouri. The rules and regulations are designed to protect water from getting contaminated by animal waste. Animal feeding operations are classified according to the number of animal units at each location. Table 25 documents the Missouri AFO classification for swine.

**Table 25: Swine AFO classifications**

| Class | Animal unit equivalence for swine weighing more than 55pounds | Animal unit equivalence for swine weighing less than 55pounds | Permit requirement |
|---|---|---|---|
| Class 1A(7000 AUs) | 17500 | 105 000 | Required |
| Class 1B(3000-6999 AUs) | 7500 to 17 499 | 45000 to 104999 | Required |
| Class 1C(1000-2999 AUs) | 2500 to 7499 | 15000 to 104999 | Required |
| Class II(300-999 AUs) | 750 to 2499 | 4500 to 14999 | Usually not required |

Source: Missouri Department of Natural Resources guide to animal feeding operations February, 2008.

The MDNR permits the construction of new hog facilities and these have to meet the buffer distances between the hog facility and public buildings or occupied residences. Classes 1A, 1B and 1C CAFOs should satisfy 3000 feet, 2000 feet and 1000 feet buffer distances respectively. A site specific permit is required for Class 1A CAFOs and Classes 1B and 1C each require a general permit. Critical watershed requirements only apply to Class 1A CAFOs. New and expanding Class 1A CAFOs must submit a spill prevention plan for approval by the MDNR with the permit application. Class 1A CAFOs are prohibited in watersheds of the Current, Eleven Point and Jacks Forth rivers. When planning changes or expanding an animal feeding operation, permitted producers must consider the location of wells in relation to animal production, land application, waste storage, composter site or other potential water contamination sources.  The Missouri Clean Water commission set the minimum separation distances affecting CAFOs. Animal waste should be land applied as a plant nutrient and should always be managed so runoff does not occur. The application separation distances range from as low as 50 feet from property lines to 300 feet from losing streams, sinkholes, caves, wells, abandoned wells, water supply structures or impoundments and any other connection between surface and groundwater. The MDN requires that AFOs be located above the 25 year flood level and that minimum design and construction requirements are met. Construction and operating permits are also required for all Class 1 CAFOs and for any Class II CAFO that will discharge through a man-made conveyance. Land disturbance permits are required for storm water discharges from Class I CAFOs if the area to be disturbed will total one acre or more for the entire project. This permit must be obtained prior to any land clearing or grading. This permit requires the installation of best management practices to limit soil erosion and sediment movement during construction activities.

**A.7. Nebraska**

Nebraska's livestock AFO regulations which also apply to hog farming are as follows;

i. The state of Nebraska permits the construction and operation of new livestock facilities. For a large concentrated animal feeding operation, a plan describing best management practices to minimize odors from the animal feeding operation, the facility, and the disposal of livestock waste

ii. The owner or operator of a concentrated animal feeding operation which discharges or intends to discharge shall apply for an individual NPDES permit or submit a request for coverage under a general NPDES permit. The permittee is required to submit an application to renew an individual NPDES permit or submit a request for coverage under a NPDES general permit no later than 180 days before the expiration of the permit unless permission for submittal at a later date has been granted by the Director. If the permittee fails to renew the permit, the feeding operation will be permanently ceased.

iii. There are effluent limitations for concentrated animal feeding operations. For existing large beef, dairy, horse, sheep, swine, poultry, and veal calf concentrated animal feeding operations and new large beef, dairy, horse, and sheep concentrated animal feeding operations, there shall be no discharge of manure, litter, or process wastewater pollutants into waters of the state from the production area except that when precipitation causes an overflow of manure, litter, or process wastewater. There has to be proof that the production facility was well constructed to contain all manure and that it operated in accordance with regulations.

iv. Livestock waste control facilities shall be designed and constructed to allow application or utilization of livestock wastes at those times compatible with crop management and available waste handling equipment. Factors to account for include, but are not limited to, the maximum length of time anticipated between emptying events, the frequency of emptying events or dewatering, the hydraulic limitations of the land application areas, the nutrient content and concentration in the storage structure, and the appropriate timing of application as specified in the applicable technical standards for nutrient management.

v. A livestock waste control facility shall not be constructed:

- Within 100 feet of any well used for domestic purposes. For the purposes of these regulations, domestic water well means a water well providing water to any water supply system furnishing water for human consumption other than a public water supply system; for the watering of livestock, poultry, farm, and domestic animals; or for the irrigation of lands not exceeding an area of two acres;

- Within 1000 feet of a public drinking water supply well, unless the applicant furnishes the Department with field-derived data giving estimates of the depth, velocity and flow direction of ground water which support the contention that the facility will not result in ground water contamination and after review, the Department concurs;
- In an area or in such a manner that, in the Department's judgment, there is a substantial threat of beneficial use impairment to surface waters of the State;
- Where the Department determines that ground water may be contaminated; or
- Less than four feet above the seasonal high ground water level. Except, that a facility for an existing animal feeding operation may, with Department approval, be located less than four feet above the seasonal high ground water level, if the design provides for structural stability, a maximum operating depth of six feet, and provisions are made to maintain the facility. In addition, for a facility located at or below the seasonal high ground water level a low permeability liner with saturated hydraulic conductivity of $1x10^{-7}$ cm/sec., or less, and at least one foot in thickness or equivalent shall be utilized. No new animal feeding operation shall be issued a National Pollutant Discharge Elimination System permit or a construction and operating permit in any part of a watershed that feeds

directly or indirectly into a cold water class A stream. An existing animal feeding operation may not expand if its livestock waste control facility is located within one mile of a designated cold water class A stream segment. For large concentrated animal feeding operations, manure, litter, and process wastewater may not be stockpiled or applied closer than 100 feet to any down-gradient surface waters, open tile line intake structures, well heads, or other conduits to surface or ground water

vi. Best management practices are required to be exercised by livestock facilities in their operation and maintenance. Best management practices shall be implemented using the most effective methods based on the best available technology achievable for specific sites to prevent or reduce the discharge of pollutants to waters of the State and control odor where appropriate.

vii. The NPDES permit holder or the owner or operator of a large concentrated animal feeding operation with a livestock waste control facility is required to have routine inspections conducted of the production area, irrigation distribution system, and land application areas.

viii. Ground water monitoring may be required for any large concentrated animal feeding operation based on a site-specific review by the Department.

ix. According to Aiken (2002), livestock facilities are subject to state environmental regulation by the Nebraska Department of Environmental Quality, and to local zoning regulations if the county is zoned. By 1999 a total of eighty nine counties where pursuing zoning regulations. County zoning regulations are implemented through a zoning permit process. The common reason for county zoning regulations is to protect existing agricultural land uses. The other reason for zoning of counties was implemented in order to regulate the size and location of livestock facilities such as hog facilities. There is great fear in the state that livestock zoning would reduce the expansion of the livestock industry.

**A.8. North Carolina**

North Carolina is one of the major hog producers in the country. Major laws related to hog farming in this state include as of 2002 include;

i. The swine farm citing act of 1995 law became effective October 1, 1995. It imposed mandatory statewide requirements on all new or expanded factory hog farms, raising 250 or more hogs. It required that hog houses and waste lagoons be at least 1500 feet, 2500 feet and 100 feet from any occupied residence, from any school, hospital, or church and from any property boundary respectively. This law also required that waste application (spray fields) be at least 50 feet from both any residential property boundary and any perennial stream or river.

ii. The 1996 Act to implement recommendations on the Blue Ribbon study commission on agricultural waste imposed a law with new requirements relating to permitting, oversight, siting, public notice, and enforcement for factory hog, poultry and other livestock operations. This law directed the state to develop a system of general "nondischarge permits" for animal operations above certain size thresholds. Factory hog farms with 250 or more hogs were required to obtain a general permit--starting in 1997, the state has five years to phase in the general permits for all affected hog and other livestock operations. It also included requirements through the permit system to obtain a livestock waste management plan

iii. The 1997 clean water responsibility and environmentally sound policy Act created a law which imposed a partial moratorium on new and expanded factory hog farms, directed the state to develop a plan to phase out anaerobic waste lagoons and sprayfields, and imposed additional requirements.

iv. Moratorium: The law imposed a moratorium on the construction of new and expanded hog operations with 250 or more hogs until March 1, 1999. The purpose of the moratorium was to give counties time to adopt zoning ordinances and to allow research on environmental impacts and alternative waste technologies to be completed.

v. Zoning: The law restored partial zoning authority to counties. This authorizes counties to adopt zoning regulations for hog farms with a design capacity of at least 600,000 steady state live weight (or approximately 4,500 hogs).

vi. Phase-out Plan: The law directed the state Department of Agriculture to develop, by May 1, 1998, a "plan to phase out the use of anaerobic lagoons and sprayfields as primary methods of disposing of animal waste at swine farms."

Additional Setbacks for Hog Houses and Lagoons: The law required setbacks from hog houses and lagoons to be at least 2,500 feet from any outdoor recreational facility, national park, state park, historic property, or child care center; at least 500 feet from any well supplying water to a public water system; at least 500 feet from any other well supplying water for human consumption. Additional Setbacks for Application of Waste (Sprayfields): increased the setback from 50 feet to at least 75 feet from any residential property line and from any perennial stream or river. (See Chapter 106, Article 67 of the North Carolina General Statutes.)

An Act to provide for the registration of swine farms associated with swine operation integrators and to extend the 1997 moratorium was passed in 1998. The law extended the moratorium on new and expanded factory hog farms by six months until September, 1, 1999. In addition it required contract hog growers to provide information to the state regarding the swine operation integrator with whom that farmer is contracted with. This law further requires the state to notify integrators of any violations at contract farms.

**A.9. Ohio**

The Ohio Department of Agriculture's Livestock Environmental Permitting Program permits, inspects and regulates the Large Concentrated Animal Feeding Facilities (CAFF) in the state with the issuance of Permission to Install (PTI) permits for installation and 5 year renewable Permission to Operate (PTO) permits for Operation. The state of Ohio also has an authorization request package into U.S. EPA for transfer of the federal NPDES permitting from Ohio EPA to Ohio Department of Agriculture (ODA). Large CAFF's for hogs are those facilities with more than 2500 hogs over 55 pounds.

Small and medium facilities are not permitted unless they discharge to waters of the state or have been referred to us by the Ohio Department of Natural Resources-Division of Soil and Water Conservation. The Division of Soil and Water Conservation and the 88 Soil and Water Conservation Districts have regulatory authority, including penalties and referral for permitting. CAFO permits include requirements that have to do with production and land application areas. These include prohibition on discharges and a requirement to develop and implement a manure management plan. Discharges of manure, litter and waste water are not allowed. Discharges are only allowed in accordance with the federal regulation exemptions cited earlier. For land application area, the permit prohibits discharges from manure stockpiles, discharges during land application, and discharges from land applied manure unless a manure management plan was implemented. The ODA requires a manure management plan and results pertaining to the discharge, manure and soil sampling. A manure management plan should include a land application plan to comply with the land application requirements of the permit and should include; a total nutrient budget, manure and soil characteristics, application methods and specific agronomic application rates. Manure storage facilities are subject to inspection by the ODA. A summary of the Ohio manure application setback restrictions is provided in Table 26 below.

**Table 26: Summary of Ohio manure application setbacks**

**Table 1. Manure Application Setback Restrictions**

| | NRCS | | ODA | | NPDES | |
|---|---|---|---|---|---|---|
| Concern | Surface Application | Surface + 24 hr incorporation OR Injections | Surface Application | Surface + 24 hr incorporation OR Injections | Surface Application | Surface + 24 hr incorporation OR Injections |
| Class V wells, sinkholes | 300' | 100' | 300' | 100' | 300' | 100' |
| Perennial Streams | 35' veg barrier(1), or 100' setback non veg or 35' in non veg setback (3) | none | 35' veg cover, 100' (9) | 35' veg cover | mandatory 35' veg buffer w/no manure applied; otherwise 100' | mandatory 35' veg buffer w/no manure applied; otherwise 100' |
| Seasonal salmonid and cold water habitat | 35' veg barrier (1), or 100' setback non veg or 35' in non veg setback (3) | none | 35' veg cover or 100' (9) | 35' veg cover | mandatory 35' veg buffer w/no manure applied; otherwise 100' | mandatory 35' veg buffer w/no manure applied; otherwise 100' |
| Intermitten Stream/Ditch or Surface Inlet | 35' veg barrier (1), or 100' setback non veg or 35' in non veg setback (3) | none | 35' veg cover or 100' (9) | none | 35' w/veg cover or 100' no veg cover | 35' w/veg cover or 100' no veg cover |
| Drainageways, grassed waterways | 35' | none | 35' | 35' w/veg cover or none | 35' w/veg cover or 100' no veg cover | 100' no veg cover |
| Pond or Lake | 35' veg cover with the remaining 100' setback in non veg cover (2) | 35' veg cover | 35' | 35' | 35' w/veg cover or 100' no veg cover | 35' w/veg cover or 100' no veg cover |
| Private / Public Well | 100' (13) / 300' | 100' (13)/ 100' | 300' | 100' | 300'/(15) | 100'/(15) |
| Public Surface Drinking Water Intake | 300' | 300' | 300' | 300' | 300' (14) | 300' (14) |
| Springs | 300' upslope | 300' upslope | 300' | 100' | 300' | 300' |
| Neighboring resiediences | 100' | 100' | 300' | 100' | no destinction made | no destinction made |
| Flooding/flood plains/floodways (7) | do not apply | permissible | do not apply | permissible | do not apply | permissible |
| Slope (8) | >15% (10) | >15% (10) | >15% (10) | >15% (10) | >15% (10) | >15% (10) |
| Maximum application rate | (16) | (16) | (11) | (11) | (16) | (16) |

**Source: Livestock Environmental Assurance Program 2003 Fact Sheet**

**A.10. Oklahoma**

The state of Oklahoma passed the Swine Feeding Operations Act which was made effective in November of 2007. Oklahoma State also enforces the AFO regulation, NDPES through the Swine Feeding Operations Act. The purpose of the Oklahoma Swine Feeding Operations Act is to provide for environmentally responsible construction and expansion of swine feeding operations and to protect the safety, welfare and quality of life of persons who live in the vicinity of a swine feeding operation. Any swine feeding operation meeting the criteria defining a concentrated swine feeding operation is required to obtain a license to operate. A concentrated swine feeding operation in Oklahoma can be defined as a licensed managed feeding operation. Any swine feeding operation may be designated as a concentrated swine feeding operation if it is determined to be a significant contributor of pollution to the waters of the state. Among the characteristics defining a concentrated swine feeding operation are; the size of the operation, location of the operation relative to state waters, method of swine waste disposal and process wastewater disposal, and land and vegetation characteristics.

Non concentrated swine feeding operations can only be regulated under the Swine Feeding Operations Act if the State Board of Agriculture has enough proof that the operation is a significant contributor of pollution to state waters. If a single owner operates two or more facilities, the facilities are considered as a single facility for the purposes of licensing if they are close to each other if they use a common waste disposal facility.

The state permits the construction of a new facility or the expansion of an existing facility if such a facility falls under licensed facilities. In order to expand an operation, the owner has to seek modification to the old license prior to expansion. Licensed swine feeding operators are required to develop a Pollution Prevention Plan which will have to be approved by the Oklahoma Department of Agriculture, Food, and Forestry (ODAFF). Modifications to the plan are required if ever the owner expands the operation. The state also requires all operations to utilize Best Management Practices in line with the rules set by the State Board of Agriculture which satisfy the Swine Feeding Operations Act. The licensee is required to report any discharge exceeding 100 gallons of wastewater to the waters of the state.

A waste management plan documenting swine waste removal procedures and records of inspections of retention structures is also required. The disposal of dead swine has to meet the standards set by the ODAFF. All licensed swine feeding operations are required to develop an Odor Abatement Plan prior to the submission of an application. The Odor Abatement Plan should address methods for reducing odors in relationship to swine maintenance, waste storage, land application, and carcass disposal. The ODAFF reviews and approves Odor Abatement Plans. Factors which the OADFF uses when deciding whether to approve an Odor Abatement Plan include; design of the facilities, odor control technology to be utilized, prevailing wind direction in relation to occupied residences, size of operation, and distance from facility to occupied residences. Setback requirements for concentrated swine feeding operations include the following:

i. Liquid swine waste cannot be land applied within five hundred (500) feet of the nearest corner of an occupied residence not owned or leased by the owner of the swine feeding operation.

ii. Concentrated swine feeding operation cannot be established within one (1) mile of ten or more residences that are occupied residences at the time of the establishment of the operation.

iii. Liquid swine waste cannot be land applied within three hundred (300) feet of an existing public or private drinking water well.

iv. Concentrated swine feeding operation cannot be established if located:

   - Within three (3) miles of a state park or resort.
   - On land within three (3) miles of the incorporated limits of any municipality.
   - Within three (3) miles of the high water mark of a surface public water supply if the concentrated swine feeding operation is located within the drainage basin for the public water supply.

v. All distances between occupied residences and swine feeding operations will be measured from the closest corner of the walls of the occupied residence to the closest point of the nearest waste facility, as determined by the OADFF.

**vi.** Any violations to the requirements of the Swine Feeding Operations Act will be punished by a penalty. The size of the penalties is documented in the Swine Feeding Operations Act.

## Appendix B: State-level Environmental Indices

**Table 27: State-level environmental indices**

| State | 1994 Metcalfe | 1998 Metcalfe | 2000 Herath, Weersink and Carpentier | 2003 Author's estimates |
|---|---|---|---|---|
| Arkansas | 3.63 HWC | 7.16 HWC | 4.46 | 13 |
| Colorado | 3.63 HWC | 7.16 HWC | 6.99 | 13 |
| Georgia | 6 | 9 | 5.24 | 11 |
| Illinois | 2 | 8 | 4 | 14 |
| Indiana | 4 | 6 | 2.62 | 13 |
| Iowa | 4 | 9 | 3.25 | 13 |
| Kansas | 4 | 9 | 4.71 | 13 |
| Kentucky | 2 | 7 | 2.66 | 13 |
| Michigan | 1 | 3 | 2 | 11 |
| Minnesota | 8 | 9 | 5.35 | 13 |
| Missouri | 6 | 7 | 3.83 | 12 |
| Nebraska | 3 | 7 | 5.2 | 12 |
| North Carolina | 1 | 8 | 4.98 | 14 |
| Ohio | 5 | 7 | 3.63 | 12 |
| Oklahoma | 4 | 6 | 4.73 | 13 |
| Pennsylvania | 2 | 7 | 3.08 | 11 |
| South Dakota | 2 | 8 | 2.11 | 12 |
| Tennessee | 3.63 HWC | 7.16 HWC | 2 | 11 |
| Texas | 3.63 HWC | 7.16 HWC | 2.09 | 13 |
| Utah | 3.63 HWC | 7.16 HWC | 2 | 11 |
| Virginia | 3 | 5 | 1.06 | 11 |
| Wisconsin | 3.63 HWC | 7.16 HWC | 4 | 12 |

Note for Table 27: 1994 and 1998 indices were constructed by Metcalfe (2000), 2000 index constructed in Herath, Weersink, and Carpentier (2005) and 2003 index constructed by the author. Indices with superscript HWC are Herath, Weersink, and Carpentier (2005)'s approximations of Metcalfe (2000)'s indices for the states that were not considered in the construction of the 1994 and 1998 indices in Metcalfe (2000)

Table 28 below shows how we constructed our current, 2003-2006, following Metcalfe (2000)'s methodology and our estimates are shown below. We make use of the regulations required of all operations by the federal government (FED): 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). In addition, all of the 22 hog producing states enforce: facility design approval (FDA); and construction and operation permits (COPs). However, variation in regulation exists within these ten states. Some states regulate hydrogen sulfide (HSR). While the federal location setback requirement (ALSB) is 1000 feet, the individual state requirements range from 1875 feet (IA) to three miles (OK). The federal government requires a manure application (MAP) setback of 100 feet to 300 feet for MAPs, while state-required setbacks range from 500 feet (IN and OK) to 3960 feet.

**Table 28: Construction of the 2003-2006 State-level Environmental Stringency Index**

| State | WMP | FDA | COPs | MRK | OAPs | Zoning | HDS | HSR | RWS | NMPs | CSP | ALSB | MAS | Index |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| AR | 1 | 1 | 1 | 1 | 1 | 0 | 1 | 0 | 1 | 1 | 1 | 2 | 2 | 13 |
| CO | 1 | 1 | 1 | 1 | 1 | 0 | 1 | 0 | 1 | 1 | 1 | 2 | 2 | 13 |
| GA | 1 | 1 | 1 | 1 | 1 | 0 | 1 | 0 | 1 | 1 | 1 | 1 | 1 | 11 |
| IL | 1 | 1 | 1 | 1 | 1 | 0 | 1 | 1 | 1 | 1 | 1 | 2 | 2 | 14 |
| IN | 1 | 1 | 1 | 1 | 1 | 0 | 1 | 0 | 1 | 1 | 1 | 1 | 2 | 13 |
| IA | 1 | 1 | 1 | 1 | 1 | 0 | 1 | 0 | 1 | 1 | 1 | 2 | 2 | 13 |
| KS | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 0 | 1 | 1 | 1 | 2 | 1 | 13 |
| KY | 1 | 1 | 1 | 1 | 1 | 0 | 1 | 0 | 1 | 1 | 1 | 2 | 2 | 13 |
| MI | 1 | 1 | 1 | 1 | 1 | 0 | 1 | 0 | 1 | 1 | 1 | 1 | 1 | 11 |
| MN | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 13 |
| MO | 1 | 1 | 1 | 1 | 1 | 0 | 1 | 0 | 1 | 1 | 1 | 2 | 1 | 12 |
| NE | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 0 | 1 | 1 | 1 | 1 | 1 | 12 |
| NC | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 0 | 1 | 1 | 1 | 2 | 1 | 14 |
| OH | 1 | 1 | 1 | 1 | 1 | 0 | 1 | 0 | 1 | 1 | 1 | 1 | 1 | 12 |
| OK | 1 | 1 | 1 | 1 | 1 | 0 | 1 | 0 | 1 | 1 | 1 | 2 | 2 | 13 |
| PA | 1 | 1 | 1 | 1 | 1 | 0 | 1 | 0 | 1 | 1 | 1 | 1 | 1 | 11 |
| SD | 1 | 1 | 1 | 1 | 1 | 0 | 1 | 0 | 1 | 1 | 1 | 2 | 1 | 12 |
| TN | 1 | 1 | 1 | 1 | 1 | 0 | 1 | 0 | 1 | 1 | 1 | 1 | 1 | 11 |
| TX | 1 | 1 | 1 | 1 | 1 | 0 | 1 | 0 | 1 | 1 | 1 | 2 | 2 | 13 |
| UT | 1 | 1 | 1 | 1 | 1 | 0 | 1 | 0 | 1 | 1 | 1 | 1 | 1 | 11 |
| VA | 1 | 1 | 1 | 1 | 1 | 0 | 1 | 0 | 1 | 1 | 1 | 1 | 1 | 11 |
| WI | 1 | 1 | 1 | 1 | 1 | 0 | 1 | 0 | 1 | 1 | 1 | 1 | 2 | 12 |

Table 28 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.