ABSTRACT OF THESIS

REGULATION OF CONCENTRATED ANIMAL FEEDING OPERATIONS: AN APPLICATION OF ECONOMIC THEORY TO FIRM DECISION MAKING AND APPLICATIONS FOR PUBLIC POLICY

The livestock industry in the United States has experienced significant concentration and vertical integration in recent years. This change has resulted in greater observed levels of pollution attributed to concentrated animal feeding operations (CAFO) and society has attempted to use regulation to remedy these problems. Despite regulation at the federal and local level no documented improvement in water quality has been observed to date. This thesis is concerned with the response of profit-maximizing economic agents to the form of environmental regulation adopted at the federal level. A theoretical model of firm profit is proposed and analyzed using comparative statics to derive a variety of firm and policy relevant results. A qualitative discussion of monitoring and enforcement aspects of regulation and transaction costs in public policy implementation is provided. Results suggest that the form that regulation has taken fails to address the economic decision making process of the firm and thus fails to create incentives for more environmentally benign behavior.

KEYWORDS: economics of regulation, asymmetric information, institutions, public policy, comparative statics, animal feeding operations

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THESIS

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REGULATION OF CONCENTRATED ANIMAL FEEDING OPERATIONS: AN APPLICATION OF ECONOMIC THEORY TO FIRM DECISION MAKING AND APPLICATIONS FOR PUBLIC POLICY

THESIS

A thesis submitted in partial fulfillment of the requirements for the degree of Master of Science at the University of Kentucky

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CHAPTER ONE

INTRODUCTION

Animal agriculture in the United States has been the source of great controversy and difference of opinion in recent years. Elected officials, livestock producers, local communities and different interest groups have been active in this public dialogue. The result has been a highly contentious environment where considerable effort has been invested in political maneuvering to alter or protect property rights. The structure of this public debate is shaped by the incentives that are established within a political economy. Recent changes in the structure of the livestock industry and the accompanying effects are what have motivated such heated debate.

Over the last thirty years the total production in several livestock sectors has risen, while the total number of firms and total lands devoted to this production has declined. This concentration throughout the livestock sector has meant a drastic change in production technology and systems used to raise some animals. The bucolic scene of several chickens grazing the barnyard amongst a handful of cattle and hogs has shifted to something more similar to the sophisticated production systems traditionally associated with heavy industry or manufacturing. The result has been that an increasing number of producers are engaging in contract production of broilers, eggs, swine and increasingly beef and milk. Confined production of livestock occurs both independently and under contract, and the institutions and incentives at work may differ depending on the contractual arrangement that may or may not exist between producers and processors. For this reason, there is some variety in the structure of production, processing and marketing among confinement operations. This thesis is concerned most directly with those operations engaged in contract production, whether managed directly by the owner of the facility, owned by an outside party that employs a manager, or owned and operated by the integrator directly, and all reference to operations and production hereafter assumes this production arrangement.

The farmer or operator employs a production system that houses large numbers of animals in a confined space where feeding operates under strictly controlled conditions specified by the company, called an integrator, that the operator has a contract with for delivery of animals or animal products (eggs, milk, feathers). The animal waste generated must be stored temporarily before being used at the facility or on nearby crop acreage. The outputs of the production system are both animals (or their products) and manure. These sophisticated production systems come at great cost and a fiercely competitive market for the goods produced has meant that competitive producers are often highly leveraged.

The nature of many of these production contracts give the integrator the animal output from the management system and the operator the manure output from the production system. The operator receives payment from the integrator based on the livestock delivered. While animal waste does have financial value to the operator as a soil amendment (which may be substituted, at least in part, for other inputs to crop production), its storage and handling generate odors, can attract flies and other pests, and pose risks of affecting surface and groundwater resources. Agriculture remains the largest source of water quality impairment in the United States; animal feeding operations are the second largest agricultural source of contamination, affecting over 24,000 miles of streams and rivers out of 128,000 miles impacted by all agricultural sources in 2000 (United States Environmental Protection Agency). These less desirable aspects of confined livestock production are not fully addressed in the industry because profits are not directly affected by operator decisions not to undertake measures to curtail these additional outputs of production. Since these discommodities generated by the production process are external to the firm's decision-making process, they are referred to as negative externalities.

The externalities discussed are associated with two different types of impacts; those affecting (1) environmental-health factors and (2) property values of surrounding farms, residences and businesses. Livestock manure releases ammonia into the air and contains nitrogen, phosphorous, guiardia, cryptosporidium, and some heavy metals that pose environmental and health risks if exposure to air or water resources occurs. Foul odors have been a source of great discontent for those living nearby animal feeding operations (AFOs) and have been the focus of several lawsuits filed against such operations. The release of manure, either directly or indirectly, into a waterway can result in a variety of outcomes from minor increases in nutrient loading that have no discernable effect on plant or animal life, to large fishkill events affecting the recreational and habitat values of the body of water affected. Several high profile environmental releases have occurred in a number of states; one major event in North Carolina resulted in the release of a volume of hog waste two times that of the Exxon Valdez oil spill—25 million gallons (Smothers). Health effects associated with exposure to water-borne pathogens carried in animal manure vary, but can be severe, especially for individuals with weakened immune systems. An April 1993 cryptosporidium outbreak in the Milwaukee drinking water system caused over 40 deaths and 370,000 illnesses; runoff from livestock waste on nearby dairy operations was believed to be the source of this outbreak (Terry).

Several studies of housing market impacts due to proximity to confinement operations have been completed (Palmquist, Vukina and Hoag; Ready and Abdalla; Thomas, et al.) indicating varying impacts on housing prices, but consistently demonstrating through hedonic pricing methods that there are statistically significant negative impacts on home price based on proximity to such operations. These estimates vary from 2% to 12% reductions in home value for the negative externality of the AFO.

Risk of waste release or system failure from AFOs is a product of three items: 1) system design and siting; 2) management; and 3) weather. A deficiency in (1) or (2) will result in increased risk to society. Extreme weather can compound the problems. Locating a facility nearby a stream or above a groundwater recharge area, applying manure before a forecast rain, or weather caused flooding individually create an elevated risk of exposure; in combination any or all of these compound the risk. Which risks are important for society is a matter of debate, and policymakers have attempted to address these risks and curtail externalities from production.

1.1 THESIS OBJECTIVES

The main objective of this thesis is to determine if the behavior of firm managers in the livestock production sector subject to environmental regulation is consistent with the economic theory of optimization. The question to be addressed is whether or not what economic theory tells us about behavior and rational decision-making is consistent with the stylized facts we see in real life. In order to come to a conclusion about firm behavior a previously developed theoretical model will be expanded to inform us about firm decision making under imperfectly enforceable environmental regulation and this model will be applied to the specific case of animal feeding operation regulation in the United States. Comparative statics from the profit function will be utilized to derive policy and firm relevant results. These results are expected to indicate firm response to different measures taken by AFO regulators based on the assumption of profit maximization. The attempt here is to explain, vis-à-vis economic theory, how regulatory policy can provide more appropriate incentives for profit motivated firms.

1.2 ORGANIZATION OF THESIS

The thesis is organized as follows. Chapter two introduces the institutional structure and incentives in place for animal agriculture. The institutional structure addresses all levels of government (non-market) and market institutions, as well as the courts. The full scope of incentives facing a producer will also be considered in an attempt to qualitatively consider the actual management circumstances faced by the operator. Chapter three consists of a review of the sizeable literature related to environmental externality, economic regulation, deterrence, and environmental monitoring and enforcement, with particular emphasis on applications to animal agriculture. Literature dealing specifically with AFOs and manure management is also reviewed in this chapter. Chapter four presents the production decision in a stylized framework and discusses the farm-level decision making process. A base theoretical model of firm profit from the literature is presented and expanded to reflect the profit-maximizing considerations of a livestock operator. Comparative statics are then derived from the expanded profit function. The fifth chapter interprets the comparative statics for policy and firm relevant implications based on changes in different factors affecting profitability. It also discusses the selection of functional form and a more detailed consideration of the costs of regulation for the firm. Chapter six offers conclusions from the model and suggests areas for future research.

CHAPTER TWO

INSTITUTIONS AND INCENTIVES IN ANIMAL AGRICULTURE

The institutional structure and incentives faced by animal feeding operations in the United States are divided into four categories for presentation in this chapter:

1. The market encompasses livestock producers (also referred to as operators), the integrators responsible for processing and marketing, and consumers who purchase the meat and other animal products that come from AFOs for consumption;
2. The government or non-market[1] category refers to regulatory and technical assistance institutions and rules at all levels of government (The important discussion of property rights determination in the livestock industry will be considered in the non-market category);
3. Private entities play an important role in shaping the property rights that govern AFOs and in providing incentives to operators and policy makers alike; and
4. The role of the courts and litigation in the context of firm profitability and the range of incentives that result from the legal environment are significant.

Together these four institutional groupings provide the backdrop for firm operation and decision-making given the motivations of all institutions and the incentives they impose on operators.

In Kentucky the national trends of consolidation and integration in the livestock sector have been observed in the hog and dairy sectors. The most drastic change that has been observed has been in the poultry sector, where production has increased more than fifteen-fold since 1991 (Kentucky Agricultural Statistics Service). While the production trends and externality issues observed elsewhere in the U.S. have also been observed in Kentucky, there have been few extremely high profile environmental events that have occurred here. The regulation of these operations has been a sensitive public policy subject and Kentucky has attempted to enact legislation more strict than federal regulations in the past, but this was stricken down in court. There have also been local efforts in the state to enact laws to govern the activities of these operations and these efforts have been more successful than statewide regulation. Kentucky is not intended to be the focus of this thesis and poultry operations are not the focus of the

[1] "Non-market" terminology to represent government entities or activities originated with Wolf (1979) and the two terms will be used interchangeably throughout this thesis.

theoretical model and comparative statics that occur later in this document. Several examples from Kentucky will be used throughout this thesis as examples of state-level consideration of the nature of regulation, local implementation of permitting, and monitoring and enforcement issues.

2.1 THE MARKET

Operators, integrators and consumers come together to form the market for livestock meat and other products. Individual animal production facilities are classified for regulatory purposes most generally as AFOs. Operations above a certain size, based on the number of animals and species, are designated as concentrated animal feeding operations (CAFOs) and are subject to regulations issued by state and federal governments. The current regulation designates operations as CAFOs if more than 1,000 beef cattle, 700 dairy cows, 2,500 swine or 125,000 broilers are produced in confinement at a single facility. Operations that meet these size criteria accounted for nearly one-third of beef cattle, more than one-third of milk, three-quarters of hogs and more than four-fifths of (meat-type) poultry produced in the United States (USDA National Agricultural Statistics Service, 1997 and 2002). Operations that are smaller but are determined to pose greater risk of environmental injury or public health impact because of location, design or other factors can also be designated as CAFOs. All operations referred to in this thesis are CAFOs.

The producer or operator of a particular facility has a contract for delivery of animals and raises the animals under very specific growing conditions, using feeds and nutritional supplements provided by integrators and maintaining temperature and other environmental factors in production houses according to the terms of the contract between the operator and the integrator. The animals are supplied to operators by integrators and are not the property of the producer. The facilities are owned and operated by the operator, who retains the animal waste generated by livestock. The large amount of manure generated by CAFOs is the source of the negative externalities that provide the impetus for this research.

A CAFO is just a particular type of firm, not unlike other small to medium-sized businesses, generally run by a family, group of partners, or a manager and employees hired by the business owner or the integrator if the facility is directly owned. The operation of the individual firm is motivated by income, or more specifically profit. The transition to a vertically integrated production system has meant that farms where livestock is raised, especially hogs and chickens, have become extremely specialized and, unlike the past, operations no longer have several species of animals and a variety of crops. For the most part CAFOs raise a single species and may have a quantity of land available for application of manure to crops or pastureland. The sophisticated production systems necessary for handling large numbers of animals and their waste are very capital intensive and mean that CAFO operators are oftentimes highly leveraged. The operator's major concern is profitability and there are many factors influencing management decisions to optimize profits. The assumption of CAFOs as profit-maximizing firms is used throughout the thesis and will serve as the foundation for analysis of firm decision-making under environmental regulation in later chapters. Profit itself is the initial incentive for a highly leveraged CAFO operator.

The operator is the primary manager for a particular facility and how management occurs is a key factor in assessing the level of externality generated or the risk of a system failure occurring. Externalities are a result of releases from the waste management system into the air, onto the land, or into water resources when the marginal cost of a particular release is not paid by the firm. A 'failure' is defined as any breakdown in the management system that results in documented damages to land or water resources, aquatic species or wildlife habitat. The role of management in reducing risk and preventing failure cannot be overstated. Profit-based management incentives mean that no activity is undertaken in the production process unless it contributes to profits. The only exception might be if the said activity is costless. How economic incentives affect management decisions concerning pollution abatement activities, and hence profits, is the focus of this analysis.

The integrator pays the producer for fulfillment of a production contract and is generally the processor and marketer of a particular animal product or groups of products. Integrators like Perdue, Tyson, Smithfield or Premium Standard Farms maximize their own profits by having a large investment in product branding and advertising. As a consequence, these companies have great incentive to protect the product image amongst consumers. Product image is critical in a concentrated sector. Anything that might damage or somehow call into question the quality of a particular brand in the eyes of consumers is extremely undesirable to an integrator. Producer management decisions can clearly contribute to public scrutiny of CAFOs if adequate attention is not given to following rules and regulations governing production practices. If a release of animal waste into an adjacent stream affects company image, then integrators have financial incentives to avoid such problems by motivating good behavior on the part of producers.

Depending on the company and the state where an operation is located, production restrictions may be imposed on an operator if regulatory fines are imposed or certain management guidelines designed to mitigate risk of system failure are not followed. For instance, a swine integrator may withhold pigs from a CAFO for one phase of the production cycle when persistent violation occurs or manure in a storage system exceeds the emergency storm storage designed to protect against overflow from extreme rain events. Being forced to skip a cycle could be financially devastating for a highly leveraged producer. This represents a powerful incentive to keep manure levels within guidelines. While this incentive addresses system storage, it may transfer the risk of storage system overflow to farm fields where dewatering[2] occurs. The unanticipated result of the incentive from integrators may be to over apply to land because it is much easier to detect when a storage system is too high than to know when manure has been applied beyond agronomic rates contributing to runoff into streams. This is an example of the hidden information held by producers. Such hidden information poses problems for integrators attempting to encourage responsible behavior and regulators seeking to limit externalities.

Consumers of animal products are the final link the market. One result of the vertically integrated and highly specialized production of chicken, pork and beef products is an extremely consistent product, which is necessary for marketing purposes. Because branded products tend to be the same, a consumer largely bases purchases on price. The price paid by consumers for unprepared meat products is low because of economies of scale and a very efficient production system. Externalities in the market have implications for consumers. Not only are firms failing to internalize the full costs of production when externalities occur, but consumers are not paying the full price of externalities as long as added production costs for pollution abatement are not a factor in pricing by integrators. While we fail to pay for the mitigation of externality problems at the grocery store, society still bears the social cost of environmental, health and property value impacts from animal agriculture in an indirect way.

[2] Dewatering is the process of applying manure storage contents onto crops or cropland.

2.2 THE NON-MARKET—GOVERNMENT

The non-market includes federal, state and local government agencies. These agents provide technical assistance to producers and monitor and enforce regulations. What underlies all government action related to CAFOs is the commonly cited market failure criterion for public intervention—externalities provide justification for restructuring property rights. The full array of agencies involved in animal agriculture will be presented along with the progression of regulations promulgated to address continued concerns about the effects of externalities from CAFOs. In regulating CAFOs the government has taken a one-sided approach that utilizes what are commonly referred to as "command-and-control" techniques that dictate standards that must be met by regulated entities. The majority of all environmental regulation that has taken place in this country since the passage of the National Environmental Policy Act in 1969 has been designed to force firms to internalize the full cost of production using a "polluter pays" approach and regulation of CAFOs has followed this protocol, placing significant costs on producers but so far failing to curtail pollution.

Animal agriculture has been largely exempted from the majority of environmental legislation passed since NEPA. Most notable are the Clean Water Act (CWA) of 1972 and the Comprehensive Environmental Response, Compensation and Liability Act, or Superfund Act of 1980. Agriculture is largely exempt from the CWA and much litigation brought against CAFOs has been through nuisance provisions in tort law. The National Pollutant Discharge Elimination System (NPDES), which established a permitting system for point sources of pollution, was modified to include Effluent Limitation Guidelines (ELG) for CAFOs in 1974 and this continues to be the only aspect of the CWA that applies directly to animal agriculture. Superfund provisions for Natural Resource Damage Assessment (NRDA) that places monetary values on injuries to natural resources resulting from the release of hazardous substances into the environment do not apply to animal waste releases or leakage from animal waste storage systems. The inclusion of permitting for AFOs above a certain size is a practice that has been modified over the last 25 years and made more stringent in some states. As with most federal environmental statutes, the laws about NPDES permits for CAFOs are implemented and enforced by state environmental agencies through what is referred to as "delegation" or "cooperative federalism". All permits for CAFOs are no-discharge permits and CAFOs are not allowed to release effluent from their operations into the "waters of the United States".

With the rapid concentration of the livestock industry that took place throughout the 1990s, came several highly publicized events where CAFO discharges occurred as a result of different factors. Hurricanes in North Carolina in 1996 and 1999 generated a great amount of publicity around large-scale hog confinement operations in that state (Kilborn). There have also been several high profile court cases in different states involving other types of operations (Sierra Club). Policymakers responded via a joint effort by the U.S. Department of Agriculture (USDA) and the U.S. Environmental Protection Agency (EPA).

The Unified National Strategy for Animal Feeding Operations was released in 1999 and mandated comprehensive nutrient management planning, requiring all CAFOs to file individual Comprehensive Nutrient Management Plans (CNMPs) by 2009 (USDA and USEPA). It should be noted that some states also addressed aspects of management to protect producers from nuisance suits and ensure a minimum performance standard from all AFOs by requiring certain baseline practices related to waste storage and land application under 'right to farm' legislation prior to the CNMP requirement. Escalated scrutiny of the livestock sector continued and in 2001 EPA initiated a public dialogue seeking input on CAFO regulations.[3] The 2002 Farm Bill created an incentive for producers to have CNMPs in place before the 2009 deadline by requiring plans before distribution of Environmental Quality Incentives Program (EQIP) cost-share funding for livestock waste facilities can occur. In December of 2002, the EPA released the Final CAFO Rule (hereafter, Final Rule) and subsequently published it in the Federal Register in February 2003.[4] The Final Rule moved up the phase-in date for CNMPs to 2006 and increased the number of operations that would be required to have NPDES permits by adjusting the definition of a CAFO (an earlier "animal unit" based criterion was eliminated), allowing state permitting authorities to designate smaller operations as CAFOs based on prior performance or aspects of an individual operation that may pose elevated risk of release, and eliminated a permitting exemption for operations that only discharge when 25 year-24 hour storm events occur.[5] The Final Rule also requires an operation to incorporate a nitrogen or phosphorus based land application standard through nutrient planning and to submit a subset of the CNMP contents

[3] 66 Federal Register 9:2959-3145 (January 12, 2001) relating to 40 CFR Parts 122 and 412
[4] 68 Federal Register 29: 7175-7274 (February 12, 2003) relating to 40 CFR Parts 9, 122, 123 and 412; became effective in April 2003
[5] The 25 year-24 hour storm event criterion was developed by the National Weather Service over 40 years ago and is triggered whenever rainfall in a 24 hour period exceeds the 96th percentile; roughly once every 25 years. (Hershfield)

to the permitting authority simply called a nutrient management plan (NMP). Increased regulation of CAFOs has resulted in real costs for operators; the EPA estimated the annual monetized cost of its Final Rule to be $335 million.[6]

The "polluter pays" approach to regulation has significantly altered the property rights of regulated firms and the public alike. To illustrate, the property rights scenario for existing CAFOs and new ones are compared. Public concern about CAFOs has meant that new operations trying to secure permits and approval for operation face more requirements designed to make the firm demonstrate that it will operate in a way that does not create risks for society. The result has been more stringent facility design requirements and greater publicity associated with the approval process, both are considered barriers to entry that did not exist when continuing operations started-up. A larger 100 year-24 hour rainfall metric has been imposed on new facilities, meaning that waste handling systems must be designed and operated to contain events of this magnitude; events occurring once every hundred years. Because the burden to demonstrate that a new operation will conduct business in ways that do not harm local resources and keep externalities at some agreed upon levels is born by the CAFO itself, society largely holds the property rights governing pollution for new or prospective firms.

Existing firms have been "grand-fathered in", or allowed to continue operating under the 25 year-24 hour storm discharge exemption and facility design requirements that existed prior to the Final Rule. While there has been elevated public scrutiny of all CAFOs, those already in operation have avoided tougher design requirements and more lengthy review before startup. Once systems are in place (after initial compliance is achieved), the burden shifts more toward the larger community (or the public) to assure that proper management is addressing environmental and health risks. As such, the property rights to pollute favor existing CAFO operators.

The continuance of the storm discharge exemption was hotly contested during the public comment period prior to the release of the Final Rule. In the end, it was determined that an exemption for certain "acts of God" beyond the control of the operator should be retained; however the rainfall metric was increased with the adoption of the 100 year-24 hour rule under the new regulations. The incentives conveyed by the persistence of such exemptions are worthy of consideration from the perspective of a firm level analysis of decision making under

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[6] 68 Federal Register 29: 7242-7250 (February 12, 2003)

environmental regulation. If a facility is designed and managed to meet either the 100-year or 25-year storm criterion, incentives to discharge or dewater manure systems are created whenever such events occur even if management could prevent any release from the system. Rational economic decision makers optimizing their management decisions based on profit considerations are responding to incentives when they opt to discharge or dewater during such storm events. Not lowering manure system levels during such an event, when it could be done without fine or other penalty, could place an operation at a competitive disadvantage later. For this reason, storm discharge exemptions actually create incentives for discharge, or what would be considered bad management absent a storm, and may actually contribute to animal waste releases when there is an expectation of exemption and management decisions are made accordingly. When you consider the incentive provided by the storm discharge exemption in combination with potential production restrictions imposed by some integrators if adequate emergency storm storage is not maintained, the incentives to discharge rather than risking elevated system levels later in the production process and the accompanying penalties become even greater.

The EPA is the federal agency responsible for regulatory aspects of CAFO operation. The federal government also provides technical assistance to producers through the USDA Natural Resources Conservation Service (NRCS). The NRCS provides assistance to producers dealing with a growing number of aspects of the production process. Free assistance to producers related to facility design and best management practices (BMPs) for storing, transporting and applying manure or poultry litter are the major services provided by NRCS. Facility design guidelines have been a particular source of discontent for many producers who criticize the design plans provided through the agency as being designed with a “one size fits all” approach that doesn’t take into account the individualized nature of a particular operation given, species, size and aspects of the site where the facility will be located. Manure management advice is directly related to the requirement for all CAFOs to create CNMPs (and NMPs) that detail basic characteristics of an individual operation and the specifics about how nutrients will be applied. Detailed assistance is necessary to determine rates of application and nutrient absorptive capacity at a site based on soil type, crops, drainage, and weather conditions. Formulating a tailored CNMP based on site specifications is key to ensuring a reduction in externalities. Keep in mind that the purpose of NRCS as an agency is to make producers aware of the regulations they are subject to and demonstrate management methods that facilitate compliance with laws.[7] Scarce resources and time constraints prevent NRCS from writing actual CNMPs with individual producers or designing customized waste handling facilities. This must be taken into account when considering producer discontent with the agency, as well as the cost of implementing the Final Rule.

The USDA Farm Service Agency (FSA) plays a key role in distributing financial assistance to producers making investments in waste handling and management systems that satisfy CAFO regulations. The EQIP cost-share program is available to help operators meet the cost of implementing CNMPs and can be very important to highly leveraged operators working to expand, update or upgrade some aspects of a waste handling facility.[8] The NRCS and FSA are oftentimes located in the same building with local offices nationwide. Most states have had a consistently larger demand for these funds than funds available in years past, but under the 2002 Farm Bill appropriations the amount of money available for this purpose doubled in 2002 to $400 million annually and will increase incrementally to $1.3 billion in 2007. Many CAFOs have also taken advantage of government sponsored independent audits of animal waste management systems to assess current or potential problems through a program administered by America's Clean Water Foundation called On-Farm Assessment and Environmental Review.

Laws and regulations originating at the federal level are implemented by states. This is important when considering the effects of increased regulation within the institutional structure because the federal agency promulgating regulations does so with the expectation that state officials will implement the regulation and enforce it locally, as promulgated. State permitting authorities, such as the state Division of Water or the Department of Environmental Protection (referred to as SEPA, hereafter), issue NPDES permits required for CAFOs and have the discretion to classify smaller operations that pose elevated risk as CAFOs if certain criteria are met. There has been a great deal of disparity among the states concerning rates of implementation (America's Clean Water Foundation), in some cases this has been a function of the prevalence of animal agriculture in a particular area or the occurrence of highly publicized events involving animal waste. In some states certain species have received a great deal more attention than others, usually this too is a function of the level of public scrutiny resulting from

[7] State departments of agriculture and cooperative extension personnel are also actively engaged in providing this type of technical assistance to producers.
[8] By statute, 60% of EQIP funds are designated for livestock production practices. Some states have provided additional environmental cost-share funds. Kentucky, for example, has committed $9 million annually since 2000 to ease the financial burden of compliance with state and federal regulation of AFOs—"double dipping" is not allowed.

past incidents. As described above, federal regulation has increased significantly; resources to pay for incremental regulatory changes rarely, if ever, accompany increased duties and scope for SEPAs.

The monitoring and enforcement (ME) duties make up the bulk of the obstacle to state implementation of federal regulations governing CAFOs because of the number of operations scattered across the landscape and the limited resources available to sort firms into groups based on achievement of performance standards. The problem is one of hidden information and high transaction costs in the face of an inadequate budget constraint to address the full range of tasks assigned to SEPAs. Producers will always have more information about their operation than a regulator, or an integrator for that matter, because it is simply too costly to constantly monitor the activities of every firm. This hidden information problem has prevented ME agencies from being able to determine exactly which firms should be permitted and distinguish good actors from bad ones. Without greater information it will be impossible to target those firms creating the biggest problems for society, so that public resources can be utilized most efficiently. The latest round of regulation instituted CNMPs that serve as an information revelation device or signal that may allow ME entities to better sort firms and focus monitoring activities based on the characteristics of a specific operation.

Given the differential implementation of federal CAFO regulations and the lack of consistency in enforcement stringency from state to state and even from one species to another within the same state, there appear to be very weak incentives for operators to invest very heavily, if at all, in environmental and risk management aspects of their production systems (unless of course the producer is located in a state or engaged a livestock enterprise that is under intense pressure). The basic economic decision to invest in pollution abatement activities or incur additional costs to deal with excess waste in a responsible manner is governed by the producer's assessment of the probability of a violation being detected multiplied by the amount of the expected fine. If the cost of abatement is greater than the expected regulatory fines, then it makes no economic sense for an operator to invest in environmental and health protection equipment beyond the minimum required for permitting. This assessment of costs is given generally by the equation,

$$\text{(Cost of Abatement)} \begin{matrix} > \\ = \\ < \end{matrix} \text{(Probability of Detection)*(Fine Amount for Violation).}$$

The cost of possible production restrictions imposed by integrators must also be considered in the firm's optimization decision. As long as enforcement remains sporadic or unpredictable there will not be sufficient incentives for producers to make long-term investments in environmental protection, especially not if the full costs of operation are never born by the firm or consumers.

In addition to state implementation of federal CAFO regulations, many states and local communities increasingly have their own laws and ordinances governing different aspects of CAFO operation. The first of these regulations came in the form of state 'right-to-farm' legislation designed to protect farmers' livelihoods and established generally accepted practices for operations that address citizen concerns (odor, water pollution, etc.); when such practices are not followed operations may be subject to fines. More recently, comprehensive state CAFO rules have been promulgated as regulations or passed by state legislatures to establish state-specific setbacks[9] for facilities and land application, permitting requirements, and in some cases integrator liability in the event of animal waste release. Kentucky is the only state that has attempted to enact integrator liability, although it was initially considered during the rulemaking process for the Final Rule. The purpose of state regulation has been to address some perceived deficiency in the federal regulations, which apply to operations in all states. State regulation has developed in response to more localized problems attributed to CAFO operations or as a result of highly visible events that elevate public scrutiny of livestock operations.

Enforcement of CAFO regulations is of greatest concern for public policy. The persistent problems that have prevented perfect enforcement of nearly all environmental laws apply directly to CAFO regulations. The producer or the firm (in the more general case) possesses superior information about the production process that the regulator or the state does not have. The day-to-day operations of any single firm cannot be monitored continuously without incurring prohibitive transaction costs for the agency assigned this responsibility, especially when the infrastructure necessary for monitoring CAFO discharges or effluent does not exist.

[9] The term 'setback' refers to rules that stipulate the minimum distance from a property line, body of water, roadway, or specific use buildings (school, church, etc.) waste handling facilities and/or land application can occur.

Given inadequate budgets to implement perfect monitoring and enforcement of CAFOs, SEPAs have to somehow prioritize their efforts to address the most serious threats to the environment and public health.[10] The task of sorting firms based on the risks that they pose is complex and the matter of which risks are most important for society to address is a topic for debate. The phase-in and implementation of CNMPs greatly reduces informational barriers previously faced by regulators and represents a significant concession on the part of producers. With greater information about operation size, the particular waste management system in use, and site conditions, sorting operations effectively for targeted inspection and monitoring purposes becomes more feasible. The question of how to structure institutions and incentives to achieve public policy objectives at the lowest cost in the presence of information asymmetry and high transaction costs is of chief concern for public decision makers.

2.3 PRIVATE ENTITIES

A number of private entities motivated by different incentives and performing different functions in society are at work in both the market and non-market environment surrounding CAFOs. These private entities fall into three categories: (1) interest groups, (2) individual citizens, and (3) the media. A variety of different interest groups exist that are intensely interested in the various aspects of CAFO operation and regulation; the two types considered in this chapter are environmental citizen groups and producer organizations or industry groups.

Many citizen groups focusing on environmental issues have been active at the local and federal level in lobbying policy-makers and agency rulemaking bodies to take actions that prevent pollution to air, water and land from CAFOs. These efforts have been advanced under the same "polluter pays" principle of regulation utilized by the federal government which has justified such actions on the basis that markets alone have failed to operate in ways that result in operators bearing the full costs of their operations. Different pollutants are generated and released into the environment that the operator does not account for in making production decisions, but which result in real costs to society—impairment of designated uses for waterways

[10] In Kentucky, there is the equivalent of three-tenths of one full time employee's work effort devoted to AFO and CAFO permitting divided among several staff members. One-third of this amount is devoted to CAFOs and the other two-thirds are dedicated to AFOs. On the ME side of things, it is estimated that around one full time employee's worth of work effort is devoted to CAFO issues (Scott).

(drinking water, recreation, etc.), insect or pest nuisances, and foul odors are commonly cited examples of negative externalities resulting from CAFOs.

Environmental citizen groups at both the local and national levels have used publicity generating events (press conferences, protests) and paid advertisements in different media to promote those aspects of CAFO operation that concern them most. The objective of these groups has been twofold: (1) to generate wider public concern and scrutiny amongst citizens and policy-makers about these issues and (2) to force operations to stop behaving in ways that create losses for society. Such groups, especially large national organizations like the Sierra Club, the Natural Resources Defense Council and the Riverkeepers Network, are motivated to maintain their public image as protectors of natural resources and environmental quality. Effectiveness in activities related to their mission is directly tied to continued financial support from their members and other outside sources can be secured. If such groups fail to act in ways that seek to eliminate pollution and health threats from animal waste, support may dwindle because the group is perceived as ineffective. These groups, often engage citizen lobbyists in state legislatures and local government meetings, mobilize their constituents through telephone calls, letter writing campaigns, e-mail messages and fax transmissions directed toward proposed legislation or administrative rules which have bearing on public policy decisions on this and all environmental issues. CAFOs have been a particularly visible focus of these groups in recent years.

Another type or class of interest group that is active in the public debate about CAFOs is what is referred to as a producer organization or industry group. Because producers feel threatened by regulation and the activities of citizen groups designed to exact higher operation costs on CAFOs, they have interest groups that represent them in the legislative and administrative decision-making processes, as well as the sphere of public opinion. Groups like the American Pork Producers, the National Cattleman's Beef Association and the American Poultry Federation serve specific clientele within the meat industry, but there are also governmental relations and lobbying firms that act on behalf of these groups collectively. Producers are not the only individuals represented by these types of institutions; integrators like Perdue, Tyson, Swift and Premium Standard Farms also provide financial support for the lobbying and promotional activities undertaken by industry groups. The members of these organizations are motivated to protect their economic livelihood and maximize profits in ways that preserve a positive public image for the livestock production industry.

Individual citizens also take actions when there may not be anything as formal as an NGO in a particular area. Complaints by neighbors and others in the community who have been affected by some aspect of CAFO operation have been filed with local authorities and SEPAs in an attempt to change the behavior of firms. Individuals may also be responsible for reporting the activities of CAFOs to media sources that result in stories in local papers detailing negative effects of these operations. The actions of individual citizens can have the same negative effects on the reputation of a company or producer as those taken by large environmental groups.

The media is an important private entity operating in a very public way to disperse information. The incentive for periodicals and newscasters is to maximize readership, viewership or listenership depending on the particular media source and to project an image as a reliable and important source for information about current events. The "watchdog" mentality that often governs environmental group activities is also common in media coverage. Public perceptions of the effects of livestock waste spills and other events are shaped almost entirely by media accounts and so public scrutiny of operations is closely connected to the media in any given locality. Integrator investments in branded products and producer reputations in their local communities are important to production and marketing, and media representations of the industry as acting carelessly with regard to water resources and public health provide incentives for better management. The effect of negative media coverage for the livestock industry may be not only to damage reputations or foster mistrust of area producers but also may contribute to the strength (funding and membership) of citizen groups working actively to eliminate externalities from CAFOs.

The interplay between these institutions influences the result of federal and state lawmaking and agency rulemaking alike. Environmental and industry groups actively intervene in the various policy-making processes while media report these events. In reporting the policy actions taken, the media reveal the actions taken by elected officials and bureaucrats alike. The potential revelation of their actions creates incentives for politicians to avoid acting in any way that may be perceived by their constituents as negatively affecting their individual or collective interests. Policymakers and bureaucrats cannot solely cater to local communities and environmentalists primarily concerned about public health and environmental protection without reaction from constituents in the livestock sector; public officials must consider the sometimes competing interests within their constituency and make policy decisions that somehow balance multiple objectives without marginalizing the concerns any single group of constituents. The media will communicate the actions taken to all news information consumers and therefore the opportunities for hidden action by policymakers are few. Publicity of public decision making and firm activities by the media form a powerful incentive for policy-makers and firms to act in ways that do not create losses for society. The full spectrum of incentives confronting CAFO operators is a result of environmental regulation and distribution of information via the media together with the threat of litigation discussed in the next section.

2.4 THE ROLE OF LITIGATION

A key consideration in the decision-making process of the firm concerns the costs associated with the operation of the legal system. In the face of sporadic and incomplete enforcement of environmental laws (for the reasons discussed in previously), the use of the court system to force government regulatory action or to force firms to limit externalities has been very common since the inception of most environmental laws in this country. Litigation has been increasingly used by individual citizens and environmental groups to force firms to mitigate environmental damages and alter their operations in ways that are consistent with laws and regulations on the books or, more generally, tort law. Because agriculture is largely exempt from the Clean Water Act (CWA), many legal actions taken over issues related to CAFOs have been under tort law. The results have been mixed, in terms of legal outcomes, but the financial impacts of litigation and the highly contentious nature of interactions between producers and citizen groups using lawsuits to execute a "polluter pays" approach to controlling environmental externalities have been substantial.[11] As a result, the expected costs of litigation have to be considered when making production decisions because even when litigation does not result in a fine the costs of defense are considerable (America's Clean Water Foundation). For this reason, the threat of litigation is an important incentive that must be considered when trying to assess the components of the firm's decision-making process and the profitability considerations that underlie such decisions.

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[11] For a more thorough discussion of trends in litigation under federal law (including the Clean Water Act, Resource Compensation and Recovery Act, and Racketeering Influenced and Corrupt Organizations Act), state law and tort law against animal feeding operations, see Appendix M of the report by America's Clean Water Foundation cited in this thesis.

From the perspective of the firm, one of the biggest problems associated with the legal system has been the nature of jury awards in cases involving CAFOs or integrators. The economic basis for the sometimes massive jury awards that have been granted is unclear and there is no way for firms to predict, with any certainty, what the cost of a court case may be.[12] When considered in tandem with the lack of clear or consistent regulatory stringency, the obstacles to rational economic decision-making become more daunting because producers have no clear expectation of the result of different management decisions or the failure of some aspect of their waste management system. There are no known ex ante consequences because of this uncertainty and it makes it even harder for a firm to make informed investment and management decisions. To the extent that regulations can provide better signals to firms that indicate the methods used to assess economic damages in the event of environmental release, it may be possible to improve the set of incentives provided to animal agriculture by the regulatory system and the courts.

Under the Superfund Act, there are established procedures to assess economic damages for natural resource injuries resulting from the release of hazardous substances into the environment. These procedures are referred to as natural resource damage assessment (NRDA) and have only been applied to toxic chemicals. Other legal provisions govern natural resource damages from oil or nuclear waste. No attempt to apply the economic principles underlying NRDA to other releases has been made even though this approach would make sense for other injuries to natural resources (Smith). The use of a variety of established economic valuation methods is authorized under NRDA. Some agencies have tried to avoid controversy associated with the use of non-market valuation techniques like contingent valuation to assess non-use or passive use values for environmental goods and services impacted by environmental releases and have preferred a method called habitat equivalency instead. There has been no attempt to update CAFO regulations to include damage assessment provisions, but the prospect of something along these lines being instituted in the future has the attention of the industry.

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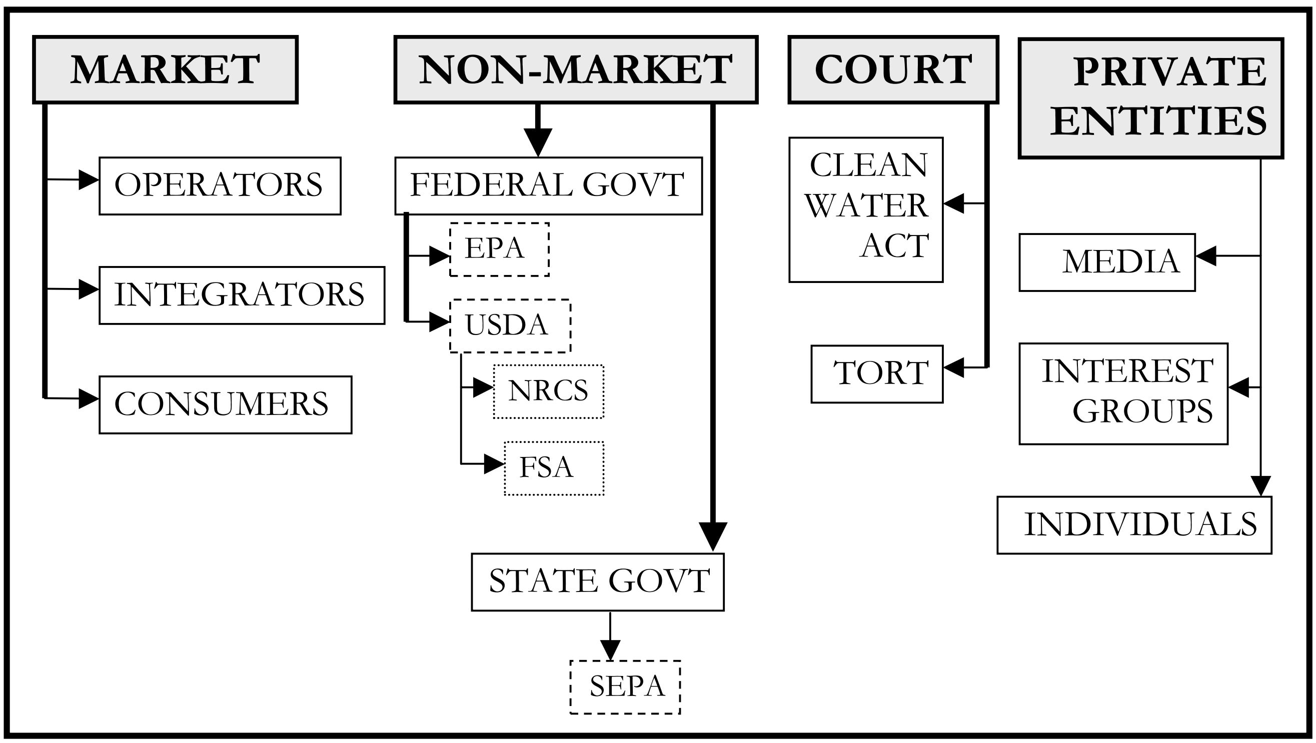
[12] In our highly litigious society, large jury awards have become a familiar news item for everything from smokers suing cigarette manufacturers to a consumer suing a fast food chain for burns resulting from hot coffee they were served. In the case of CAFOs, litigation has focused on everything form labor practices to environmental impacts of operation. The focus in this thesis is on environmental and health concerns related to CAFOs; in these cases jury awards have been as high as $19.7 million for civil nuisance (Associated Press) and $12.6 million for dumping violations in the CWA(Nakashima).

The base economic decision that must be made by a producer involves an assessment of the expected cost of litigation to the firm. This is determined by multiplying the probability of litigation by the expected cost of litigation (inclusive of attorney fees, jury awards and fines which result from regulatory infractions). An argument can be made that the threat of litigation provides the single largest incentive for firms to comply with CAFO regulations given the considerable resources required to reach a resolution via the court system; not the least of which is the opportunity cost of time required to resolve legal disputes. The sum of the expected cost of litigation and the cost of regulatory fines that may result from environmental enforcement actions, compared to the cost of environmental compliance (facilities investments, management in accordance with CNMP) will govern the operator's final decision.

FIGURE 2.1. Institutions in Animal Agriculture



This chapter has presented the institutional structure that CAFOs operate within and has discussed the incentives that form the framework for decision making. Government and market institutions interact with one another, and with CAFOs, in production, regulation, and litigation. Each institution has different incentives that motivate its actions and these institutions in turn attempt to provide incentives to CAFOs that advance institutional objectives. Figure 2.1 above presents the different institutions discussed. Changes in the market, regulation or other factors in this institutional and incentive framework will impact other components and must be considered in analyzing this complex issue. The next chapter reviews the academic literature that has relevance for this public policy problem and subsequent chapters address the complex nature of this problem to evaluate how changes in property rights affect CAFO externalities.

CHAPTER THREE

LITERATURE REVIEW

There are four closely related areas of the academic literature that bear particular relevance to the objectives of this thesis: externality, regulation, crime or deterrence, and environmental monitoring and enforcement. These areas of the academic literature are addressed in separate sections of this chapter, with careful attention to the connections between the topics and their application to issues surrounding CAFOs. The fifth and final section of the chapter reviews the literature specific to CAFO regulation, rather than the more general literature covered in the first four sections. The rationale for regulation of CAFOs is driven by the existence of externalities. The government activities of environmental monitoring and enforcement are the main regulatory functions performed. The academic literature in several broad areas, as well the literature dealing specifically with CAFOs, will be considered to demonstrate the validity and uniqueness of the analysis undertaken in subsequent chapters of this thesis.

3.1 ENVIRONMENTAL EXTERNALITY

The *New Palgrave Dictionary of Economics* (1987) defines an externality as

> "…the indirect effect of a consumption activity or a production activity on the consumption set of a consumer, the utility function of a consumer or the production function of a producer. By indirect, we mean that the effect concerns an agent other than the one exerting this economic activity and that this effect does not work through the price system."

The consideration of external effects or externality began as a subject of welfare economics, initially addressed by Pigou (1920). The treatment of externality as a case of market failure resulting in non-optimal resource allocation comes from Pigou's original analysis and is generally accepted in economics. The generally proscribed remedy for this market anomaly has been government intervention in the market. The publication of Ronald Coase's "The Problem of Social Cost" (1960)[13] stimulated a massive amount of debate about the nature of externality and the approaches taken to remedy what had been previously viewed by most within the

[13] Hereafter referred to in this thesis as "Social Cost".

profession as a market failure. Coase's 44-page article has been one of the most frequently cited articles in all of economics and especially in the area of environmental and natural resource economics. What has become known as the Coase Theorem is a basic concept known to any student of this field. Stigler (1966, quoted in Coase,1988) was the first to refer to Coase's arguments published in "Social Cost" as the now familiar 'Coase Theorem'; the theorem states that, under perfect competition and irrespective of the assignment of legal liability, the result of resource allocation will always tend toward that activity which maximizes the value of production. It was phrased differently but with identical interpretation (in the Pigouvian terminology) by Stigler as "under perfect competition private and social costs will be equal." Coase contended that regardless of whether liability for external effects (he never used the term 'externality' in "Social Cost") rested on the party that was the source of damages or the receptor, an agreement or bargain could be reached between the parties affected, the result of which would always maximize the value of production.

The key aspect of the perfect competition assumption that underlies Coasean bargaining, as it became known, is the costless operation of the pricing system. Coase (1937) had previously elucidated the significance of administrative costs on the operation of the market system in his first seminal work, and transaction costs are perhaps the single-most important aspect of "Social Cost" as well. The assumption of zero transaction costs is what makes Coasean bargaining a possibility, but this assumption has been a source of great criticism of the Theorem. This assumption is no more a departure from reality than most theoretical economic work, however, including the standard set of assumptions in the perfect competition framework. As Coase (1988) later pointed out, the firestorm of criticism and debate that followed the publication of "Social Cost" was a result of even those who sympathized with him misunderstanding his argument. The extended examples provided from English case law that involve externalities that could be resolved through bargaining were provided to reveal that economists' use of a theoretical system that didn't account for transaction costs prevented effective analysis of the effect of changing property rights on the allocation of resources.

Coase's charge to "Social Cost" readers struggling with questions of liability and economic efficiency was to be mindful of the overriding economic problem in cases of harmful effects (the maximization of the value of production) and that courts would decide who has the legal right to do what, not what should be done by whom. The rearrangement of rights via market transactions (Coasean bargaining) will occur only when the transaction costs necessary to alter or combine rights are less than the increase in the value of production that would result. If this optimal arrangement of rights is not the one established by the legal system, the transaction costs required to achieve it may prevent the optimum arrangement of rights from being realized. Coase was careful to point out that when a vast number of people are affected by harmful effects, the transaction costs may be too great for a single firm to attempt to deal with the problem through the market. This would seem to be the predominant case when considering pollution and certainly applies to the case of CAFOs.

The conceptualization of the government as a "super-firm" by Coase (1960) distinguishes it from all other institutions acting within the market system. The distinguishing factors of government as a market institution are: (1) government can influence the use of factors of production by administrative decision; (2) government can avoid the market altogether (a firm cannot); and (3) government can utilize police and other enforcement agencies to ensure regulations are carried out. Coase finds no overriding reason why either the market or the government would be better suited to address a particular externality. He points out that particularly for the case when "a large number of people is involved and when therefore the costs of handling the problem through the market or the firm may be high" government regulation is likely to result in increased economic efficiency. It is for this reason that government intervention has been the most relied upon mechanism to address environmental externalities.

The greatest amount of debate in the literature was over a single aspect of "Social Cost" that contested the use of a Pigouvian tax as the most efficient way to resolve the market failure created by externality. Coase asserted that damages occurred as a result of both the polluting activity and the presence of the receptor, and therefore both parties should share in the cost of addressing a particular externality. Coase believed that unless both parties shared this cost and paid the damages directly to the other party (or parties) harmed by their actions, the convergence of net private and net social costs would never be achieved. Baumol (1972) defended the conclusions of the Pigouvian tradition as 'impeccable' and mathematically rebuffed Coase arguing that if the source of smoke damage (just one of Coase's examples from "Social Cost") directly compensates the injured party in proportion to the amount of damage caused, the level of the impacted activity in the vicinity of the smoke producing activity will not be restricted.

In Coase's (1988) follow-up to "Social Cost" it becomes clear that he and Baumol are in agreement concerning the validity of the Pigouvian tradition, on theoretical grounds, because both recognize the impossibility of implementing the Pigouvian tax given its information requirements (individual preferences, etc.). Recognizing this, Baumol instead proposed a taxation scheme that is based on a set of minimum standards of acceptability where offending inputs or outputs are taxed to achieve some maximum level of a particular pollutant. Given that an acceptability criterion approach is something that policymakers are comfortable with, it is reasoned that this approach would be operable, unlike the pure Pigouvian tax. The Baumol approach, it is argued, is a satisficing one as opposed to the maximizing approach taken by a Pigouvian tax, and avoids some theoretical pitfalls that reveal themselves in the mathematics of optimization (multiple maxima). There are a considerable number of solutions that satisfy a set of acceptability conditions (more flexibility in meeting a pollution standard because various resource allocation arrangements can achieve a pollution reduction) whether or not the second-order conditions are satisfied. There remains the theoretical promise of a Pareto improvement achieving a more optimal allocation (i.e. Pigouvian taxation arrangement), but there isn't any known way to operationalize this efficiency gain because of information obstacles.

Another key point to come out of the "Social Cost" debate has been Coase's assertion that optimality (Pareto equilibrium) can be achieved in the presence of externality. Buchanan and Stubblebine (1962) painstakingly demonstrated this point using mathematics to arrive at equilibria where marginal private cost (marginal evaluation of a particular activity by private parties in the language of their article) equals marginal social cost of a particular activity, given that the receptor is compensated for the marginal diseconomy suffered despite the persistence of a marginal economy for the generator. The conclusion of both articles being that the elimination of externality is not required for an efficient allocation of resources to occur; a market for externalities can achieve Pareto equilibrium. Buchanan and Stubblebine also advocate a 'bilateral tax' similar in reasoning to that proposed by Coase (1960), but are careful to make clear that there is no *prima facie* justification for government intervention where an externality is observed. This is a key point made in "Social Cost" which Coase devotes considerable effort to making clear. This point was first made by Samuelson (1947, cited in Buchanan and Stubblebine) and is also demonstrated by Turvey (1963), among others. All of this theoretical welfare economics adheres to strict assumptions of perfect competition where transactions (and bargaining) are costless activities and where distributional aspects are not a matter of concern. This is troubling for anyone working with external diseconomies in an environment where standard assumptions made about the operation of the market do not apply. The case of animal feeding operations poses these problems for policymakers and economists alike.

Baumol and others have argued that the case of small numbers bargaining to reach an agreement over external effects applies to only a very small number of cases involving pollution and the case of a CAFO is no exception. Where large numbers are involved, as stated by Coase, a firm or the market may not necessarily provide the optimum solution. Transaction costs quickly become an obstacle to bargaining with large numbers; firm decision-making is based on an assessment of the probable transaction costs (inclusive of legal costs) required to either reduce damages into the future through bargaining or recoup damages already suffered through the courts (Auten, Randall, Mishan). The approach taken by public policy to address externality resulting from CAFOs has solely taken the form of government intervention in the market to attempt to force firms to internalize the external costs of their operations. Concerns about the efficiency or optimality of this approach are real, but the only actions taken to address the externality problems to date have been through administrative decision (i.e., EPA's Final CAFO Rule) and litigation.

One major point contained in "Social Cost" was that economists be mindful of their role in the public policy debate about choosing the appropriate social arrangement for dealing with harmful effects; "all solutions have costs…there is no reason to suppose that government regulation is called for simply because the problem is not being handled well by the market or the firm" (1960). Coase states:

> "What has to be decided is whether the gain from preventing the harm is greater than the loss which would be suffered elsewhere as a result of stopping the action which produced the harm. In a world in which there are costs of rearranging the rights established in the legal system, the courts, in cases relating to nuisance, are, in effect, making a decision on the economic problem and determining how resources are to be employed." (Coase 1988, p.132-133)

Coase is very concerned, and rightfully so, that legal decisions and statutory enactments delimit rights which may not be in accordance with economic efficiency. We have seen this occur as federal and state regulation of CAFOs has escalated, continually altering the property rights for producers and for society. Coase recognizes the work of Frank H. Knight that has continually emphasized the role of aesthetics and morals in welfare economics. Of chief importance when trying to reconcile economic theory with applied problems, is recognition of the political-economic environment surrounding the public policy issue in question. Recognizing that economic analysis may often take a back seat to such non-economic concerns is frustrating, but important for the applied economist working in a world with transaction costs where distributional considerations are not ignored, as with Coase's total value of production approach (Auten).

Coase suggests that the problem is chiefly one of devising practical arrangements which will correct defects in one part of the system without causing more serious harm in other parts. To operationalize this when evaluating social arrangements he suggests that economic analysis start with a situation that approximates reality, examine the effects of a proposed policy change, and attempt to decide if the result is, in total, better or worse than the *status quo*. A similar approach is advocated for non-market analysis by Wolf (1979 and 1988). The charge issued by Coase to the entire economic profession in his classic "Social Cost" article is to take into account the cost of operating various social arrangements as well as the cost of transition to a new system so that "in devising and choosing among social arrangements we should have regard for the total effect." Professor Coase (1988) clarifies this further by writing that once transaction costs are accounted for many measures to reduce or eliminate harmful effects will not be undertaken because they will cost more to bring about than the gain they make possible.

The model developed for analysis of firm decision making under environmental regulation later in this thesis attempts to heed Coase's call for models that better resemble the world in which economic decisions are made. The motivation for this work is to develop a theoretical model that achieves greater insight into the impact that different regulatory emphases, legal threats, and transaction costs have on firm decisions, so that the total effect of a given social arrangement may be examined more accurately.

3.2 REGULATION

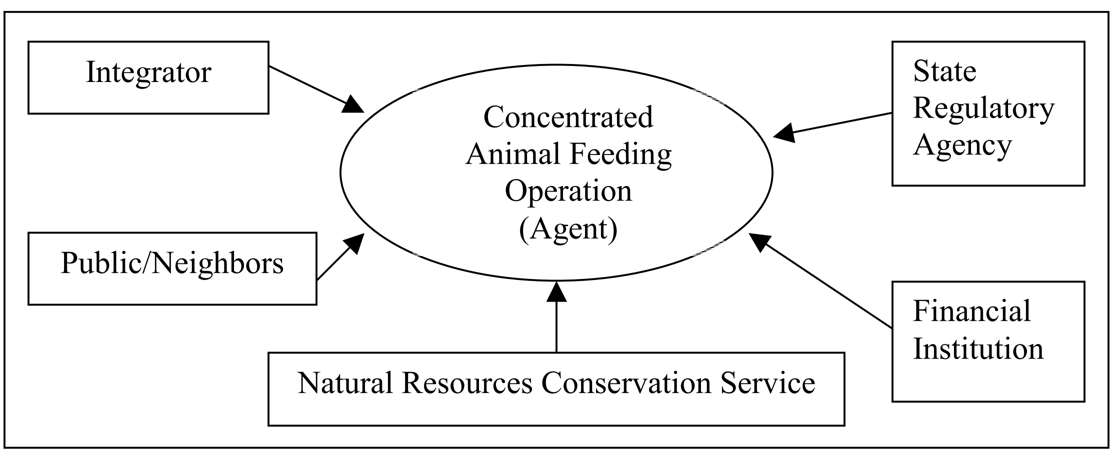
The regulation of economic activity has been a subject of extensive economic analysis and debate. The two predominant theories of economic regulation will be presented and applied to the case of animal feeding operations. One is guided by normative welfare considerations and operates under the rubric of correcting market failures to serve a larger public purpose (i.e., health, safety, environmental quality). The other view is that regulation is a result of calculated political actions taken by organized and effective interests to enhance or protect economic positions in the marketplace. In reality, this author believes that neither view stands alone in describing the reasons regulation occurs, but rather regulation is a result of aspects of both views at work simultaneously and operating jointly. For instance, a regulation intended to address cancer causing pollution may have the effect of a barrier to entry for other competitors.

In the welfare economics view of things (this is based on a Pigouvian approach, as discussed in section 3.1), there are three reasons for government control or regulation that provide areas for analysis in the literature of market failures. Sappington and Stiglitz (1987) designate these as imperfect competition, imperfect information, and externalities. Information and externalities are the two aspects of market failure that are most pertinent to CAFOs because firms continue to be price takers in the livestock production industry despite the existence of externalities and information asymmetry. As Joskow and Noll (1981) have pointed out, the aspects of regulation that involve violations of standard assumptions in microeconomics (perfect and costless information in particular) are those that are most intriguing for research and most useful in terms of society's attempts to correct such market failures. If information were perfect and costless, optimal source-specific standards could simply be legislated to correct the problem. Joskow and Noll's statement rings true for CAFOs; standards and performance criteria imposed on the industry have not resulted in the apparently desired public policy outcome, resulting in still more regulation.

The reasons for regulation of CAFOs by government have been based on externality problems and welfare improvements have been the desired result of interventions in the market to reduce pollution and reduce public health concerns. This reasoning or justification for regulation has been a result of public scrutiny and several high profile events that were mentioned in chapter two of this thesis. As public awareness of this complex problem has grown, the demand for reduced risk of exposure to fecal coliform, nitrogen and phosphorous has been directed at public officials. Local, state and federal institutions have enacted laws and promulgated regulations to attempt to address these problems. Sappington and Stiglitz (1987) refer to this process as rent extraction from the private sector by the public sector. The information problems they emphasize in their framing of the regulation problem are of greatest concern because it is widely held that those involved in production have more information about production processes, the demand structure for the commodity in question, and relevant factor costs than does any outside party. Overcoming this limited information problem is a central focus of regulation theory because of the impact the asymmetry has on government's attempt to control the firm and extract rents (Sappington and Stiglitz). Sappington and Stiglitz assert that differences in firm behavior must necessarily be associated with differences in institutional structure.

The problem of regulation is framed in the familiar principal-agent format; more specifically, from the perspective of the firm, it is a problem of multiple principals. Figure 3.2 shows a simple mapping of the different principals that a CAFO operator must be accountable to, to a varying extent. Each principal depicted has different objectives and the interaction between each principal and the agent is governed by these objectives and the nature of the particular relationship. In attempting to exercise control over the CAFO and elicit the desired behavior from the agent, the firm faces multiple objectives (those of the financial institution, the integrator, and the government), which it must balance to sustain operation.

FIGURE 3.2. Multiple Principal-Agent Problem for Animal Feeding Operations



The Pareto efficiency of the operational equilibrium created by the firm in juggling its different objectives is of chief concern to the economist. It has been demonstrated that Pareto efficiency cannot be achieved when operating at the equilibrium in a multiple principal-agent scenario (Braverman and Stiglitz, Bernheim and Whinston, Arnott and Stiglitz). The best that government can hope to achieve in regulating this industry, it would seem, is a social welfare enhancing (as opposed to maximizing) Pareto improvement. If one considers the multiple objectives, especially those of principals outside the public sector, which must be balanced by the profit-maximizing firm, it becomes intuitively clear why externalities persist. What is not so intuitively clear is how to achieve Pareto improvements through a combination of market interventions (regulation, subsidy, tax, etc.) and market instruments that maximize social welfare.

In Joskow and Noll (1981), there is regret that so much reliance had been given to effluent limitations and particular control technologies, as opposed to corrective taxes and tradable licenses. While so-called command-and-control approaches still dominate in practice (the most recent round of CAFO regulations are no exception), the emphasis from government has turned toward more market-based mechanisms, the merits of which have been demonstrated successfully by emissions trading instituted under the 1990 Clean Air Act Amendments (Joskow, Schmalensee, and Bailey). The difficulty in implementing market mechanisms lies in the problems of information costs, administrative feasibility, and uncertainty (Joskow and Noll). While the current regulatory climate seems to favor market mechanisms over standards, the implementation of these approaches remains extremely limited. Water quality trading and expanded air emissions trades appear to be in the works, but administrative and policy design hurdles remain.

The other predominant view of regulation is variously characterized as legislative or political in nature. This second characterization is also known as the "Chicago School" approach because it was first espoused by faculty of the University of Chicago and has dominated the approach to research on such problems at this institution ever since. Stigler (1971) presents this view of regulation by writing that "political systems are rationally devised and rationally employed, which is to say that they are appropriate instruments for the fulfillment of desires of members of the society." When and why an industry is able to use the state for its purposes (to gain economic advantages) is the "problem of regulation" stated by Stigler. The power of the state to coerce (taxation as legal seizure of money, control movement of resources, etc.) is what sets government apart from any firm or individual in the market[14] and creates the possibility for an industry to utilize the state to enhance its own profitability.

Stigler describes four main policies sought by firms or industries to benefit themselves. The "most obvious" of these is a direct subsidy in the form of a transfer from government to the firm. It is argued that this is the least likely policy sought (unless certain conditions are met) because the subsidy will likely have to be shared with all new entrants into an industry, resulting in a diminishing allocation divided among a growing number of rivals. The second policy sought is control over entry into an industry or occupation. The theory expounded in Stigler's article (1971) states that any entity with enough political power to utilize the state will seek this policy to enhance its economic position. Control over entry can take many forms and generally also works to retard the growth of new firms. Vertical integration (as in the CAFO industry) is one form of control over entry, but it is "vastly less efficacious" than an import or production quota. A third class of policies sought affects substitutes or complements. Inputs in the production process might be viewed in this class and subsidization of feed grains might even be viewed as one aspect of such control over entry in the livestock sector. The final category of policies sought is price controls, and, without the coercive power of government, price-fixing is impossible in industries with very many firms. Even in the presence of entry control, the absence of price controls will make it impossible to achieve more than competitive rates of return.

In practice, this political approach requires careful consideration of the profitability of regulation on the part of the industry because the "political process erects certain limitations upon the exercise of cartel policies" (Stigler, 1971). Once controls are enacted, the distribution of influence among firms in an industry changes from the competitive market where production shares determine control of price and output to a scenario where political efficacy dominates cost-minimizing practices in determining profits. The cost of achieving such regulatory changes are great because of procedural safeguards required for public processes. The power of other industries that will be affected by a proposed regulation must also be taken into account when deciding to seek regulation.

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[14] Coase (1960) apparently preceded Stigler in making this important distinction between the power of government and firms operating in the market, but Coase did not discuss the possibility that the powers possessed by government might be harnessed to benefit the firm. Coase and Stigler are longtime colleagues from the University of Chicago.

To understand why firms and industries are able to utilize the political process to gain economic advantage, Stigler articulates two differences between democratic political decision-making and market decision processes: simultaneity of decision and non-excludability in the decision-making process. All decisions must be made simultaneously by a large number of persons or their representatives, which makes the political process extremely expensive to operate. Because the political process must include everyone, it does not allow for participation in proportion to interest and knowledge and there are not good incentives to acquire knowledge (as there are in private markets). These differences are what determines the nature of interaction between the private market and the non-market, where elected officials organized into political parties (a type of firm or industry group) and constrained by bounded rationality require resources and votes in order to be able to affect public policy decisions. The industry seeking regulation must be prepared to provide both inputs, noting that the cost of legislation probably increases with the size of the particular industry.

Vertical integration has provided some protections for the livestock industry in the form of increased costs of entry for new firms, which likely benefits established producers the most. Environmental regulation is strongly opposed by agricultural interest groups, so it has not been the result of CAFOs courting elected officials for increased regulation to protect against entry by competitors or control prices, but the result of this regulation has had the same effects that Stigler cites as motivation for firms to seek regulation in their industry, especially where it pertains to control over entry by new rivals. Agriculture has a long history of government intervention. While most of this intervention has been to the advantage of farmers (target prices, LDPs, emergency assistance for drought, and subsidized crop insurance), environmental regulations on livestock production are seen largely as profitability crippling penalties because they don't seek to remedy financial losses on the part of the farmer (as other interventions do) but rather losses previously unaccounted for in the financial decisions of the farm that have negative effects external to the farm itself. To consider this in the context of utility functions, producer utility functions are negatively impacted by regulation that increases production costs, but the intent of regulation is to remedy negative impacts on society's utility and the production functions of other firms and sectors impacted by CAFO activities.

The regulatory buildup affecting CAFOs has introduced costs (or extracted rents in the Sappington and Stiglitz terminology) through permit requirements, comprehensive nutrient management planning, and facility design requirements (related to storm capacity). High marginal cost farms are less likely to be able to afford to make such improvements and many farms operating without confinement may not be profitable enough to be able to afford to meet the regulations. Firms with contracts for delivery of animals or animal products (milk, eggs, etc.) have advantages under increased regulatory scrutiny because access to capital, markets for their products and technical assistance are more readily available than for independent or smaller farms that may operate in a more traditional manner. Non-regulatory government interventions in the market may further exacerbate entry effects on smaller operations through subsidies on feed grains that keep input costs for livestock producers artificially low (Westcott and Price) as well.

Stigler calls for the acceptance of a "rational theory of political behavior" to counter the idealistic view of public regulation that is deeply imbedded in professional economic thought. Such a theory, it is asserted, would greatly benefit the economic analysis of regulation and likely help to overcome the "imponderable, …unpredictably shifting mixture of forces" that characterize politics, and by implication political decision making. Stigler joins Coase in rejecting any *a priori* justification for regulation (not surprising since they are both proponents and figureheads of the "Chicago School") and harboring a great preference for unhindered operation of the market; both call into question the apparent acceptance by a majority of the economics profession that government intervention (regulation) is the remedy for market failures.

In the review by Joskow and Noll, it is believed that far too much emphasis in the literature has focused on whether or not to regulate, while far too little has focused on how to improve the performance of regulatory policies. Stigler's article (1971) is of this first type of work and seeks to determine the reasons why economic regulation occurs; in a response to the chapter by Joskow and Noll, Stigler (1981) questions how we can know what questions to ask about the effects of regulation unless we know why we have a particular regulation. More directly, "if one cannot explain why some regulations appear and some do not, one simply cannot deal with the fundamental questions of regulation." While Stigler's point is clear, this author wonders whether work assessing the source or reason for regulation serves to improve the efficiency of the regulatory system. After some thought it seems that to the extent that such analyses shed light on the nature of the political decision making process (which they no doubt do) and can help to provide information to the public about the nature of this process, perhaps the result of future decisions can be improved. The deciding factor will be whether or not the public educate themselves (once this information is available) about the inefficiencies that result from such capture of the public sector by the private market. Stigler's own article would seem to indicate that this is not occurring in political decision making because the incentives to be informed aren't the same as those in the private market. The importance of institutional knowledge and the course of events leading up to the present when analyzing a particular economic problem is essential, but if the hope is to improve the efficiency of public policy, time may be better spent working to improve the performance of regulatory policies, as suggested by Joskow and Noll. Afterall, economists play no direct role in the political processes that have already resulted in social welfare losses, but economists may play an active role in making Pareto improvements to remedy such welfare inhibiting policies.

Empirical research in this area has suffered from a lack of data to analyze environmental regulation but has made strides in recent years with new and improved data sets available (see Jaffe, et al for a good example). The political economy of regulation has thus far not been explicitly addressed but is a very important consideration to make when assessing different policy options. Joskow and Noll point out that the two basic problems which arise in political debate over regulatory changes are: (1) some will gain and others will lose with a change in regulation; (2) the timeline for transition between regulated and unregulated (or vice versa) states of the world. First, there is often great uncertainty about the gain-loss distribution as a result of a regulatory change. While government might wish to intervene to alleviate inefficiency, in practice, intervention may be equally likely for distributional reasons (Sappington and Stiglitz). Second, the long-run equilibrium focus of economists is not consistent with the short-run considerations of legislators (economic response time during transition to new equilibrium, re-election, etc.).

Regulation is created and nurtured by Congress and Congressional behavior appears purposeful and rather predictable. Several studies have demonstrated this purposefulness and corroborate the predictability implied by Stigler's analysis. Rohde and Shepsle (1973) found that committee assignments are nearly a perfect match to preferences, and thus are geared toward re-electability. Shepsle (1978) also found that when demand for committee membership increases, a new equilibrium membership level is achieved through expansion; the implication of this is stated as "legislative oversight is by choice". A similar finding from Ferejohn (1974) is that committee membership and reelection are linked via the use of oversight to reward the legislative districts represented on a particular committee. One key mechanism of legislative control pointed out by Weingast (1977) is the relative distribution of the budget for an agency among functional categories of expenditures. One course of action for industry capture of regulatory agencies appears to be to intervene in the budget allocation process to reduce the resources devoted to analytical and enforcement responsibilities, thus making the regulatory agency more dependent on outside information for decision making.

Some analysts of these matters focus entirely on the question of redistribution that occurs as a result of regulation and others are perhaps more concerned with the specific regulatory mechanism, but the approach here is not immediately concerned with either of these more than the other. This thesis attempts to realistically model the structure of decision making given the actual regulatory framework and insights from other less restrictive models of firm decision making under regulation (uncertainty). Joskow and Noll point out that researchers must be mindful of work that calls to question two of the behavioral foundations of the current theory of decision making under uncertainty, both of which are pertinent to the analysis in the later sections of this thesis. Research into how expected utility maximization and Bayes' Rule may not accurately categorize decision making is a growing body of literature that originated with March and Simon (1959), in the context of organizational decision making, and Tversky (1972). Tversky laid the foundation for what is now known as psychological economics and worked extensively with 2003 Nobel Laureate Daniel Kahneman to advance this understanding. For a thorough review of this literature that discusses how human judgment differs from the way it is traditionally portrayed by economists, see Rabin (1998). Work in this area is focused on finding alternative methods that may more accurately represent choices under uncertainty (given limited information), the nature of human preferences and the rationality of human decision-making. A review of the literature would not be complete unless this work was mentioned. The standard expected utility framework is utilized to analyze these sorts of problems throughout the literature and will be incorporated into the model of decision-making in this thesis.

3.3 ECONOMICS OF CRIME (AND DETERRENCE)

Economic analysis of crime has been an area of extensive inquiry over the last thirty years. The economic approach to this analysis will be presented in this section with application to the specific problem of environmental crime in section 3.4. Gary Becker (1968) has contributed to the literature the single most influential article on the economic analysis of crime, enforcement and punishment to date. His work, for all intents and purposes, represents the only (economic) attention paid to the subject matter since the time of Bentham (Polinsky and Shavell) and is the basis for almost all modern approaches to economic analysis of criminal activity. While the data and examples provided throughout Becker (1968) reference criminal acts only, the usefulness of this analysis is broadly applicable to all illegal activity, whether civil or criminal in nature. He devises a model that focuses on the social loss from offenses committed after accounting for the damages from the crime (damage = harms – gains), the cost of apprehending and convicting the accused, and the cost of punishment (fine or incarceration). The goal throughout is to arrive at an optimal level of criminal activity and enforcement for society; this optimal level is one where the cost to society of maintaining a particular level of criminal activity (supply of criminal offenses to use Becker's terminology) is not greater than the economic damages caused as a result of offenses committed.

Becker uses the familiar expected utility (expected cost as a proxy for utility) approach to evaluate the supply of offenses from offenders, whereby, as long as the expected utility from committing an offense (engaging in a particular economic activity) is greater than the expected utility from using time and resources in another activity, offenses will continue to be committed. The highest valued use of time and resources predominates. The expected utility framework for evaluating choice is a powerful tool that has been mentioned and that is utilized within the model of firm decision-making presented in the next chapter of this thesis. As evidenced by Becker's application of expected utility to illegal behavior and the vast body of subsequent work performed in this area using the same framework, it is a well-accepted method of analysis despite work in the area of behavioral and psychological economics (cited in the previous section) which has cast doubt on the accuracy of expected utility as a model of human choice for economic analysis. No better models have yet been developed to characterize the nature of human decision-making under uncertainty, although researchers hoping to improve on the expected utility model from microeconomic theory are performing this work currently.

The aspect of Becker's article with the most importance when applied to the analysis of CAFOs in this thesis is the discussion about deterrence of illegal activities (alternatively described as incentives to behave in accordance with laws and administrative regulations) and the calculus of probabilities of getting caught and the accompanying fines or punishments that are assessed on violators. While other considerations in the social welfare criterion approach provided by Becker are very important aspects of the larger optimization problem from the perspective of society and government in particular, the bulk of attention given to Becker's treatment that will be covered here centers on the variables *p* and *f*, probability of detection or getting caught and the size of fine or punishment (probation, prison sentence, etc.), respectively. Other important social welfare considerations drawn from Becker's work will be addressed as the analysis of the model and interpretation of the comparative statics are undertaken in later chapters.

The expected utility of offenders (and thus the supply of offenses) is governed in large part by *p* and *f*. These variables are a function of federal, state and local laws, legislative priorities (budget making process), budgetary constraints, and government enforcement agencies' implementation (effort). These two variables are the most important in this thesis because of their deterrence effects on offenders (or potential offenders) and because of the costs they impose on society. An increase in either *p* or *f* will reduce utility expected from an offense and in turn would tend to reduce the number of offenses because either the probability of getting caught (increased chance you will have to "pay" via the established punishment) or the cost of getting caught itself will have increased [Mathematical proof in Becker (1968, fn.16) shows this as: $\partial E(U)/\partial p < 0 > \partial E(U)/\partial f$]. An interesting finding from the literature indicates that offenders, in responding to different values of *p* and *f* or (and by implication) changes in either variable substitute among offenses (Smigel, 1965) is cited in Becker (1968). Substitution among offenses is in effect what occurs at CAFOs when certain poor management practices are more heavily discouraged based on penalties or probabilities of detection than others. For instance, firm decisions to over-apply manure to resolve a waste storage problem rather than draining a lagoon into an adjacent waterway may be viewed as an example of such substitution among offenses because the likelihood of getting caught discharging into a public waterway and the expected fine are likely to be much less than for over application. Harford (1978) and others examine *p* and *f* extensively in the more specific literature of environmental monitoring and enforcement, where pollution, effluent or waste is the more specific variable that replaces Becker's general use of offenses, *O*, that will be discussed in the next section of this chapter.

Risk preference is an important aspect of the analysis of effects of *p* and *f* on offender behavior when trying to arrive at an optimum level for each variable that achieves an overall Pareto improvement when using Becker's social welfare function approach. The simple analysis presented in the preceding paragraph assumes risk neutrality on the part of the offender, as do the analyses contained in the more applied theoretical work presented later in this thesis. Becker shows however that differences result from risk preferences that depart from neutrality. He demonstrates that an increase in *p* would reduce the expected utility, and thus the number of offenses, more than an equal percentage increase in *f* if the individual has preference for risk; and that an increase in *f* will have greater effect if the offender has aversion to risk. "The widespread generalization that offenders are more deterred by the probability of conviction than by the punishment when convicted turns out to imply in the expected-utility approach that offenders are risk preferrers (Becker)," which seems to make intuitive sense to this writer. Empirical confirmation of this is cited in Becker (Smigel; Ehrlich) and high correlation coefficients indicate not only that *p* and *f* have negative effects on *O* but that the effect of *p* exceeds that of *f* indicating that offenders tend to be risk preferrers. Becker then draws conclusions about the potential impact of public policy's influence on whether or not "crime pays" based on its selection of *p* and *f*; his complete analysis concludes that society can minimize social loss from illegal activities by selecting these values from "regions where risk is preferred" and therefore "crime does not pay."

A second aspect of Becker's (1968) article that does not bear directly on the firm decision-centered analysis presented here but holds important significance from a public policy perspective are the social welfare effects of manipulations of *p* and *f* that manifest themselves in the cost associated with changes in the two variables. The optimality of different social arrangements is a chief concern for the economist and hopefully for the public official as well. With a sole objective of deterrence, *O* could be reduced very effectively by simply raising *p* to close to 1 and increasing *f* to the point where punishments exceed gains from offenses. Becker warns however that the cost of combating offenses (raising *p*) and of increasing fines is considerable. Selection of values for these variables requires a detailed social calculus that Becker presents as being governed by social loss from offenses, *L*. The social welfare function, given by L, is a criterion used to give “due weight to the damages from offenses, the costs of apprehending and convicting offenders, and the social cost of punishments,” the objective being minimization of social loss. Variables subject to social control that ultimately determine L are the amount spent combating offenses (a function of p) and the punishment per offense, f. A final consideration that must be a factor in assigning levels to probability and punishment that is raised in Becker is the elasticity of offender response to changes in these variables. With regard to these response levels, the greater the elasticities or the smaller the costs of apprehension and conviction (which may be reduced through improved technology), the smaller the cost of achieving a reduction in offenses and the greater the effectiveness of social manipulations of p and f. Elasticities are likely to vary considerably among offenses, with more calculating crimes being more responsive to such manipulations. Illegal actions taken by CAFO operators seem to fall in this category; they are production decisions made by firm managers.

Becker (1968) places a great emphasis on the use of fines, as opposed to other more costly punishments (institutionalization, probation, etc.) for offenders, concluding that whenever feasible fines should be used to increase social welfare. One major argument in favor of fines has been that they provide compensation to victims[15] and do not require additional public resources from the victims. Polinsky and Shavell (2000) note that one of the major contributions made by Becker was his recognition that the social cost of increased levels of p is much greater than increases in f. Because combinations of p and f determine the level of deterrence, the most effective way to minimize enforcement costs is utilizing low probabilities in tandem with the highest possible fine; the implication of this being that “some degree of underdeterrence is desirable” to conserve enforcement resources. Polinsky and Shavell find that this approach to lowering enforcement expenditures may not achieve first-best behavior on the part of offenders, but the decline in deterrence that may result involves no first-order effect on social welfare. Their analysis agrees with Becker that fines should be used to the extent possible, and goes perhaps a step farther stating that maximum feasible fines should always be imposed before imprisonment is considered unless the additional deterrence achieved is worth the additional cost of institutionalization. Key to social welfare is the inclusion of the cost of apprehension and conviction in fines.

[15] By “victims”, Becker (1968, fn. 36) means the rest of society and not just the persons directly harmed

Polinksy and Shavell (2000) raise one important aspect of enforcement not addressed in Becker (1968) that is of additional value when considering the nature of legal rules and property rights in cases of environmental externality—the distinction between strict liability and fault-based liability rules. Strict liability imposes a sanction on the injurer[16] regardless of her behavior; fault-based liability imposes a sanction on an injurer only if the act committed is determined to be socially undesirable. The importance of the offender's risk preference is also considered when comparing liability rules. Polinksy and Shavell find that in the risk neutral case fault-based and strict liability are equally desirable; if the standard is optimally selected, the same fine will lead to compliance under either liability rule. Under risk aversion, fault-based liability may be preferred because the fine required to elicit the desired behavior is smaller than under neutrality and deterrence can be achieved without imposing risk on risk averse individuals. Though not explicitly stated, the implication from Polinsky and Shavell (2000), when considered in light of Becker's (1968) findings about the risk-loving nature of offenders, is that strict liability is the preferred legal rule given optimal standards and attention to the social welfare effects of values for p and f. Additionally, Polinsky and Shavell find that the incentive effects of strict liability are superior to fault-based rules because "socially excessive" levels of harmful activity are avoided resulting in a preferred social arrangement, on welfare grounds. They find that in practice, the theoretical findings presented in the literature are being implemented in some respects and not in others. Chiefly, enforcement costs could be substantially reduced if enforcement efforts (p) were reduced and fines raised; the level of deterrence also should be raised above current levels if more socially optimal outcomes are to be realized.

The optimum enforcement of laws was further addressed by Stigler (1970) in a short article that seeks to "construct a theory of rational enforcement", which goes along with Becker's (1968) economic treatment of issues related to crime. Stigler's main contribution is to describe the importance of the concept of marginal deterrence in setting enforcement policy. Important recognitions he makes that have bearing on the assumptions made by Harford (1978) [discussed in the next section of this chapter] are that: (1) the probability of detection is an increasing function of the frequency of offenses; (2) the greater the frequency of offense, the greater the probability of detection because the enforcement authority learns more about your behavior as

[16] Polinksy and Shavell (2000) use the more legal terminology "injurer" to refer to the individual who violates a regulation or breaks a law; Becker (1968) uses the term "offender" to refer to the same individual. The terms are used synonymously in this thesis.

time goes by[17]; and (3) the size of *p* and *f* increase in the size of the offense ("violation" in Harford's terminology). Viscusi and Zeckhauser (1979) further contribute to this body of literature in attempting to assess the nature of optimal standards when there is incomplete enforcement, a situation that poses many obstacles for those attempting to model the scenario but one that arguably presents a more realistic situation in practice given budget constraints. Viscusi and Zeckhauser take issue with the analysis of regulatory standards on a single representative firm and note that differential response frameworks are more appropriate, demonstrating that higher levels of standards may actually result in increased violation of the standard because costs of compliance become too great. They advocate that policy design should pay closer attention to the reaction and concentration of firms at the critical response point, and not simply the average firm in the market. Non-uniform standards are found to offer a far "greater potential for effectiveness and are particularly appropriate when old and new investment activities entail different compliance costs."

The approach taken by Becker (1968) and others in the literature has been from the viewpoint of society, with the choice variables being the level of fines and probability of detection. This thesis seeks to investigate how current regulation has impacted the profits of the firm and to determine the importance of a firm-focused consideration of policy actions when attempting to structure incentives in a way that achieves the desired outcomes.

3.4 ECONOMICS OF ENVIRONMENTAL MONITORING AND ENFORCEMENT

As noted in Russell (2003) the literature covering instruments for environmental protection and natural resource and environmental damages have dwarfed that of monitoring and enforcement (ME), but there is a distinct thread within the environmental economics literature that addresses this issue. The reasoning behind the decidedly smaller volume of publication in this area is assigned to the desire of environmental economists to work in areas relevant to policy decisions; politicians have never paid very close attention to the ME aspects of legislation tending to concern themselves more with the specification of punishments than ensuring the

[17] Stigler (1970, p.529) describes this as a statistical inference problem, whereby the regulator or enforcement authority attempts to estimate the average, durable propensity to offend on the basis of a sample of observed behavior, indicating how propensity responds to changes in penalties; the larger the sample, the more accurate the estimate of propensity.

threat of punishment is credible. Nevertheless, these problems are very important to the implementation of policy and deserve attention. ME is an essential area of consideration when examining the behavior of regulated firms, which is a key aim of this work. The more general economic foundations for this work were presented in the previous section. The subsections covering specific applications to environmental externalities here will cover:

- the costs of environmental enforcement (3.4.1);
- the structure and types of penalties associated with violation of environmental regulations (3.4.2);
- issues of regulation in practice (3.4.3); and
- consideration of the role that the courts play in enforcing environmental law (3.4.4).

Each subsection will attempt to make application of the various aspects of ME to the current regulatory and legal environment surrounding animal feeding operations in the United States. It should be noted here that the vast literature on instruments for environmental policy is not covered beyond discussions of the use of standards because emission taxes, marketable permits and other economic incentives for environmental compliance are not utilized in the regulation of CAFOs, although water quality trading is one such mechanism that has been proposed in policy discussions. The analytical focus of this thesis being construction of a model that is consistent with economic theory and that performs according to the stylized facts we have about management decisions being made by CAFO operators, the literature on policy instruments will largely be left for another author to review[18]. The final section of the chapter (3.5) investigates the CAFO-specific literature relating to the effects of regulation on the firm, the costs of CAFO regulation to the firm and to society, and the structure of regulatory approaches (optimal solutions) to the problem of CAFO externality.

3.4.1 Costs of Environmental Enforcement

The discussion so far about enforcement costs has centered on public policy decisions regarding the selection of p and f, with probability of detection contributing most to enforcement

[18] Stavins (2000) provides an excellent review of such instruments in an economic and public policy context.

cost on the part of regulatory agencies, as discussed in Becker (1968) and Polinsky and Shavell (2000). The general implication is that to the extent that public authorities can lower *p* and raise *f*, cost of enforcement can be reduced without affecting optimality (a Pareto improvement). Extensions of the general model of behavior to a decentralized enforcement regime like that commonly found under federal environmental regulation complicates these models somewhat and the more directed literature that addresses these problems has raised some important issues for policymakers to consider. Chief among them is the different incentives that local enforcement agencies have compared to a central agency where standard setting occurs (Linder and McBride), which results in uneven implementation of many environmental regulations. A rational local agency is very sensitive to political costs and benefits of its actions and there are advantages to a cooperative relationship between firms and local agencies.

Enforcement is not perfect in the sense that all infractions cannot possibly be detected and some infractions will not be detected even when audited or inspected. Linder and McBride (1984) construct a model to assess the compliance of firms and obstacles for regulatory agencies when there are stochastic discharges and either standards or taxes can be utilized. Under standards, it is found that probability of detection is the key variable determining behavior even if penalties are increased and standards made more stringent because the behavior of the profit-maximizing firm will remain unaltered unless detection occurs. Without detection there is no increased expected cost of non-compliance on the part of the firm. Linder and McBride also find that a firm's past behavior influences regulatory stringency, another incentive for the firm to comply with standards (or at least avoid getting caught). Oljaca, Keeler and Dorfman (1998) found empirical evidence that past actions taken by the firm (prior regulatory infractions) significantly influence penalty levels in water quality enforcement actions. The authors also consider the role that concealment actions taken by regulated firms play in reducing the expected cost of non-compliance; when concealment occurs, it is likely to impact *p* even more, further marginalizing the importance of *f* and stringency of standards.

Malik (1992) takes up the assertion, long-held in the environmental economics field, that economic incentives are less costly to enforce than standards or direct controls. He demonstrates that assumptions about administrative costlessness of instruments like taxes or tradable permits are not accurate and that the transaction costs associated with the operation of economic incentives can actually exceed that of standards, even when you relax the assumption of perfect enforcement. The overriding point in this article that has bearing on the study of CAFOs is consideration of the role of transaction costs in implementing regulations and the relative transaction costs associated with different forms of regulation (public versus private regulation will be discussed in subsection 3.4.4). Profit-maximizing firms and enforcement authorities with different objectives (from locality to locality and from a central, rule-making agency) both have to take into account the relative transaction costs of different courses of action.

Segerson (1988) proposes a method for addressing pollution which can only be measured from ambient levels because of resource or feasibility constraints; non-point source pollution from farms in particular. While CAFOs are regulated by the EPA as a point-source of pollution requiring an NPDES permit (subject to size and other requirements), there is no mechanism for continuous monitoring of pollution from CAFOs, except in special circumstances where other monitoring activities in a watershed may be ongoing. Additionally, there are different stages in the production process that have properties of both point and non-point sources. Storage lagoons for instance are easily classified as a point source, but areas where waste is applied to the land cannot be classified in this way, in the same way that croplands where pesticides are applied are not considered point sources of pollution. The "difficulty-of-monitoring curse" (Russell) addressed by Segerson is the predominant scenario for animal feeding operations which are often clustered within a watershed. Even when ambient water quality monitoring is available (a least-cost monitoring improvement over no monitoring at all), free riding is possible and likely from an expected-cost, profit-maximizing firm perspective. Segerson proposes a fine or charge be imposed upon all operations in the watershed equal to the total marginal benefit of reduced ambient pollution levels and not just an equal share of the cost, which allows free riding to persist. This is a proposal to cope with information asymmetry and uncertainty on the part of a regulatory authority, given an externality problem that cannot be monitored directly (at the individual farm level) and has a range of possible damages that depend not only on pollutant levels but also on factors like stream flow and exposure risks.

In Segerson's article she describes required best management practices applied on a site-specific basis as "generally impractical"; it occurs to this author that current build-up of regulation on CAFOs has resulted in this very scenario, especially when you consider CNMPs. In short, since it is impractical to measure the problem the regulation is attempting to measure the inputs that will reduce the problem. The regulatory impracticality of this scenario is readily apparent to anyone who has a moderate familiarity with the regulations in place. Perhaps an ambient monitoring arrangement would provide a more efficient way to improve behavior or incentivize compliance with CNMPs than the present system, but one must be mindful of implementation hurdles posed by decentralized enforcement discussed in Linder and McBride. Group performance contracts for agricultural non-point source pollution reduction have recently been proposed to address some of these issues and may hold promise as a future environmental policy instrument (Taylor, Randall and Sohngen).

Harford (1978) presents the model and uses the approach that motivates the quantitative analysis in this thesis. Harford's main objective is to compare the behavior of firms under imperfectly enforceable pollution standards and taxes. A very general model of firm behavior based on the principle of profit-maximization is presented and analyzed through a careful discussion of first- and second-order conditions and the derivation of comparative statics. Because the chief objective of the Harford article is to compare the environmental and behavioral effects of different policy instruments, the level of market output and the level of pollution are treated as the endogenous (choice) variables in his model of firm decision making. The general model presented by Harford focuses on a firm profit function[19] (as viewed from the perspective of society or a social planner) which takes the form

$$\pi = R(x) - C(x,w) + b[C(x,w) - C(x,w^{\circ})] - PF_s G(v)\,. \qquad 3.1$$

Profit is represented by revenue as a function market output, $R(x)$, minus the cost of production which is a function of both market output, x, and untreated waste emitted, w, plus a government provided subsidy to defray the costs of pollution abatement (taken to be some share of the difference between the cost of production given the selected amount of waste emitted, w, and the cost of production based on an amount of waste emitted in the absence of standards, w°), minus the expected cost of regulation, which is the product of the probability of detection, P, the expected fine under standards, F_S, and the size of the violation, $G(v)$, where v is the difference between w and w_S, the waste standard. Because x and w are treated as the endogenous variables in the Harford model, firm profit-maximizing decisions don't focus on the more fundamental

[19] Here the focus will be only on Harford's formulation of the profit function under pollution standards, because standards are the policy instrument present in CAFO regulation. The original article also formulates a profit function under emission taxes. All reference to Harford's analysis here only refers to his work dealing with standards.

production decisions which underlie the joint outputs of the firm. This is consistent with the objectives of the Harford analysis and is one aspect of his 1978 article that this thesis aims to expand upon by looking more closely at firm-level decision making and more specifically at a particular source of externality. Whereas Harford is focused exclusively on the effects of changes in socially controlled variables on levels of output and waste emission, the focus here is meant to be more detailed and attempts to gain insights into how regulation affects firm-level production decisions (at the input level), not just changes in waste standards (and emission taxes), pollution abatement subsidy levels, probability of detection and fine levels.

The nature of comparative statics is such that the result of changes in the socially controlled variables yield expected results; namely that increases in the probability of detection or the fine level will lower waste emitted and that an increase in the subsidy on abatement will lower emissions also. There were several ambiguous results in the Harford analysis, the most notable of which result from the effect on emissions and market output of increases in (a loosening of) the waste standard. The direction of change in both emissions and market output follows the slope of the fine function (the second derivative of the fine function, given by G''). Because of the nature of the second order conditions, a decreasing fine function is theoretically possible in the Harford analysis. This leads to perhaps the largest single insight from the Harford article: making the standard marginally stricter will increase the actual amount of waste released by the firm, *ceteris paribus*. Because of the nature of expected costs of violation, Harford finds that the size of the violation increases in the same magnitude as the reduction in the allowed level of wastes. A firm may go from full compliance to totally ignoring the standard as it increases in strictness if the expected fine does not increase rapidly enough with the size of violation. An application of Harford's approach is made and the profit function expanded for the case of CAFOs in the next chapter. The aim of this is to provide a richer analysis which considers not only the emissions effects of standards but also the input decisions of rational producers responding to incentives in the market.

3.4.2 Penalties in Environmental Regulation

The general theory of regulation, deterrence and choice proposes and weighs the merits of two forms of punishment, fines and incarceration (with probation and other less severe forms of institutionalization falling under this category of penalty for the purposes of this thesis), given the nature of the offense and other case-specific information. The finding, in terms of cost, of different sanctions unambiguously favors fines over imprisonment, as discussed previously in both Becker (1968) and Polinsky and Shavell (2000). Imprisonment is found to be a cost-effective deterrent only when the financial resources of the entity being penalized are not sufficient to cover the damages or when reputation costs of imprisonment are high relative to marginal costs of imprisonment (Segerson and Tietenberg). The distinction in penalty form is made within the more focused environmental enforcement literature, imprisonment being reserved only for criminal offenses. Imprisonment has not been utilized to date to punish CAFO managers or integrators for environmental offenses related to the operation of animal production facilities, but it has been used in at least one case for discharge violations of the CWA in integrator owned and operated slaughter and processing facilities (U.S. Dept. of Justice, Washington Post).

Segerson and Tietenberg (1992) present a complex principal-agent model to investigate the efficiency implications of different sanctions (fines versus imprisonment). At first glance this article may not appear to have much relevance to environmental enforcement of CAFO regulations, but there do seem to be subtle and valuable insights. The principal-agent relationship analyzed at length in their insightful article views the firm as the principal and the employee or environmental manager within the firm as the agent. In determining whether individual penalties or penalties imposed on the firm are more efficient, the determinant is the operation of the contractual relationship between employee and firm. If fines imposed on the firm can be easily transferred to the employee through a "compensating wage reduction", imposing penalties on the firm or principal will be Pareto-preferred. There are far fewer firms to deal with than individuals, lowering transaction costs for the regulatory agency. While transaction costs are a key determinant of efficiency, the "correctness" of the penalty is paramount from a social welfare standpoint. As discussed in an earlier section and depicted in Figure 3.2, there is a multiple principal environment surrounding CAFOs. If the integrator can be viewed as the principal and the CAFO operator as the agent[20] (a contractual relationship which allows for "compensating wage reduction" to occur exists between the integrator and

[20] Individual CAFOs, by and large, do not employee enough people for the CAFO to represent the principal-firm considered in Segerson and Tietenberg's analysis, with its employees as agents.

CAFO), then an application of the principal-agent framework constructed by Segerson and Tietenberg can be made to our problem. Production constraints as penalties within the integrator-operator relationship mimic those of compensating wage reductions discussed as means of imposing individual penalties through the firm without individual enforcement by the regulatory authority. For example, when lagoon storage levels encroach into the emergency storm storage, a penalty can be assessed if it is detected by a regulator. Some integrators impose additional penalties if such a violation occurs, which places heavy burdens on operators. Despite the nature of the production contract as a possible mechanism to implement the type of penalty structure preferred for its efficiency, legal constraints will prevent it except in a very limited number of cases. Integrators are not legally responsible for actions taken by their contract growers, a concept called integrator liability. While some individual states have pursued this, it has not been widely implemented (for a broad range of offenses) anywhere and is not provided for in federal regulations governing CAFOs. Integrators have been successfully sued as a result of violations that occur at operations under contract with them and this will be discussed in the next section.

Despite the lack of integrator liability in a legal sense, the role of reputation costs as an incentive for integrators is clearly significant, given the penalties assessed by integrators on operators when certain violations occur. The only time such a penalty is imposed, however, is when the regulatory agency fines the operation, creating concealment incentives and perhaps strengthening the incentive for poor management (discussed in chapter two). Full observability and completely flexible compensation schemes are the binding constraints on the transfer of corporate (integrator) penalties to the worker (operator). Segerson and Tietenberg discuss the significance of reputation costs in determining efficient penalties and the importance of these costs to the integrator cannot be overlooked. In the expected utility decision-making framework, the reputation costs of a violation or highly publicized lawsuit are costs over and above the financial penalties assessed. Capturing reputation costs in a profit-maximizing model of firm decision-making is likely to be as difficult as accounting for transaction costs in such models because they are a function of firm costs (investments in branding, etc.) and prior consumer preferences for the particular product or brand, both details unknown to social planners and academics modeling market and non-market behavior.

Legal rules that prevent integrator liability appear to prevent the use of efficiency-maximizing penalty structures proposed by Segerson and Tietenberg, but it is clear that aspects of their analysis of the principal-agent relationship are applicable to the integrator-operator contract. From the perspective of the regulatory agency, we are limited to individual penalty assessment, which entails decidedly more transaction costs. These transaction costs translate into welfare reductions in the Becker (1968) model of social loss minimization and rational regulation that remain as long as property rights of integrators are shielded by legal rules that don't allow for integrator liability.

The use of fines as the chief enforcement tool in dealing with CAFOs raises questions about the deterrent effects of this specific mechanism when trying to arrive at socially optimal levels of pollution. Kadambe and Segerson (1998) investigate the comparative static effects of a fine on probability of a violation by the regulated party. Several previous analyses have utilized different models to assess the effects of a fine on violation, but this is the first to incorporate the regulatory process in the form of a decision tree that includes the actual decisions made by both the regulator and the firm. The Kadambe and Segerson model allows for interaction between the two parties which results in indirect effects upon the intermediate stages in a regulatory procedure. A change in the fine a firm is subject to can affect both the likelihood that a regulator will take certain actions against a violator and that the violator would challenge the regulator's actions in the course of the regulatory process. It is found that if these indirect effects are positive and large an increase in the fine could actually reduce the likelihood that a firm will comply with regulations; increased fines do not necessarily increase compliance (reduce violations).

The decisions made by both the regulator and the firm as the regulatory process plays itself out are made based on expected costs and benefits, with each party acting to maximize their own gains. The importance of indirect effects in analyzing the regulation of CAFOs is an important consideration given that there is considerable interaction between the regulated party and the enforcer. Remaining cognizant of the decentralized nature of enforcement also becomes important because enforcers may be motivated by factors other than social welfare.

3.4.3 Regulation in Practice

Various mentions have been made to the implementation of regulations promulgated or originating from federal government and there seem to be many questions about differential implementation under cooperative federalism. One common complication resulting from decentralized implementation that is discussed is the issue of unfunded mandates and budget constraints of SEPAs. Another factor determining local enforcement is political in nature. An empirical study of Clean Water Act enforcement by Hellund (1998) investigated the relative importance of budgetary and political pressures on stringency. The General Accounting Office (1995) first presented empirical evidence about concerns that implementation under federalism results in inefficiently low levels of state expenditure on pollution abatement because of resource constraints. By analyzing both budgets and politics in tandem with stringency (whether measured by p or some other proxy), it is demonstrated that heterogeneity in costs and benefits at the local level results in variations in enforcement and that more funding is not the solution to the problem. This finding is particularly relevant to CAFOs because of the daunting set of regulatory tasks for SEPAs to complete if compliance is to be upheld. Without any additional funding to implement the provisions of the Final Rule released at the end of 2002, state permitting authorities and NRCS personnel in the states have been given even more tasks to perform. Faced with increased regulatory tasks, implementing agencies must make a resource allocation decision.

The nature of inspections are such that they entail either a visual, facility inspection or a sampling inspection, the latter being more comprehensive and likely to uncover a violation. The cost of sampling inspections is greater than that for more cursory methods, but the reliability and likelihood of detection are greater when samples are taken. Hellund finds that contrary to conventional wisdom resource-constrained states need not reduce stringency if they conduct fewer, more comprehensive inspections. On a similar note, he finds that when increased federal resources are provided to local enforcement authorities inspection stringency does not increase because the nature of additional inspections is such that they are less comprehensive. Even when budgets for enforcement are higher, regulatory presence is not uniform[21]. Pollution is not reduced as a result of additional enforcement resources unless increases are quite substantial.

[21] The economic health of the firm being inspected and the larger local economy appear to influence which firms are inspected.

While the results indicate that heterogeneity across districts is an important factor in determining stringency they do not address efficiency. Uneven implementation of permitting requirements and differential enforcement of CAFO regulations has been found from state to state (America's Clean Water Foundation) and resource constraints are a common reason given. Hellund's analysis may offer an alternative explanation of enforcement actions taken against CAFOs and offer some reasons why regulation has failed to achieve the desired result to date.

3.4.4 The Role of the Courts in Environmental Enforcement

Two forms of law will be addressed in this subsection: torts and environmental laws. Torts are the oldest form of law used to address harm caused by environmental releases but are severely limited in their application (especially to CAFOs). As pointed out by Dewees (1992), tort is most effectively utilized to address "local pollution problems involving a single polluter and very substantial damage, and is of little significance for pollutants…discharged in a developed area with many other pollution sources, including most air and water pollution problems." The bulk of tort litigation has involved property damage where causation is easily demonstrated. He points out that because the tort system is "terribly inefficient" its use is precluded except in cases where major harm has occurred. Government regulation is stated as having been effective in some areas, but it is noted that the cost of technology-based emissions standards is great as well. Overall, Dewees finds that "tort litigation is enormously costly, highly uncertain in its outcome, and may deal with only one source at a time." He notes that expanding the authority of private citizens to enforce environmental laws and regulations may augment the deterrent effects of law (both torts and more specific laws) applied to the environment. This leads us into the subject of specific environmental laws, which have been a larger source of litigation against CAFOs, most notably under the CWA.

The use of the courts to force compliance with environmental statutes has been utilized extensively since the inception of most of these federal statutes in the 1970s. Naysnerski and Tietenberg (1992) take up "private enforcement" as a tool to achieve compliance with federal environmental law with some clear implications for private litigation of CAFOs. Private enforcement or the threat of a lawsuit is viewed as a good incentive to accompany public regulation and this threat can originate with individual citizens or citizen groups (such lawsuits will be referred to simply as "citizen suits" hereafter). In authorizing citizen suits, Congress enacted several controls or limitations (such as legal standing to file suit) on their use and made several types of remedies available to private enforcers. The three types of remedies are injunctive power, penalties (fines), and attorney fee reimbursement. Different environmental laws provide for different remedies and these remedies are demonstrated to create incentives for their use. The demand for litigation activity is a result of environmental organizations' assessment that government is not providing an adequate level of environmental quality. Citizen groups have to operate within a budget constraint and act rationally to achieve their objectives, characterizing the expected benefits and costs of each potential lawsuit, and taking on additional suits to the point where marginal costs equal marginal benefits for the organization. The benefits of a suit could be to stop a polluting practice (increase environmental quality) and possibly to set legal precedent (facilitate subsequent enforcement). Citizen suits as enforcement actions are inversely related to the amount of public enforcement and evidence of increased private enforcement under reduced public enforcement exists for the early 1980s (Naysnerski and Tietenberg).

The determinants of litigation activity are the availability of penalty remedies, the disposition of penalties, presence of attorney fee reimbursement and burden of proof requirements. If penalties can be imposed it increases benefits of private litigation by conveying higher deterrence value to would-be polluters. If penalties assessed as a result of a citizen suit are earmarked for improvements in environmental quality (instead of the general treasury), the benefits to the group bringing suit are also enhanced[22]. Attorney fee reimbursement provisions in environmental law help budget constrained environmental organizations recover legal costs in addition to the environmental improvement sought. Burden of proof in citizen suits is another cost consideration for environmental groups and one that can be very costly to satisfy. Aspects of the different environmental laws under which citizen suits are brought make certain laws more attractive because of the deterrence effects, the cost of litigation, and the spectrum of benefits that result when a suit is a won. The sample of over 1400 suits analyzed by Naysnerski and Tietenberg reveal that 945 claims were filed under the Clean Water Act which has attributes that enhance deterrence (monetary penalties and injunctive power) and reduce litigation costs

[22] Naysnerski and Tientenberg find that earmarked penalties (=$223,527) are higher, on average, than non-earmarked penalties (=$72,543) and are utilized in 80.9% of citizen suits where penalties are imposed.

(attorney fee reimbursement and information requirements satisfied by publicly available discharge reports) for environmental groups. Other laws that have some or all of these characteristics (all allow for penalty remedies) and account for another 428 of the 1400 suits analyzed are the Resource Compensation and Recovery Act (RCRA; governs solid wastes) and the Superfund law.

The existence of public enforcement alongside private enforcement increases the expected cost of noncompliance. Firms facing suit under statutes that authorize penalties or offer other enticements (fee reimbursement, etc.) for citizen groups are more likely to be in compliance than firms facing suit under other statutes because there is a greater likelihood of private enforcement. Naysnerksi and Tietenberg find that private enforcement may be more effective than public enforcement in pursuing public polluters whom public enforcers may be reluctant to regulate. Public and private enforcement are found to complement one another because priority areas for public and private enforcement are likely to differ, maintaining a continuous threat of enforcement for violation of laws. Overall, the existence of private enforcement should contribute to increased compliance with regulations.

Turning specifically to the CWA, where a significant portion of CAFO litigation is centered (America's Clean Water Foundation), Naysnerski and Tietenberg point out that several studies have demonstrated the cost-ineffectiveness of discharge standards which are the hallmark provision in the law. When you consider that the single-largest source of all citizen-suits filed has been this law, it becomes clear that environmental groups are targeting areas of the law where cost-effectiveness problems are most acute. These groups are responding to the incentives provided in the law when they behave in this way, but this doesn't change the fact that whenever standards are not cost-effective citizen suits secure environmental improvements from precisely the wrong firms. Private enforcement holds promise where fee reimbursement provisions of the law can be utilized to transfer costs of enforcement onto the offender allowing the public sector greater flexibility in targeting its limited enforcement resources. Private enforcement priorities (like those of private firms) are established on the basis of private costs and benefits, not social costs and benefits. Firms and citizen groups both react to the incentives and institutions that operate around them; these incentives and institutions have been crafted in a piecemeal fashion over time which needs to be more uniform so that public and private litigation priorities might be determined by the seriousness of the problems rather than the generosity of a given statute.

Regulations for CAFOs are no exception to the piecemeal fashion in which environmental policy has been developed in the U.S. over time. Competing incentives described in chapter two are also at work.

3.5 CAFO-SPECIFIC ISSUES AND REGULATION

References and applications to CAFOs have been made as the more general literature related to this analysis has been reviewed. This section addresses the literature dealing specifically with animal feeding operations. The greatest amount of publication in this area has probably been devoted to estimating the impact of various types of regulations on producers. Examples are provided as early as Ashraf and Christensen (1974; dairy farm impacts from regulations) and more recently in Fleming (1999; land application setbacks) and Johnson, Wheeler and Christensen (1999; effluent limitation guidelines in Unified National Strategy for AFOs).

The most recent papers to address costs from the Final CAFO Rule consider willingness-to-accept-manure (WTAM) for land application and the effectiveness of EQIP in helping farmers meet nitrogen- or phosphorous-based application standards. Ribaudo, Agapoff and Cattaneo (2003) use a modified version of the model developed in Fleming, Babcock and Wang (1998; discussed below) to assess the cost to producers of revised manure management guidelines based on farm operation data from the USDA's Agricultural Resource Management Study (ARMS) database. They are able to assess available acres for application and proximity to required acreages under N or P application standards and demonstrate the importance of WTAM in complying with the Final Rule. EQIP is generally determined to be most effective in meeting N standards because of the larger number of acres (and thus greater hauling costs) required to meet a P standard, but can only be utilized to fully meet nutrient standards in a single production region of the United States. Large farms in the Cornbelt, having the largest production acreages of manure accepting crops, hold the greatest promise for relatively lower hauling costs based on proximity to receiving acres. Small farms are determined to benefit from EQIP funding but aren't likely to volunteer to meet standards because their full costs will not be covered by cost-share. A high WTAM is found to not only help AFOs, but decrease the amount of EQIP funding required on a per farm basis, potentially making cost-share funds for environmental improvements more widely available to livestock producers and for other conservation issues.

In addition to regulation-specific work in the literature, there is a synthesis of state-level regulation of CAFOs (Metcalfe) and more qualitative assessments of the regulatory regime, such as that found in Centner and Mullen (2002). Metcalfe provides a thorough overview of different regulatory structures being imposed in local jurisdictions that go beyond federal regulations. Centner and Mullen evaluate federal regulations, calling into question the credibility of the enforcement threat and asserting that continuing lax enforcement imparts benefits for non-compliance that dilute the effectiveness of regulations designed to reduce pollution. Given the lack of results from regulation to date, Centner and Mullen urge policymakers to consider whether other mechanisms might achieve a more efficient result.

A game-theoretic approach to explaining the clustering phenomenon in animal agriculture is utilized by Thurow and Thompson (1998) to evaluate cooperative behavior amongst livestock operations. It is determined that a lack of economic incentive to cooperate is not necessarily the reason for non-cooperation in the sector. The game-theoretic approach suggests that a lack of communication capacity or mismatched norms may be at work. Their finding is somewhat counterintuitive to the purely neoclassical view, but seems plausible given the highly competitive nature of the industry where individual CAFOs are price takers and are highly leveraged.

Several hedonic studies of property value have been undertaken; the first notable finding from Palmquist, Roka and Vukina (1997) determined that proximity to an AFO had a significant negative effect (up to -9%) on house prices. A comparison of three recent studies, which considers property value impacts from hog operation disamenities in coastal North Carolina sheds further light on this subject (Thomas, et al). Additionally, Ready and Abdalla (2003) investigate property value impacts for a number of local amenities and dis-amenities in Pennsylvania, including AFOs and other agricultural activities. It is clear that many types of microeconomic analysis have been applied to the multi-faceted problem posed by CAFOs.

Two articles that present a very production oriented analysis of farm management decision-making that has implications for policy are Roka and Hoag (1996) and Fleming, Babcock and Wang (1998). These two studies are very helpful to the applied economist seeking to understand the key factors that govern firm decision-making and the cost and benefit tradeoffs that occur while optimizing. The key finding from both studies is that the market value of hogs drives production decisions and not manure value. Fleming, Babcock and Wang present a model that allows production decisions to maximize the net benefits of manure and is broadly applicable based on delivery cost under a nutrient standard, the type of land application and manure storage system utilized by the firm. The two largest factors found to impact manure management decisions are hauling distance and nutrient content of manure with firms optimizing based on the number of animals per operation, crop rotation (for land application), and type of storage system. Overall it is determined that "while manure management is important, other production considerations generally drive management's decision to go large and / or to switch" storage systems.

A more theoretical treatment of regulation and production decisions is offered by Innes (2000). He uses a theoretical model to assess spatial aggregation of livestock production facilities and the efficiency implications of various policy and regulatory measures in achieving social welfare improvements. His work approaches the problem of regulation and more efficient outcomes with similar assumptions about the information obstacles faced by enforcement agencies, focusing specifically on the unobservability of application practices which perpetuates the classification of this pollution source as non-point in nature. Innes also takes issue with the 25-year, 24-hour rainfall rule, which he asserts should vary geographically and based on concentration in a particular area. The most important consideration made by Innes' model (one that remains unaddressed in regulation to date) is that of spatial variability of concentration and the implications this has for pollution levels. Concentration in a watershed, regardless of BMP adoption and regulation adherence, has been demonstrated to result in water quality impairments from aggregated marginal impacts that may be efficient when considered alone (Pratt, Jones and Jones). Innes finds that environmental benefits from dispersion are maximized when there are more and smaller facilities than when there are fewer and larger facilities (the environmental problem posed by intense concentration in production). His key regulatory result suggests that observable producer behavior (as opposed to land application) be brought under regulation to induce efficiency because producers will always over-apply when they can't be observed.

Innes (2000) does not suggest any tractable possibilities for observable regulatory requirements[23], but he does make clear that the challenge is to find enforceable aspects of manure management to achieve the desired result from regulation. Insights into this problem are a possible outcome of the analysis resulting from the decision-making model presented later in this thesis. The crux of the regulation problem considered by Innes and agreed upon by this author, is to "provide firms with optimal incentives, rather than *unenforceable* directives, for environmentally friendly manure management."[24]

The literature review provided in this chapter has been broad and is intended to encompass the set of issues that pertain to both public policy aspects of CAFO regulation and firm decision making by regulated economic agents. Connections between the regulation of CAFOs and other areas of economic inquiry have been drawn and a theoretical model that takes these topics into account will be developed and evaluated. To the extent that such analysis can illuminate the factors underlying observed management decisions and, in particular, those with the greatest incentive effects on producer behavior, it may be possible to improve the efficiency of public policy. This analysis will be undertaken in the next two chapters.

[23] Innes (2000) suggests the use of a fertilizer tax to incentivize manure utilization, but he fails to address the impacts on production cost of greater manure utilization (see Fleming, Babcock and Wang) associated with this proposal or the feasibility of enacting a tax which would harm a very concentrated special interest whose political activity level and resource endowment are likely to quash any attempt to enact such a tax.
[24] Italics not in original.

CHAPTER FOUR

PRODUCTION DECISIONS AND A MODEL OF PROFIT-MAXIMIZATION

In an attempt to frame the issue in terms of microeconomic principles and theory and provide a foundation for the more stylized model of firm profit presented later in this chapter, the basic assumptions adhered to throughout the remainder of the thesis will be presented. By presenting a general production function and discussing the array of decisions faced by producers faced with regulation, the intent is to demonstrate the practical application of the thinking presented in this thesis to an actual firm. A more rigorous, theoretical treatment of this material is then provided by expanding a profit function from the literature to reflect CAFO revenue and costs. Comparative statics are derived to examine different variables in the decision making process. In the following chapter, the comparative statics are interpreted and qualitative considerations are discussed.

4.1 BASE ASSUMPTIONS, PRODUCTION ECONOMICS FRAMEWORK AND BASIC MICROECONOMICS

The analysis presented here uses several standard assumptions from economics for the purpose of analysis. The assumption of rationality in making economic decisions is adopted throughout. Producers, or economic agents to use a more general term, are assumed to abide by the basic axioms of rational choice (completeness, transitivity, and continuity) that form the basis for utility ranking first proposed by Jeremy Bentham (Nicholson). Profit-maximization is the assumed objective of the firm and choice of inputs, selection of production technology, and other firm decisions are made consistent with this objective. A variety of assumptions could be made about the risk preferences of the producer, but risk neutrality is assumed in this investigation to aid derivation of first and second order conditions and evaluation of comparative statics. However, allowing for risk seeking or risk averse preferences could have important public policy implications (Becker, Polinsky and Shavell).

To analyze the decision making process of the firm, a simple model of production at the farm level is presented and then complexity is added to more closely model the specific scenario for CAFO operators. The firm production function is such that market output (hogs, broilers, eggs, milk, beef, etc.) and animal waste are jointly produced. CAFOs represent a case where inputs contribute to the two outputs in different ways. Thus, two production functions are included in the proposed model, one for livestock and one for effluent. Cobb-Douglas type production functions are used for a number of reasons: to aid mathematical derivation of comparative statics, because production is assumed to always occur in Stage II where profits are maximized, and because the Cobb-Douglas functional form is supported by the literature, especially for agricultural production. Specifying the production functions in this way avoids functional dependence between hog output and effluent. This specification also maintains a realistic structure for the production arrangement in the stylized model. This is discussed in further detail in section two of chapter five. Swine operations will be considered specifically in discussing firm-level production decisions because they have been the source of some of the most visible and the largest environmental release events which have led to tighter regulation of all CAFOs.

The production function for hogs is presented first and is characterized generally as having two inputs. The three most significant inputs (in terms of cost of production) for swine production are capital, labor and feed (McBride and Key). A general production function for hogs, given by

$$Q = f(x_1, x_2), \qquad 4.1$$

is presented for illustrative purposes. In (4.1) the number of hogs or units of hogs (total cwt. produced), Q, is a function of two inputs, x_1 and x_2, which may represent capital for production technology, farm labor, feed or land for the purpose of analyzing the optimization decision of the firm facing environmental regulation. The familiar analysis of input decisions by the producer illustrated graphically as a set of production isoquants on an x-y axis is a useful visual to keep in mind. Producers can use different combinations of inputs x_1 and x_2 to produce different levels of output, where each isoquant represents the different combination of inputs that yield the same level of output. Producers will optimize the allocation of inputs in such a way that cost is minimized for a given level of production. The outermost isoquant on an isoquant map represents the maximum productive capacity of a given technology or production process, which is a limiting factor for production and is related to available capital (access to credit) and environmental regulation (permitted size of operation based on a number of factors). A simple two input production function is used to limit mathematical complexity (both for the reader and the author) and because when the pollution production function is presented, these inputs will also be inputs that contribute to pollution. There is of course a different relationship between input quantities and hog output than there is between inputs and pollution output. This difference will become clear when more specific forms of both production functions are presented. The more specific Cobb-Douglas type form that is used in this thesis is given by the hog production function

$$Q = Ax_1^{\alpha_1} x_2^{\alpha_2} , \qquad 4.2$$

where A is a constant that may be taken to represent hog production technology and economies of scale exist in hog production (McBride and Key) such that $(\alpha_1 + \alpha_2) > 1$.

The general production function for pollution (hereafter referred to only as effluent, E) is given by

$$E = f(x_1, x_2, K), \qquad 4.3$$

where E is a function of two of the same inputs to the hog production process (again, while only two are used in this analysis, a larger subset of any greater number of inputs to hog production is possible), x_1 and x_2, and pollution abatement capital, K. The choice of production and abatement technologies is made simultaneously but after this initial investment of capital the two systems are assumed to operate as independent processes. It is assumed that abatement costs dominate technology adoption decisions and are heavily influenced by environmental regulations (via permitting requirements and design standards). Because hog and effluent production are taken to be independent processes it is further assumed that hog production yields returns to profit, but pollution abatement expenditures do not. Just as producers optimize their input bundle to minimize costs in hog production, so too do they optimize their input bundle according to effluent production to minimize the costs of abatement activities.

Highly sophisticated production systems utilized in confinement production operations have significant capital requirements which often mean that livestock producers are highly leveraged. In the face of changing regulations, risks from weather (rainfall in particular), and possible equipment failure, there are many management challenges for the producer constrained in the short-run by long term capital investments. Income risks of production can be addressed through futures markets or may be handled through production contracts. In an effort to ensure a certain level of income, the number of animals being produced may at times exceed the design specifications for a particular facility—increasing environmental risk.

In the short-run (SR) it is assumed that K is fixed because investments in costly waste handling technology and abatement are long-term investments that are not easily or quickly adjusted. The nature of the technology employed is largely an engineering problem that has been one of the most significant aspects of CAFO regulation to date. While a specific production or abatement technology has not been incorporated into the regulation, as in the case of the familiar 'technology standard' from the literature, a design standard for facilities above a certain size (number of animals based on species/stage of production) has been instituted. Capital investments in technology therefore are investments in an engineering solution to the waste management problem society has attempted to address through regulation. With K (technology) fixed in the SR, adjustments to x_1 and x_2 are available to the producer who may be required to reduce effluent (potential pollution) output. If x_1 and x_2 are taken to be feed and land, as inputs to production which have an impact on effluent, adjustments to feed rations can be viewed as one way to achieve some reduction in the nutrient content of animal waste[25] (through the use of feed additives like Phytase for instance) or utilizing more land for application of waste might also be an option in the SR that would not require the producer to reduce the number of animals in production but rather utilize the manure generated in a different way. Adjustments to either input, reducing the number of animals in a particular facility to address waste management challenges, or some combination of these options will affect costs and may affect the economies of scale. This may defeat at least a portion of the economic returns which motivated the producer to make an investment in the production system. The specific Cobb-Douglas form for the effluent production function that is utilized in this thesis is given by

$$E = \beta x_1^{\delta_1} x_2^{\delta_2} K^{\gamma}, \qquad 4.4$$

where β is a constant in the effluent production process, x_1 and x_2 contribute to effluent production differently than hog production, and abatement technology, K, is the only allocable factor in the determination of the quantity of effluent that can be adjusted without affecting Q. The relationship between abatement and the value of the pollution generation function 4.4 is such that $-1 < \gamma < 0$, expressed alternatively as $\partial E / \partial K < 0$. Constant returns to scale in the production of effluent are assumed and are given by $(\delta_1 + \delta_2 + \gamma) = 1$.

[25] Changes in ration may also impact average daily gain and therefore Q; only changes in K that occur without affecting Q are considered here.

Regulations imposed by society on CAFOs have had the effect of forcing firms to make investments in their operations that yield no return to profits. Prior to regulation there was no private cost to firms associated with the externalities generated in the production process; regulation has been an attempt to force the firm to internalize the costs of these externalities. While regulation has meant that greater costs are imposed on operations through facility design and permitting, this has not been effectively translated into the environmental outcomes that justified the regulation in the first place. Firms are not only required to manage their operations according to specific agronomic considerations and build their facilities according to certain weather and scale of operation metrics, but they are required to do this even in the absence of demonstrated water quality, odor and other improvements sought by regulations. In the production and firm profit way of thinking about the problem, society has imposed a price on the previously unpriced non-market output (effluent), but this price is not charged to the firm in a direct manner whereby quantity of effluent is multiplied by an established price (cost) per unit, it is arrived at more indirectly via extra cost imposed by regulation.

4.2 THEORETICAL MODEL OF FIRM PROFIT

The quantitative analysis in this thesis is based on the approach taken in Harford's (1978) article, and as such focuses on maximization of the profit function. Harford's model was very general and didn't present a production function or apply the analysis to any particular industry. His framework of firm revenue and cost alongside abatement subsidy and fines for exceeding emission standards is expanded and applied to the case of a confinement hog operation here.

From the standard formulation of the profit function, and carrying forward from production functions 4.2 and 4.4 identified in the previous section, total revenue for the firm is given by

$$TR = PQ(x_1, x_2)\,, \qquad 4.5$$

the product of the market price per unit ($/cwt, $/head, etc.), P, and the number of units produced, Q. Total cost for the firm is given by

$$TC = r_1 x_1 + r_2 x_2 + r_3 K + \sigma[E(x_1, x_2, K) - \lambda]\,, \qquad 4.6$$

where TC is a function of the cost of x_1, r_1, the cost of x_2, r_2, and the cost of abatement capital, r_3. In the context of the TC function, the assignment of a per unit price to effluent has taken the form of σ. This "price" is really a cost of production resulting from the scale of the operation in question, as opposed to *P*, the market price for good *Q*. In economic terms, σ may be viewed as the per unit shadow price of compliance. This regulatory cost term in equation 4.6 is determined by the difference between the products σE and $\sigma\lambda$. All units of effluent produced are not translated into regulatory costs over and above the cost per unit of abatement capital given by *r*3. Rather, the expected cost of regulation should be a reflection of only those units of effluent that exceed the total units that can be land applied based on agronomic rates and the amount of land (and crops) available for a particular operation. This is information contained in the CNMP for a particular operation and represents the maximum allowable level of production based on land characteristics, production and abatement technology utilized, scale of operation, and the nitrogen or phosphorous based land application standard an operation has adopted. Expressing the cost of regulation in this way greatly simplifies the complex nature of the cost of regulation to firms. A detailed qualitative discussion of the nature of the expected costs of regulation is provided in the next chapter of this thesis, but for the purposes of first and second order conditions and comparative statics no loss of insight results from this simplification of the cost of regulation.

The firm's overarching optimization problem then is to maximize profit (π), where π = *TR* – *TC*, and is given specifically by

$$\pi = PAx_1^{\alpha_1}x_2^{\alpha_2} - r_1x_1 - r_2x_2 - r_3K - \sigma[\beta x_1^{\delta_1}x_2^{\delta_2}K^{\gamma} - \lambda]. \qquad 4.7$$

In this stylized model of firm profit, the last term of the equation represents the cost of regulation beyond abatement technology and BMPs (referred to hereafter as the shadow price of compliance). First order conditions, represented by partial derivatives with respect to the endogenous variables x_1, x_2, and *K*, are represented by the familiar subscript notation. The first order necessary conditions for an interior maximum are given by:

$$\pi_{x_1} = \alpha_1 PAx_1^{\alpha_1-1}x_2^{\alpha_2} - r_1 - \delta_1\sigma\beta x_1^{\delta_1-1}x_2^{\delta_2}K^{\gamma} = 0; \qquad 4.8$$

$$\pi_{x_2} = \alpha_2 PAx_1^{\alpha_1}x_2^{\alpha_2-1} - r_2 - \delta_2\sigma\beta x_1^{\delta_1}x_2^{\delta_2-1}K^{\gamma} = 0; \text{ and} \qquad 4.9$$

$$\pi_K = -r_3 - \gamma\sigma\beta x_1^{\delta_1}x_2^{\delta_2}K^{\gamma-1} = 0. \qquad 4.10$$

Conditions 4.8 and 4.9 provide the familiar result that marginal revenue (MR) should equal marginal cost (MC) for each input. Notice that the MC side of these two equalities doesn't just include the marginal factor cost, r_i, for each input, but also what will be referred to as the marginal factor cost of regulation (MFCR) for each input, given by $\partial[\sigma(E(\cdot)-\lambda)]/\partial x_i$. Again, MFCR represents the form that regulation has taken in terms of firm accounting for the purposes of the stylized model presented here.

The added regulatory costs of production for the firm might be viewed as the difference between the private and social costs of the firm's activities (from the perspective of the social planner), however there is no evidence to suggest that any such calculations are made when imposing these costs on the firm (such calculations would be extremely difficult and likely infeasible because of information asymmetries) and there does not seem to be a clear connection between the size of these costs and any environmental benefits which result from them. With these additional private costs imposed on the firm, it means that, MR ≠ MC in the textbook treatment of these topics and also presents a clear divergence in terms of the cost of a firm's activities. A profit-maximizing firm does not operate under a social welfare maximizing framework in making production decisions. It is clearly in the interest of government that firms are profitable (for purposes of employment, tax income, etc.), but government also has a broader objective. This divergence between private costs and social costs of the firm's activity has been the reason for regulation targeted at imposing the full cost of operation on CAFOs and one of the reasons that economies of scale have been widely observed in confined livestock production—because the external costs of operation were not previously born by the firm. Under an assumption of perfect competition, where long run profits are zero, conditions 4.8 and 4.9 then indicate that MR is equal to the MC for each input plus the MFCR, where MR alone is greater than MC because of the presence of externalities.

Condition 4.10 indicates that the marginal cost of pollution abatement has no offsetting revenue component. This is intuitively reasonable given that the abatement activities yield no discernable return to profits in and of themselves.[26] Returning to the basic production decision of the producer subject to environmental regulation discussed above, one can conceive of a limited number of SR adjustments to inputs common to hog and effluent production to satisfy regulation. Note that spreading manure over a larger area to meet application standards imposes more costs than just the rental of additional acres but also the labor, operation of machinery, and

[26] For specialty market meat and animal products such as free range chicken or other "organic meats", abatement and the production method used can result in a premium price for producers. Such a price premium is not considered for the case of confined production because of the lack of environmental or other properties that distinguish these niche products in the marketplace.

cost of transport to utilize more acres; which warrants the reminder that there are more than two inputs to the overall production process that is presented in this stylized model and some adjustments will mean greater costs from more than one input category.

Thinking about the LR introduces the opportunity to consider production and abatement technology. It is conceivable that a change in technology might result in three distinct outcomes.

1) The first is that effluent levels remain the same while the number of animals produced increases. This would result from an investment in abatement when there is capacity for more animals in the production system (determined by capacity of waste handling facilities, land available for application, etc.).
2) The second is that the number of animals in the system is maintained while effluent levels are reduced. This would result from an investment in abatement when system capacity is already capped or the nature of the regulatory change is such that more land or other inputs are required to produce the same number of animals.
3) The third scenario one could think of is one where the number of animals produced increases while effluent levels are reduced. This scenario would seem to require either a drastic change in the abatement technology that allowed for a greater number of animals to be produced in the same facilities or a concurrent change in both abatement and hog production technology.

It should be noted that some potential changes discussed here would require costs over and above expenditures on technology because of the transaction costs involved in amending or updating operation permits and CNMPs. There may be other additional costs that result from scrutiny of the operation by regulators, citizen groups, or the media as a result of permit adjustments which occur in the public arena.

Following from the necessary first order conditions 4.8, 4.9, and 4.10, the second order conditions for a maximum are derived by taking the second order partial derivatives of the profit function 4.7 and evaluating the Hessian matrix. Symbolically, the 3x3 Hessian matrix is given by

$$H = \begin{bmatrix} \pi_{x_1 x_1} & \pi_{x_1 x_2} & \pi_{x_1 K} \\ \pi_{x_2 x_1} & \pi_{x_2 x_2} & \pi_{x_2 K} \\ \pi_{K x_1} & \pi_{K x_2} & \pi_{KK} \end{bmatrix}. \qquad 4.11$$

The second order sufficient conditions for profit maximization are derived by evaluating the three principal minor determinants of $[H]$, denoted as $|H_i|$, successively. The complete mathematics involved in taking the second order partial derivatives and evaluating $|H_1|$, $|H_2|$, and $|H_3|$ in 4.11 are included in Appendix A of this thesis for completeness and for reference by the interested reader. Only the results of this process are reported in the body of the thesis in an effort to maintain flow and not bog the reader down with too much mathematical jargon.

From the Hessian, it is demonstrated that the second order sufficient conditions for maximization of the profit function may be satisfied, whereby $[H]$ is negative definite. Negative definiteness (given necessary conditions I, II, and III discussed in Appendix A) ensures a single interior maximum provided the function is continuous and twice differentiable, which is assumed. Comparative statics are now presented to demonstrate the effect of changes in the endogenous variables (denoted with bars to indicate that they are evaluated at the optimum or equilibrium value) with respect to parameter changes in the model of firm profit. The full mathematical treatment necessary to derive the comparative static results is provided in mathematical Appendix B of this thesis. The results for the three input cost parameters, the market price for hogs and the per unit shadow price of compliance variable are presented below. Comparative static derivatives that were found to be indeterminate in sign are not presented but are included in Appendix B and discussed in chapter five for completeness.

$$\frac{\partial \bar{x}_1}{\partial r_1} < 0 \qquad 4.12 \qquad\qquad \frac{\partial \bar{x}_1}{\partial r_2} < 0 \qquad 4.15 \qquad\qquad \frac{\partial \bar{x}_1}{\partial r_3} > 0 \qquad 4.18$$

$$\frac{\partial \bar{x}_2}{\partial r_1} < 0 \qquad 4.13 \qquad\qquad \frac{\partial \bar{x}_2}{\partial r_2} < 0 \qquad 4.16 \qquad\qquad \frac{\partial \bar{x}_2}{\partial r_3} > 0 \qquad 4.19$$

$$\frac{\partial \bar{K}}{\partial r_1} > 0 \qquad 4.14 \qquad\qquad \frac{\partial \bar{K}}{\partial r_2} > 0 \qquad 4.17 \qquad\qquad \frac{\partial \bar{K}}{\partial r_3} < 0 \qquad 4.20$$

$$\frac{\partial \bar{x}_1}{\partial P} > 0 \qquad 4.21$$

$$\frac{\partial \bar{K}}{\partial \sigma} > 0 \qquad 4.23$$

$$\frac{\partial \bar{x}_2}{\partial P} > 0 \qquad 4.22$$

These results will be interpreted in the next chapter and are presented here in short form for inspection by the reader.

The model of firm profit presented in this chapter has been shown to be negative definite, confirming the desired concave shape of the profit function in the economic region of production, and more specifically demonstrating that there are conditions under which an interior maximum for the profit function is achieved. The next chapter interprets results presented in this chapter, discusses a variety of challenges to modeling such a complex problem that were encountered while selecting a functional form for the model, and provides an expansion of the simplistic representation of regulatory cost included in the base model accompanied by a qualitative discussion of a more complex form of the profit equation.

CHAPTER FIVE

MODEL RESULTS AND EXTENSIONS

The model of firm profit in the previous chapter is highly theoretical and makes an incremental contribution to the analysis of swine discommodity and public policy in the literature by representing the production of hogs and their waste in the context of a firm's decision-making structure. Other analyses have looked at particular aspects of production costs (Fleming, Babcock and Wang; Ribaudo, Agapoff and Cattaneo), what motivates production decisions most (Roka and Hoag), and another theoretical treatment has examined the nature of regulatory instruments and spatial considerations in the concentration of swine production (Innes). This contribution attempts to bridge the gap between cost of production and waste management focused analysis and the previous theoretical work to advance economic theory based understanding of a more complete set of decisions made by producers subject to regulation. The profit-maximization analysis by Harford provides a theoretical approach to this problem but is so general as to never specify a functional form or apply it to a particular industry. The attempt here is to specify a functional form with limited restrictions and that is applicable to the specific public policy problem posed by swine CAFOs. This chapter discusses the results of the comparative statics work in chapter four, considers the difficulties encountered in attempting to construct a theoretically consistent model for analysis in this thesis, and provides a qualitative analysis of the more complex nature of regulatory (and litigation) costs represented in the context of the profit function only as $\sigma[E(\cdot)-\lambda]$.

5.1 INTERPRETATION OF COMPARATIVE STATICS OF THE PROFIT FUNCTION

The comparative statics for the profit function are derived in chapter four to examine the impact of changes in exogenous variables on endogenous variables (the inputs to the hog and effluent production functions). Each of the choice variables are examined first with respect to changes in their individual costs and with respect to changes in the cost of the other inputs. The result of a change in the cost of input x_1 is discussed first. The comparative statics indicate that an increase in the cost of input x_1 will lead to a decrease in the use of that input (condition 4.12), which follows intuitively from theory and is an expected result because firms are likely to substitute away from more costly inputs and toward less expensive ones (movements along the production isoquant) in an effort to minimize cost (maximize profits). An increase in r_1 is also expected to lead to a decrease in x_2 (condition 4.13) according to the comparative statics which is also interpreted as a response to an increase in cost of x_1 because the two are joint inputs in the hog production process. When more hogs are produced, more waste is produced (*ceteris paribus*) and there is a higher expected cost of regulation from the profit function. Conditions 4.12 and 4.13 are consistent with the change in abatement capital with respect to a change in r_1, which is positive from condition 4.14. This is interpreted to mean that when the cost of the input rises, evasion of pollution standards becomes too costly and more abatement occurs (lowering the regulatory cost of operation, σE). Similar results follow for the change in the endogenous variables with respect to an increase in the cost of input x_2 (the associated conditions are given by 4.15, 4.16 and 4.17). The use of inputs x_1 and x_2 decrease as r_2 rises for the same reasons discussed above for an increase in r_1. Likewise, abatement will increase with a rise in the cost of the second input to hog production because evasion becomes costly in the face of rising production costs for the firm.

The effect on input use of an increase in the cost of the third endogenous variable in the profit equation, r_3, is examined next. As the cost of pollution abatement capital increases, the cost of abatement rises and the comparative statics suggest that firms will reduce the amount of K employed while increasing the amount of x_1 and x_2 (conditions 4.20, 4.18 and 4.19, respectively). The implication of this third group of comparative static results is that when the cost of abatement rises, firms will not only abate less but increase the use of the other inputs to the production process which will lead to an increase in effluent. The cost per unit of abatement has come to exceed the expected cost per unit of evasion. In other words it pays to violate pollution standards once the cost of abatement rises above a certain level and abatement levels will actually fall. Such an increase in abatement costs could result if new regulations require stricter control of effluent or a particular control technology. This result is very similar to the finding in Harford's much more general analysis that found that tighter emission standards could actually lead to a greater level of violation. The use of government subsidies to cover a portion of the cost of installing BMPs has been widely used as one approach to reducing pollution from CAFOs and is one mechanism that helps to reduce the cost of complying with regulations and may help operations to offset increased abatement costs.

Two additional exogenous variables were examined in the comparative static analysis to learn more about how the market price for hogs and the shadow price of compliance affect production decisions in the context of the profit function. An increase in the market price of hogs, *P*, leads to an increase in the use of inputs x_1 and x_2 (from conditions 4.21 and 4.22). This is a result that is expected from theory. As the market price (revenue) received per unit of hog output increases, firms will increase production (which is the result of increases in the amount of x_1 and x_2) to increase profits. The increasing profits from an increase in market price means that the opportunity cost of hog production has risen and firm resources devoted to abatement may remain constant, decrease or increase (the sign of the derivative of *K* with respect to *P* is indeterminate, as discussed in Appendix B) depending on the magnitude of the change in *P*. Manure generation, and thus *E*, is likely to increase with an increase in market price. It is possible that as hog production rises an accompanying increase in K could offset any increase in *E* (no net gain in effluent), though the gains to *P* would have to be quite considerable for this to occur and don't seem likely given the nature of the effluent generation function.

The final comparative static result to consider comes from a change with respect to the regulatory cost per unit of effluent, σ. An increase in the regulatory cost to the firm per unit of effluent indicates an accompanying increase in abatement (condition 4.24). This result indicates that as evasion becomes more costly for the firm, the firm will reduce its level of evasion by abating more pollution to smooth profits. The signs of the comparative statics for the effect of this increase on x_1 and x_2 are indeterminate because there are no strong theoretical grounds for imposing a certain sign where the magnitude of terms will determine the sign of the comparative static derivatives. It should be noted that conditions for both positive and negative results for these two derivatives could exist without violating any of the conditions required for the previously reported comparative static signs to hold or the second order conditions for a maximum. Negative signs for $\partial \bar{x}_1 / \partial \sigma$ and $\partial \bar{x}_2 / \partial \sigma$ indicate that the increase in abatement would be accompanied by reduced hog output; meaning that evasion is both too costly under increased cost per unit of evasion, and that it would be less costly for the firm (in the context of the profit function) to reduce hog output along with increased abatement than to continue to evade effluent standards. In other words, the reduction in revenue from lower hog output plus the increased cost of greater employment of abatement capital would translate into a preferred profit scenario when the cost of violation rises. Increased regulation in this scenario would influence the scale of production in some way, which is likely to have an impact on the economies of scale achieved through confinement production methods. The details of the mathematics of these and all the comparative statics discussed in this section can be found in Appendix B. The conclusions drawn from these comparative statics are found in chapter six.

5.2 NOTES ON SPECIFICATION OF FUNCTIONAL FORM AND RESEARCH CHALLENGES ENCOUNTERED

One of the gaps in the literature that this thesis attempts to address is whether or not producer decisions that increase environmental risk are consistent with economic theory. A key task was to specify a model for analysis that reflected the joint production of hogs and effluent and somehow incorporated the additional costs or expected costs incurred by the producer outside of production. The discussion of costs outside of production will be left to section 5.3 and a discussion of the functional form selected for hog and effluent production is provided in this section.

The difficulty of constructing a model that encompasses the full range of revenue and costs faced by the firm in an environment of incomplete information is a likely reason why no such formulation seems to have appeared in the literature to date. The joint nature of production when dealing with pollution or externality in the environmental economics literature has incorporated the emissions from one facility as a (negative) input in the production process or utility function of those firms or individuals who experience the disamenity in question (Baumol and Oates). Another approach to modeling externality comes from Zilberman and Marra (1993), where a model of agricultural production is paired with a pollution generation function in a utility maximization framework. Zilberman and Marra's treatment looks at farm output and the externality from the perspective of society and welfare maximization via the design of optimal public policies.

In an attempt to take a firm-level decision making approach to the problem, the cost of abatement technology and its operation may be an argument in the profit function, but there is no widely accepted method of incorporating expected costs of regulation into a production economics and profit maximization framework. The negative impact of hog production externalities on the utility functions of individuals and production functions of other firms is what has led to regulation of these operations, and this regulation has resulted in real costs for producers, in addition to the costs of those affected by externalities. The attempt in this thesis to incorporate regulatory costs into a model where commodity and discommodity are jointly produced (and a feasible functional form for this is specified) and accounted for in the firm's profit maximization problem is unique to the best of this author's knowledge.

The difficulty of specifying a functional form involves a combination of production economics, environmental economics and the economics of crime and deterrence. The first attempt made in working through this thesis was to specify a single production function which yielded both hogs and effluent[27] and had desirable properties for theoretical consideration (continuous and twice differentiable with a unique solution). In this formulation effluent was simply a scalar (constant proportion of market output, *ceteris paribus*) of hog production, whereby changes in abatement technology affected the scalar value which was multiplied by hog output to determine effluent produced. The single production function utilized in this initial formulation of the model was a neoclassical production function of the general form $Q = ax + bx^2 - cx^3$, where hogs, Q, are produced through a very simple single input cubic production function and effluent, W, is given by the product of a scalar and Q. Proceeding to work within this formulation, conceptualized with Harford's (1978) profit function in mind, it became clear once working through the first and second order conditions that there was a problem which might have been clear from the beginning with a little more critical thinking about the functional form assumed. Q and E are functionally dependent because E is a function of Q and could in fact be written as $E = f(Q)$. Therefore the Hessian matrix derived from the second order partial derivatives of the profit function with respect to hogs and effluent has a vanishing determinant, $|H| = 0$, and a maximum is not achieved (the Hessian is not negative definite, as required for maximization). At best, such a formulation yields a negative semi-definite result, indicating some portion of the concave function is linear; this may yield some insights upon interpretation but it was believed that such a model would not provide a very useful method of analyzing firm decision making under environmental regulation.

[27] This was consistent with the very general approach taken by Harford (1978) where he does not include a production function in his analysis, but simply states that output and waste result from a single production process.

A formulation where hog and effluent production have common inputs that contribute differently to the quantity of *Q* and *E* produced (and where investments in abatement only have returns to abatement and not to profit) was sought. After trying to reformulate the theoretical hog production and pollution generation functions it became clear that continuing to work with a neoclassical production function was too difficult to work with algebraically. Another type of production function was desirable. The Cobb-Douglas type production function was utilized for this and the other reasons mentioned in chapter four. The revised theoretical formulation using a Cobb-Douglas type form, where $Q = f(x_1, x_2) = Ax_1^{\alpha_1} x_2^{\alpha_2}$ and $E = f(x_1, x_2, K) = \beta x_1^{\delta_1} x_2^{\delta_2} K^{\gamma}$, as presented in the previous chapter, achieved the desired properties for the resulting profit function.

The static nature of this analysis does represent a departure from the highly dynamic reality of agricultural production and environmental externality, but provides a production decision making framework from which to consider the environmental regulation of CAFOs. A producer or firm focused analysis of environmental regulation of CAFOs that seeks to examine economic decision making (firm behavior) is something that does not occur in the literature to date. Some aspects of this model that may represent a departure from the more dynamic setting observed "on the ground" are considered in the next section, where the simplified nature of the term $\sigma[E(\cdot)-\lambda]$ in the profit function is expanded. Recall that this simplified form was assumed in the profit model for the purpose of the comparative static analysis and resulted in no loss of insight in terms of the results reported in section 5.1 of this chapter.

5.3 A MORE DETAILED CONSIDERATION OF THE EXPECTED COSTS OF REGULATION FOR THE FIRM

In terms of the total cost function, two variables pertain directly to the cost of regulation and are given by the cost per unit of pollution abatement capital, r_3, and the expected cost per unit of effluent, σ. While there is an explicit cost that can be assigned to pollution abatement capital, the expected cost of regulation cannot realistically be represented by a single variable. The expected cost of regulation is taken to consist of three components for the purposes of the qualitative discussion in this section. In the Harford model any level of emission over an established standard is considered a violation and there is only one type of violation which can occur. For CAFOs this scenario is too simple (and indeed it may be for many if not most other situations where environmental regulation occurs) and two stages of non-compliance with regulation are presented.

First, let us consider violations where no environmental release occurs but firms are still subject to a fine if detected. Some possible scenarios are when: the maximum allowable level in the waste storage system is exceeded (minimum storm storage capacity may be required based on the type of management system and location in the US); deviation from a NMP occurs (exceeding agronomic application rates for manure or spreading before a forecast rainfall event when the likelihood of runoff is increased); the number of animals that a system is designed to accommodate (and the facility is permitted for) is exceeded; an equipment failure results in the discharge of some amount of waste small enough to be completely contained within the farm boundary. The cost of any such fine is not the only thing to consider because there are two associated probabilities that determine the expected cost associated with a particular violation—the probability of detection and the probability that an event will occur which triggers a violation. While management decisions are calculated ones and can be made based on expected probabilities of detection, the probabilities of events which could result in a release is much harder to account for in decision making. Such events might include chronic rainfall[28] or an equipment failure in the waste handling system. The expected cost of a (non-release) standard violation (hereafter referred to simply as a standard violation) is determined by multiplying the probability of a standard violating event occurring, P_s, by the probability of detecting a standard violation, P_d^s, by the fine (per unit) for a standard violation, F_s, by the magnitude of the violation, $(E - e_s)$, calculated as the difference between E and the effluent standard, e_s, based on the NPDES permit[29], which is linked to the NMP. The formulation of the last term in the expected cost of standard violation equation could be different depending on the type of standard violation that occurs; the form presented here is for the case where the maximum storage system level required for a certain amount of storm storage is represented by the variable e_s. E in this case is some level greater than that allowed. This is given in equation form as

[28] Only rainfall events smaller than those which trigger the 25 year, 24 hour storm exemption (for continuing operations) or the 100 year, 24 hour storm exemption (for new operations) fall into this category

[29] Recall that all NPDES permits currently issued to CAFOs are no discharge permits; as such the effluent standard referred to is contained in the effluent limitation guidelines (ELG) which has taken the form of either a nitrogen or phosphorus based land application standard (among other requirements) under the Final Rule.

$$P_s P_d^s F_s (E - e_s)\,, \qquad 5.1$$

and is the first of three sub-components of the simplified term, σ[E(·)-λ], utilized for the purposes of comparative static analysis in chapter four.

The second type of violation involves an environmental release, whether this release impacts soil or water resources[30], where a release event is defined as any event where effluent from the production process leaves the property where animals are being produced or waste is being land applied. This is likely considered the more severe of the two types of violation delineated here from the perspective of environmental effects. This second type of violation has been the subject of the majority of media coverage of high profile events involving CAFOs. Such releases are taken here to include all events where the impacts extend beyond the farm gate and are likely of greatest concern to public officials and regulators. A release can result from a variety of different events taking place. Some examples are excessive rainfall that causes a storage structure to overtop, a structural failure such as the collapse of a dike that retains animal waste, the failure of some equipment in the waste handling system like a pipe that transports waste breaking, or the leaching of waste material through the ground from a storage or land application area into groundwater. The expected cost of these violations can be expressed in a similar fashion to 5.1 as

$$P_r P_d^r F_r (E - e_r)\,, \qquad 5.2$$

where the probability of an event which leads to a release, P_r, is multiplied by the probability of a release being detected, P_d^r, multiplied by the fine (per unit) for a release, F_r, multiplied by the magnitude of the release, $(E - e_r)$. Notice that the last term in 5.2 could be expressed in different ways, as with the similar term in 5.1, depending on the nature of the release that occurs. The expression presented here is representative of an overtopping incident, whether resulting from poor management or weather events. In this case, e_r represents the maximum capacity of the storage system, where E is some amount greater than this capacity that accounts for rainfall contributions to system storage level and land applications that reduce storage level. The

[30] Impacts to air resources are not included here because the majority of events which have led to regulation of CAFOs involve land and water contamination. Odor as a disamenity has been a topic of heated discussion and the focus of several producer BMPs. Regulatory activity dealing with air quality concerns from CAFOs is currently being reviewed inside the EPA and several very recent legal actions have been filed based on the Clean Air Act (Lee).

expected cost of a standard violation (5.1) and the expected cost of a release (5.2) are clearly highly interconnected with the natural and built (manmade) systems in a given location and are greatly influenced by environmental and weather variables, as well as management. Also note that past performance is very likely to influence the probability of detection (scrutiny of the operation by regulators) into the future and therefore avoiding the first detection of any type of violation has a very big impact on the expected cost of regulation into the future.

The third component of the expected costs outside of production is the expected cost of litigation. Because of the increasing threat of a lawsuit against CAFOs by individual citizens or citizen groups, this is an area of increasing concern, particularly for the largest operations. The probability of litigation, P_l, the cost of litigation (inclusive of attorney fees, the cost of legal proceedings, other transaction costs involved, and any fines resulting from legal action), F_l, and the quantity of effluent are the factors thought to embody the expected cost of litigation. These costs are given by

$$P_l F_l E \,. \qquad 5.3$$

The nature of 5.3 is such that there is no clear level of effluent production that results in legal action against the firm, but the expected cost of litigation seems to be increasing in the size of E, which is increasing in the size of Q. According to this logic, the larger the operation, the larger will be the size of 5.3. Also, note that while the probabilities expressed in 5.1 and 5.2 are clearly difficult to assess, some approximation of the probability of detection is possible through personal and observed experience with regulators and the probability of events that lead to standard and release violation (rainfall events that are large enough to create management problems without triggering storm discharge exemptions, for instance) can also be estimated based on past experiences. The value of 5.3 is very different because there is even greater uncertainty involved in trying to assess the probability and magnitude of legal actions. The probability can be seen as a function of management that complies with regulations and limits externalities. In this way, P_l is a function of E and is believed to be greatest for events where $E > e_r$. F_l differs from the fine terms in 5.1 and 5.2 because there are clear rules for the maximum extent of fines for release under the Clean Water Act and producers are likely aware of realistic examples of how fines are levied for different standard violation and release events for a particular SEPA. Fines resulting from litigation can be subject to jury awards, which are highly unpredictable and have reached into the millions of dollars already in a variety of lawsuits involving CAFOs (Sierra Club). The highly litigious nature of environmental regulation has been extended to CAFOs in recent years and this is clearly a source of expected costs that CAFO operations must consider.

One thing that must be kept in mind is that the expanded profit function, written here in general terms for compactness as

$$\pi = PQ - r_1 x_x - r_2 x_2 - r_3 K - P_s P_d^s F_s (E - e_s) - P_r P_d^r F_r (E - e_r) - P_l F_l E , \qquad 5.4$$

includes the more complex terms 5.1, 5.2 and 5.3 in place of σE and is greatly influenced by the production decisions of the producer. Any changes in the inputs to Q or E has an impact on the magnitude of 5.1, 5.2 and 5.3. Increasing hog output without increasing the quantity of abatement capital employed or updating abatement technology will lead to higher levels of E and this gets translated into higher expected costs of regulation and litigation through 5.4. Instituting new BMPs, increasing abatement capital, or adopting new abatement technology will reduce the level of E and simultaneously gets translated into reduced expected costs of regulation and litigation in 5.4. In this expanded model of firm profit it is clear that firm-level production decisions not only influence firm hog and effluent output levels, but also the expected cost of regulation and litigation. While it may not be feasible from a benefit-cost perspective for the firm to do so, it is theoretically possible to reduce E to a level where all costs in excess of production are virtually eliminated. This is the situation where no violation of standards occurs, expressed alternatively as $E \le e_s$ and by implication $E < e_r$.

The intuition about firm behavioral responses to changes in probabilities of detection and fine levels was discussed in the context of the literature in chapter three and will be examined qualitatively within the expanded theoretical profit function 5.4. The comparative statics in Harford (1978) demonstrate that the level of emissions (and thus violation or evasion of pollution standards) is affected by increases in the p and f variables. More specifically, Harford found that output, x, and waste, w, were both negatively affected by increases in either p or f, given by the comparative statics $\{\partial\overline{w} / \partial p, \partial\overline{w} / \partial f, \partial\overline{x} / \partial p, \partial\overline{x} / \partial f\} < 0$. The result in this thesis that is consistent with Harford's finding is given by $\partial\overline{K} / \partial\sigma > 0$, where the cost of emissions in the simplified profit function 4.7 is used as a proxy for the combined effect of P_i, P_d^i, and F_i variables (expressed here in general form) on firm profit. The interpretation of the finding in this thesis is consistent because as the cost of evasion increases firms are expected to abate more (evade less). A more detailed analysis of firm response to changes in *p* and *f* is desired because of the interconnectedness between firm activities that have an effect on environmental risk faced by society and the expected cost of regulation and litigation for the firm. While comparative statics are nice for establishing the general relationship between an increase in detection effort or penalties for evasion and firm decisions, the literature has demonstrated the importance of the magnitude of such increases, the risk preferences of the offender, and the differential impact of *p* and *f* on firm decision making about evasion. For instance, even with very high fine levels, like those that accompany violations of the CWA (up to $25,000/day), compliance with an environmental regulation likely won't meet the expectations of policymakers if probability of detection remains low. In agreement with previous literature on the subject, offenders are believed to respond more to *p* than *f* (Becker, Smigel, Ehrlich). The assertion here is that we are seeing this played out with CAFOs where financial penalties are at least theoretically very high yet probabilities of detection are small enough that producers continue to operate in ways that place society at risk of environmental release because the product $P_i P_d^i F_i$, the per unit expected cost of a violation, is too small to incentivize the behavior that society desires.

Three graphs in Appendix C demonstrate the expected cost per unit of violation over a range of values $P_d^i = \{1/100 \ldots 1\}$ and $P_i = \{1/100, 1/50, 1/10\}$ for different expected fine levels. The expected cost of permit violation is far lower when the maximum CWA fine is reduced to lower levels. Using lower values for the fine level is consistent with observed implementation across the states (America's Clean Water Foundation). Following from the Becker (1968) and Harford (1978) insights about offender response to variations in *p* and *f*, it would appear that producers are likely assessing the expected costs of regulation based on low probabilities of detection as well as low fine levels when penalties are assessed if they are continuing to manage their operations in ways that allow externalities to persist despite regulation. The incentive to avoid being discovered in violation the first time is viewed as considerable for CAFOs because of the hassle of repeated visits by a regulator as scrutiny increases following the first infraction. In addition, Oljaca, Keeler and Dorfman (1998) have empirically found that repeated offenses also have a positive significant impact on fine levels for water quality violations.

If, as Becker (1968) has asserted, adjustments to *p* do in fact have a greater impact on offender behavior (firm abatement in the case of CAFOs) than changes in *f*, it should be clear that this may be one area that needs to be addressed if firms are to change their behavior to achieve the intended objectives of regulation. The solution is not so easy as to simply increase the probability of detection by means of more monitoring equipment, more SEPA personnel or some other method because the cost of increasing p is substantial (a point originally made by Becker and later extended by Stigler, 1970). Another aspect of this problem that must be considered is that farm managers may assess the probability of detection for different infractions in different ways because of the ease of detection or the presence of informational barriers that are significant enough to shield the operator from detection for violations in one aspect of their operation but not in others. This is where Becker's finding that offenders substitute among offenses is directly applicable to the analysis of CAFOs. If waste storage levels have exceeded the minimum storm storage required by regulation it is very easy for a regulator to go directly to the lagoon and observe the lagoon level, but it is far more difficult to observe application of manure at higher than agronomic rates to keep the system storage level within regulatory (and in some cases integrator) standards.

Turning to the expected cost of regulation in the case of release, the components of the expected cost function 5.2 are essentially the same as those in equation 5.1 and the same considerations need to be made when evaluating manipulations of p and f for 5.2. Because of the nature of 5.2 it is only triggered (becomes an actual cost) when effluent leaves the property boundary of the operation. When this occurs and documented damage to water or land resources occur, not only is the firm responsible for the regulatory costs that come in the form of fines but also for additional costs of cleanup (restocking fish killed is the most common expense that falling into this category). Elevated scrutiny by neighbors and citizen groups (a form of p or private enforcement) is also a possible result. Neighbors play a potentially important monitoring role that is not easily quantifiable.

The expected cost of litigation calculated in 5.3 has the potential to be the largest of the three terms in profit function 5.4 that account for costs over and above factor costs. There may very well be a fixed cost associated with any litigation that occurs which is higher than such costs for standard and release violations because of the nature of attorney fees, but the potential for even greater costs exists because in the event that litigation results in a defendant being found at fault there is the potential for a plaintiff to recoup legal costs from the CAFO when suits are filed under the CWA (as discussed in chapter 3.4.4). The time costs of a lawsuit are likely to be very substantial and the likelihood of incurring reputation costs as a result of a lawsuit via negative press coverage is also increased. The uncertainty associated with cases where rulings are subject to jury awards could further increase the cost of litigation by an amount that is very hard to calculate as an expected cost when trying to make business planning decisions.

CHAPTER SIX

CONCLUSIONS AND FUTURE RESEARCH

The final chapter presents conclusions based on the comparative static analysis and qualitative considerations presented in the previous chapter, discusses some limitations to this work, and points out several areas for future research and extensions of the work in this thesis.

6.1 CONCLUSIONS

The analysis in this thesis set out to examine the institutions and incentives in large scale livestock production in the United States and more specifically to determine if the profit maximizing decisions of producers in response to regulation was consistent with economic theory. The case of a hog operation is examined via a theoretical model of firm decision making under CAFO regulation and a variety of results have emerged. The model results presented in chapter five are applied to the theory of the firm and insights for policymaking (regulation) are offered.

The observed behavior of firms operating under CAFO regulations has not met the objectives of policymakers. Economic theory might suggest that firm decision making based on the incentives in the system of production and regulation could offer insights about why regulation has failed to elicit the desired behavior. The comparative statics reported as 4.12 through 4.20 are as one might expect when analyzing the use of inputs and factor costs in a production process. As the cost of any of the three inputs (feed, land and pollution abatement capital) rises, the results suggest a fall in the use of that input (4.12, 4.16, and 4.20). The effect of changes in all factor costs has the same effect on the quantity of those inputs employed in the hog production process and an opposite effect on the quantity of pollution abatement utilized by the firm. This result suggests that as the cost of hog production alone rises, the returns to evasion decrease and the firm will engage in higher levels of abatement. As the cost of abatement rises, however, the returns to evasion increase and firms will employ fewer resources in abatement as they increase hog output.

In the context of the firm and public policy this combination of results indicates that as regulation becomes more costly via the cost of abatement (as opposed to fines or probabilities of detection) firms will not only abate less but produce more. This suggests that increased regulation which takes the form of technology requirements or particular practices that raise the abatement costs of the firm leads to increased effluent production and therefore greater potential for pollution. The majority of the producer cost of regulation to date has taken this form by instituting design requirements and operational guidelines as solutions to CAFO externality. Rules requiring livestock production and waste handling facilities to be able to contain the effluent from 25 or 100 year, 24 hour rainfall events is one example. The requirement of best management practices for manure utilization via a CNMP is another. The model suggests then that the predominant form which regulation has taken would not result in the desired reduction in pollution from such operations but rather the potential for an increase in effluent is possible. This is consistent with what has been observed as the cost of operation has increased for producers with regulation but the desired environmental outcomes have not been observed.[31] There seems to be a connection between this observed behavior and the shadow price of compliance (expected costs of regulation and litigation) discussed below.

The effect of a change in the expected cost of operation via fines for violation of regulations or probabilities of detection (litigation) on the level of abatement finds that abatement will increase as the cost of evasion or violation rises. This result is consistent with the finding in Harford (1978), that emissions will fall with an increase in either the probability of getting caught or the fine for a violation. This is of course to be expected and it is the reason why a simplified form of the costs of violation can be utilized for the purpose of comparative statics in chapter four. When considered alongside the result that an increase in the per unit shadow price of compliance alone may lead to higher levels of violation in CAFO production, the conclusion is that regulation that fails to realistically impact the cost and-or likelihood of being found in violation will not result in reduced levels of externality. The design and implementation of public policy intended to curtail externality seems to have failed to consider the way that regulation impacts firm decision making via the profit function.

The model results mimic what we see occurring with CAFO operations and public policy. Regulation has consisted largely of design-based standards that rely on engineering solutions to problems of production externality, but there has been little connection between the strictness of

[31] There is no evidence to suggest externalities have increased or conditions have worsened, but it is widely acknowledged that the objectives of regulation have not been achieved. Biannual EPA Water Quality Inventory reports to Congress from 1996-2000 do not strongly indicate any increase or decrease in the share of surface water pollution attributed to animal feeding operations.

these standards and the performance of operators required to abide by them. The regulations seem to be effective at getting systems that meet design standards in place, especially for new operations. In this way, the costs policymakers have sought to make producers internalize have been realized through the promulgation of regulations at EPA. The performance or continuing compliance that is required for the social welfare benefits sought by policymakers to be realized appears to be a matter of much greater uncertainty or doubt. While the literature indicates that devoting more funds to implementation or ME for environmental regulation (Hellund) isn't necessarily the solution in cases where cooperative federalism is a factor, there appear to be great differences in the implementation of federal regulations governing CAFOs across the states (America's Clean Water Foundation).

The infrastructure and personnel necessary to implement both system design and ME aspects of CAFO regulation comes at a significant cost to society. Just as Becker (1968) pointed out, certain aspects of law enforcement cost considerably more than others, and CAFOs are no exception. Given the highly dispersed and varied nature of CAFO operations, producers have wielded a considerable informational advantage over society and regulators charged with implementing regulations. For this reason there seems to be a large enough gap between initial and continuing compliance that producers have assessed the cost of evading pollution standards once design and CNMP criteria have been met (embodied in K and its cost r_3) as small enough to justify continued noncompliance with certain aspects of regulation; this results in the persistence of externality that CAFO regulations were enacted to curtail. There appears to be substitution among offenses which this writer asserts is a result of the disconnect between the stringency which producers expect to be subject to regarding design requirements and permitting versus management and implementation of CNMPs. A profit maximizing producer is acting in an economically rational manner when she evades those aspects of environmental regulation which she views as having little or no expected economic consequence.

The publication of the Final Rule in December 2002 has ushered in a considerable change in the information asymmetry that previously existed between CAFOs and society. A substantial concession of previously private information is contained in the CNMP required by NRCS and the NMP required by the permitting authority. Recent work by Skees, Black and Gramig (2003) has proposed the use of contingent claims contracts coupled with third party auditing to reduce the environmental risk posed by animal waste management systems. The risk management instruments proposed utilize the site-specific information contained in a CNMP in an engineering model of livestock waste management to model firm-level risk of environmental release. The use of biophysical-engineering models like the one developed by Considine and Burns (America's Clean Water Foundation) may provide opportunities for ex-ante risk mitigation and more effective monitoring and enforcement by regulators.

The model indicates that producers will respond to regulatory threats they view as credible. The prediction from this model is that regulations contributing only to the cost of demonstrating that an operation is capable of meeting effluent requirements will not achieve the desired environmental outcome because they fail to impact the producer's assessment of their likelihood of being caught when violations occur.

By advancing the implementation of design or engineering-based solutions to the public policy problem regulators have embraced the idea of building our way out of the problem. This approach has limitations in reducing the risk of environmental release. By building bigger and more sophisticated waste management systems, we have enabled the placement of increasing densities of animals over the same geographical space. With larger and larger operations that result from engineering requirements for systems, the occurrence of events (equipment failures, poor management, weather) that result in releases, however frequent or infrequent, will mean even larger catastrophes when they do occur. Regulation that enables greater concentration through engineered systems but fails to address the spatial distribution of animals may never meet the environmental objectives of policy makers.

While regulations have placed restrictions on the amount of manure (nutrients more specifically) that can be applied to land or crops, if this aspect of regulation is not viewed as a credible threat by those subject to regulation, compliance is likely to be lax given the economic incentives. In this way, increasing the (fixed) cost of operation for all producers above a certain size may have the effect of contributing to the increasing size of operations and concentration in the livestock sector as fewer producers can afford the costs needed to obtain permits for facilities, but once in operation these facilities have no greater expectation of being detected when out of compliance. The question of whether or not regulation of this kind may actually be a factor in the scale or structure of the industry is a potential question for future research to investigate. This type of research question may be viewed as a logical extension of Stigler's

(1971) analysis of the theory of economic regulation. Some other potential topics for future research will be identified later in this chapter.

6.2 LIMITATIONS OF THIS MODEL

The limitations of this study should be stated very clearly for the reader. A static study of this type does not account for the truly dynamic nature of the problem and a highly stylized model of this kind cannot possibly account for every aspect of firm decision making. Comparative statics, while highly useful in predicting changes in individual endogenous variables based on changes in exogenously determined variables, cannot take into account simultaneous changes in more than one variable. The nature of production and abatement adjustments on the part of the firm is such that greater abatement not only impacts the quantity of effluent produced (as accounted for in the model) but also impacts the probability of detection, the magnitude of any release event that may occur and potentially the nature of any legal action taken against a firm or integrator resulting from the operation of a particular facility. This is one example of the dynamic nature of changes to variables in the profit function.

The comparative static results are only as good as the model used to derive them. The pains taken to specify this model in a way that is consistent with the actual regulatory environment have attempted to avoid this pitfall. The analysis presented has been careful not to violate the rules for interpreting comparative statics. The fact that the results from the model agree with the behavior and environmental outcomes we have observed adds weight to the specification of the model presented in this thesis. The findings from comparative statics are helpful in specifying research problems for more detailed study and this comparative static analysis is no exception. An empirical examination of the theoretical model would provide the strongest verification of the model's realism and usefulness in evaluating firm-level production decisions and public policy that seeks to change individual behavior. Several research questions for future work have resulted from this analysis and a discussion of these research topics follows.

6.3 FUTURE RESEARCH

One of the most interesting research questions to emerge from this work is the comparative static result that increases in the cost of meeting initial compliance standards for

CAFO operations without credible enforcement of the continuing compliance provisions in the law will fail to meet the environmental objectives intended by public policy. If a dataset were available to apply to the theoretical firm profit model and a more complete range of hog and effluent production inputs were incorporated, an empirical examination of the model could be performed and would contribute to the evaluation of the model, firm decision making and the design of public policy. An empirical study of this kind could provide valuable insights into the nature of the hog production and pollution generation functions and may contribute to modeling a decision framework for profit maximizing economic agents that must account for an array of regulatory costs (both certain and uncertain).

The qualitative discussion of the expanded model of firm profit that accounts for the cost of violating standards and litigation is a starting point for research into the effect of changing the probability of detection and fine levels on improving firms' continuing compliance with regulations. Compliance is not the only important issue in considering different policy changes, part of the analysis must consider the social cost and benefit of such changes to regulation as noted by Becker (1968) and re-iterated by Polinsky and Shavell (2000). Efficiency does not require the complete elimination of externality (Buchanan and Stubblebine) and with CAFOs it is clearly the case that perfect enforcement likely comes at a cost to society so great that the benefits of this arrangement could not be justified by the costs. Assessing the impact of the various probabilities and magnitudes of penalties on firm decision making in the profit maximization framework would seem to be an important area for further research. The nature of the various probabilities seems to provide a particularly interesting problem for research in and of itself.

A far more detailed and stronger set of comparative static results from this analysis could be derived by specifying a feasible range of values for the different exponents in the hog production and pollution generation functions. The use of the word "stronger" refers to the set of restrictions necessary for negative definiteness of the Hessian matrix that satisfies Second Order Conditions for profit maximization. A specific range of values for which different comparative static outcomes result could shed a great amount of light on the nature of firm decision making and profitability conditions. This gets at Becker's discussion of establishing an understanding of the conditions under which crime does and does not "pay". His analysis concludes that risk preferences may play a role in determining how agents respond to public policy. The use of mathematical analysis software such as Mathematica or Matlab could be used to derive optimal values for the endogenous variables and examine the impact of a range of values for different variables in the profit function graphically. By specifying the range of values for which different comparative static results occur (and do not occur), it may be possible to determine the magnitude of a change in enforcement variables necessary to impact firm decision making. Such magnitudes are necessary to attempt to assess the social cost of adjusting probabilities of detection to levels where firm response satisfies the goals of regulation.

Some of the same conclusions reached here regarding the nature of regulation and what may be needed in considering the scale and spatial distribution of operations were findings in Innes' (2000) theoretical study. Investigating the environmental risk of different public policy designs and considering new types of solutions is an interesting area for further research. Some research in this area is underway (America's Clean Water Foundation; Skees, Black and Gramig) but for society to be able to better manage the risk of such operations, the ramifications of integrating built (manmade) systems with environmental systems (soil types, watersheds, groundwater hydrology, weather, etc.) and the risk transfer system must be examined. Adherence to engineering solutions has meant larger and larger waste storage systems and the accompanying ability to increase animal density within watersheds must be considered in light of studies like Pratt, Jones and Jones (1997) which indicate that there may be a physical limit to the number of animals that can be located over a particular spatial distribution regardless of the implementation of BMPs if externality is to be curtailed.

The incentives at work are clearly what motivates producer decision making and these have been discussed in a largely qualitative manner. A formal modeling of these diverse incentives in a multiple-principal environment to evaluate the nature of equilibria under different industry and policy scenarios would be very challenging. The flow of information in the multiple-principal environment is also an area of particular interest given the information asymmetries that are widely cited as a major obstacle to efficiency. Analysis capable of dissecting the movement of information and the incentives operating to influence firms and policymakers in this complex institutional arrangement is likely to provide a variety of useful insights for researchers and policymakers alike.

The attempt to model firm decision making under environmental regulation of CAFOs presented here has found that economic theory does seem to be consistent with producer's actions. The design of the model seems consistent with the nature of production and regulation and the model findings parallel the observed behavior of producers and regulators. It is found that the implementation of regulation is key to eliciting desired behavior from firms and that firm decision making which results in continued externality is rational economic behavior on the part of firms. CAFO managers are operating in ways that are consistent with economic theory when they make decisions that increase environmental risk for society. If public policy intended to reduce externality from such operations is to be successful, closer attention needs to be given to the nature of firm decision making. A careful consideration of the costs and benefits of different regulatory emphases and possible market-based solutions is necessary as policymakers proceed.

APPENDIX A: MATHEMATICAL APPENDIX TO CHAPTER FOUR, PART I

NECESSARY AND SUFFICIENT CONDITIONS FOR PROFIT-MAXIMIZATION

The profit function to be evaluated is given by equation 4.7 and is expressed as

$$\pi = PAx_1^{\alpha_1}x_2^{\alpha_2} - r_1x_1 - r_2x_2 - r_3K - \sigma[\beta x_1^{\delta_1}x_2^{\delta_2}K^{\gamma} - \lambda].$$

First order conditions, given by the partial derivatives of π with respect to the endogenous variables x_1, x_2, and K, are denoted with the usual subscript notation and are expressed as 4.8, 4.9, and 4.10 in the text. These conditions are, respectively,

$$\pi_{x_1} = \alpha_1 PAx_1^{\alpha_1-1}x_2^{\alpha_2} - r_1 - \delta_1\sigma\beta x_1^{\delta_1-1}x_2^{\delta_2}K^{\gamma} = 0,$$

$$\pi_{x_2} = \alpha_2 PAx_1^{\alpha_1}x_2^{\alpha_2-1} - r_2 - \delta_2\sigma\beta x_1^{\delta_1}x_2^{\delta_2-1}K^{\gamma} = 0, \text{ and}$$

$$\pi_K = r_3 - \gamma\sigma\beta x_1^{\delta_1}x_2^{\delta_2}K^{\gamma-1} = 0.$$

These first order conditions satisfy the necessary conditions for a profit maximum. An attempt to solve for the optimum or equilibrium values of the endogenous variables, as is customary in working through first and second order conditions for an economic function, was made in performing this analysis. The algebra was such that the steps or order of substitution to solve for x_1^*, x_2^*, and K^* could be determined, but the mathematical manipulation necessary to arrive at these values was too complicated even for a mathematical analysis software program to solve symbolically. For this reason, no such optimal values for the maximum point on the profit function are included in this analysis. The author feels confident that by specifying feasible values for the exponents in the *Q* and *E* functions, such values could be calculated more easily and examined in greater detail, but this work is left for future analysis.

The sufficient conditions for a maximum are met by satisfying the second order conditions and are derived from the Hessian matrix given in the text as 4.11. The components of $[H]$ are listed below using matrix notation (where H_{ij} indicates the *i*th row and *j*th column of the matrix) that corresponds to the 3x3 matrix:

$H_{11} = \pi_{x_1x_1} = \alpha_1(\alpha_1 - 1)PAx_1^{\alpha_1-2}x_2^{\alpha_2} - \delta_1(\delta_1 - 1)\sigma\beta x_1^{\delta_1-2}x_2^{\delta_2}K^{\gamma}$

$H_{12} = \pi_{x_2x_2} = \alpha_1\alpha_2 PAx_1^{\alpha_1-1}x_2^{\alpha_2-1} - \delta_1\delta_2\sigma\beta x_1^{\delta_1-1}x_2^{\delta_2-1}K^{\gamma}$

$H_{13} = \pi_{x_1K} = -\delta_1\gamma\sigma\beta x_1^{\delta_1-1}x_2^{\delta_2}K^{\gamma-1}$

H21= $\pi_{x_2x_1} = \alpha_1\alpha_2 PAx_1^{\alpha_1-1}x_2^{\alpha_2-1} - \delta_1\delta_2\sigma\beta x_1^{\delta_1-1}x_2^{\delta_2-1}K^{\gamma}$

H22= $\pi_{x_2x_2} = \alpha_2(\alpha_2-1)PAx_1^{\alpha_1}x_2^{\alpha_2-2} - \delta_2(\delta_2-1)\sigma\beta x_1^{\delta_1}x_2^{\delta_2-2}K^{\gamma}$

H23= $\pi_{x_2K} = -\delta_2\gamma\sigma\beta x_1^{\delta_1}x_2^{\delta_2-1}K^{\gamma-1}$

H31= $\pi_{Kx_1} = -\delta_1\gamma\sigma\beta x_1^{\delta_1-1}x_2^{\delta_2}K^{\gamma-1}$

H32= $\pi_{Kx_2} = -\delta_2\gamma\sigma\beta x_1^{\delta_1}x_2^{\delta_2-1}K^{\gamma-1}$

H33= $\pi_{KK} = -\gamma(\gamma-1)\sigma\beta x_1^{\delta_1}x_2^{\delta_2}K^{\gamma-2}$

The second order sufficient conditions for a maximum require that the successive principal minor determinants of the Hessian matrix alternate in sign as follows

$$H_1 = \pi_{x_1x_1} < 0,$$

$$|H_2| = \begin{vmatrix} \pi_{x_1x_1} & \pi_{x_1x_2} \\ \pi_{x_2x_1} & \pi_{x_2x_2} \end{vmatrix} > 0, \text{ and}$$

$$|H_3| = |H| = \begin{vmatrix} \pi_{x_1x_1} & \pi_{x_1x_2} & \pi_{x_1K} \\ \pi_{x_2x_1} & \pi_{x_2x_2} & \pi_{x_2K} \\ \pi_{Kx_1} & \pi_{Kx_2} & \pi_{KK} \end{vmatrix} < 0.$$

The first principal minor is given by

$$H_1 = \alpha_1(\alpha_1-1)PAx_1^{\alpha_1-2}x_2^{\alpha_2} - \delta_1(\delta_1-1)\sigma\beta x_1^{\delta_1-2}x_2^{\delta_2}K^{\gamma},$$

where the first and second terms are both negative. In order for the second order conditions to be satisfied for the first principal minor, the absolute value of the first term must be larger than the absolute value of the second term so that their difference is negative and $H_1 < 0$.

The second principal minor is given by

$$|H_2| = (\pi_{x_1x_1}\pi_{x_2x_2}) - (\pi_{x_1x_2}\pi_{x_2x_1}),$$

where, like $\pi_{x_1x_1}$ in H_1, the first and second terms in $\pi_{x_2x_2}$ are negative, making the first term in $|H_2|$ positive. From Young's Theorem we know that $\pi_{x_1x_2} = \pi_{x_2x_1}$, which means that the second term of $|H_2|$ can be treated as $(\pi_{x_1x_2})^2$. The nature of $\pi_{x_1x_2}$ is such that it could potentially be either positive or negative, but a specific sign is ultimately necessary in order to satisfy the second order conditions when the determinant of the third principal minor is evaluated in the next step. Regardless of the sign of $\pi_{x_1x_2}$, the second order conditions may be met for the second principal minor determinant provided that $\left|\pi_{x_1x_1}\pi_{x_2x_2}\right| > \left|\pi_{x_1x_2}\pi_{x_2x_1}\right|$.

The third principal minor determinant is given by

$\left|H_3\right| = \left|H\right| = \pi_{x_1x_1}(\pi_{x_2x_2}\pi_{KK} - \pi_{x_2K}\pi_{Kx_2}) - \pi_{x_1x_2}(\pi_{x_2x_1}\pi_{KK} - \pi_{x_2K}\pi_{Kx_1}) + \pi_{x_1K}(\pi_{x_2x_1}\pi_{Kx_2} - \pi_{x_2x_2}\pi_{Kx_1})$,

where in order for $\left|H_3\right|$ to be unambiguously negative, the three terms must have particular signs which will depend on the magnitude of certain components of the particular terms. The three terms will be referred to in this appendix as I, II and III, respectively. The first necessary condition is given by

$$\text{(I)}\left|\pi_{x_2x_2}\pi_{KK}\right| > \left|\pi_{x_2K}\pi_{Kx_2}\right|,$$

which assures that $I < 0$. In considering $\left|H_2\right|$, the sign of $\pi_{x_1x_2}$ did not matter in order to satisfy $\left|H_2\right| > 0$ because the value was squared, but here it is necessary that $\pi_{x_1x_2} < 0$ in order for $II > 0$. The second necessary condition is given by

$$\text{(II)}\left|\pi_{x_2x_1}\pi_{KK}\right| < \left|\pi_{x_2K}\pi_{Kx_1}\right| \text{ and } \pi_{x_1x_2} < 0,$$

which is required in order for $II > 0$. An unambiguously negative sign for $\left|H_3\right|$ requires that $II > 0$. Carrying the negativity of $\pi_{x_1x_2}$ forward (for the remainder of the analysis provided in this appendix and the comparative statics in Appendix B), the third necessary condition for an unambiguously negative sign for $\left|H_3\right|$ is given by

$$\text{(III)}\left|\pi_{x_2x_1}\pi_{Kx_2}\right| > \left|\pi_{x_2x_2}\pi_{Kx_1}\right|,$$

which ensures that $III < 0$. Provided that conditions I, II, and III are satisfied, $\left|H_3\right| = \left|H\right| < 0$ satisfies the second order conditions for a maximum. If the magnitude of $\pi_{x_1x_2}\pi_{Kx_2}$ is less than $\pi_{x_2x_2}\pi_{Kx_1}$, the second order conditions for profit maximization could still be met provided the second term of $\left|H_3\right|$ is greater than the sum of the other two terms. There are clearly values for which the profit function is negative definite—the theoretically desirable result.

NOTE: Negative semi-definiteness is also a possible outcome. The second principal minor determinant could be vanishing if $\pi_{x_1x_1}\pi_{x_2x_2} = \pi_{x_1x_2}\pi_{x_2x_1}$; in other words $|H_2| = 0$. If one of the conditions necessary for the third principal minor determinant to be positive is not met, specifically that $\pi_{x_1x_2}\pi_{Kx_2} < \pi_{x_2x_2}\pi_{Kx_1}$, then it is conceivable that $|H_3| < 0$. In the situation where $H_1 < 0$, $|H_2| = 0$ and $|H_3| < 0$ the profit function is found to be negative semi-definite. The conditions for negative semi-definiteness are met when all the nonzero *k*'th principal minor determinants have the same sign as $(-1)^k$(Chiang). While not as theoretically pleasing a result as negative definiteness, this result would indicate that some portion of the function is linear. This is still a theoretically consistent shape for the profit function (concavity). Because the conditions for negative definiteness can be met and this result provides a more rich result for comparative static analysis, necessary conditions I, II, and III from Appendix A will be carried forward in this thesis to evaluate the comparative static derivatives.

APPENDIX B: MATHEMATICAL APPENDIX TO CHAPTER FOUR, PART II

COMPARATIVE STATICS OF THE PROFIT FUNCTION

Starting with the profit function 4.7, given by

$$\pi = PAx_1^{\alpha_1}x_2^{\alpha_2} - r_1x_1 - r_2x_2 - r_3K - \sigma[\beta x_1^{\delta_1}x_2^{\delta_2}K^{\gamma} - \lambda],$$

the first order conditions expressed in the body of the thesis as 4.8, 4.9 and 4.10 (also in Appendix A) are expressed here as the implicit functions:

$$F^1(\bar{x}_1, \bar{x}_2, \bar{K}; r_1, r_2, r_3, P, \sigma) = \pi_{x_1} = \alpha_1 PAx_1^{\alpha_1-1}x_2^{\alpha_2} - r_1 - \delta_1\sigma\beta x_1^{\delta_1-1}x_2^{\delta_2}K^{\gamma} = 0;$$

$$F^2(\bar{x}_1, \bar{x}_2, \bar{K}; r_1, r_2, r_3, P, \sigma) = \pi_{x_2} = \alpha_2 PAx_1^{\alpha_1}x_2^{\alpha_2-1} - r_2 - \delta_2\sigma\beta x_1^{\delta_1}x_2^{\delta_2-1}K^{\gamma} = 0; \text{ and}$$

$$F^3(\bar{x}_1, \bar{x}_2, \bar{K}; r_1, r_2, r_3, P, \sigma) = \pi_K = r_3 - \gamma\sigma\beta x_1^{\delta_1}x_2^{\delta_2}K^{\gamma-1} = 0.$$

The bars over the endogenous variables in the three implicit functions indicate that the first derivatives are evaluated at the optimal values of the profit function. From these first order conditions the effect of a change in the exogenous variables on the optimal values of the endogenous variables can be determined by use of comparative statics. The total derivatives of the first order conditions with respect to the exogenous variables are taken and these values are placed in matrix form as follows:

$$\underbrace{\begin{bmatrix} \frac{\partial F^1}{\partial x_1} & \frac{\partial F^1}{\partial x_2} & \frac{\partial F^1}{\partial K} \\ \frac{\partial F^2}{\partial x_1} & \frac{\partial F^2}{\partial x_2} & \frac{\partial F^2}{\partial K} \\ \frac{\partial F^3}{\partial x_1} & \frac{\partial F^3}{\partial x_2} & \frac{\partial F^3}{\partial K} \end{bmatrix}}_{J} \underbrace{\begin{bmatrix} \frac{\partial \bar{x}_1}{\partial i} \\ \frac{\partial \bar{x}_2}{\partial i} \\ \frac{\partial \bar{K}}{\partial i} \end{bmatrix}}_{X} = \underbrace{\begin{bmatrix} -\frac{\partial F^1}{\partial i} \\ -\frac{\partial F^2}{\partial i} \\ -\frac{\partial F^3}{\partial i} \end{bmatrix}}_{B}.$$

The generic variable *i* represents the particular exogenous variable being evaluated and this formulation of matrices in performed for each comparative static relationship measured in this appendix. The specific matrix form for each of the five exogenous variables examined are not provided here, only matrix *B* will be provided for each exogenous variable for this step in the calculation of comparative statics. Matrix *J* is the Jacobian from the first order conditions which is equivalent to the Hessian matrix examined for the second order conditions, written here in terms of the implicit functions F^1, F^2, and F^3 for notational simplicity. Matrix *X* contains the values whose signs are sought for the comparative static results in chapter four. Because $[J] = [H], |J| = |H|$ and recall that from the second order conditions derived in Appendix A $[H]$ is negative definite, $|J| \neq 0$ and (assuming continuous first and second derivatives) Cramer's Rule can be used to find the desired derivatives in matrix *X*. The five $[B_i]$ matrices that will be utilized in applying Cramer's Rule for each exogenous variable are provided below, where subscripts indicate the *B* matrix for each individual exogenous variable.

$$\underbrace{\begin{bmatrix}1\\0\\0\end{bmatrix}}_{B_{r_1}} \qquad \underbrace{\begin{bmatrix}0\\1\\0\end{bmatrix}}_{B_{r_2}} \qquad \underbrace{\begin{bmatrix}0\\0\\1\end{bmatrix}}_{B_{r_3}} \qquad \underbrace{\begin{bmatrix}(-)\\(-)\\0\end{bmatrix}}_{B_P} \qquad \underbrace{\begin{bmatrix}(+)\\(+)\\(-)\end{bmatrix}}_{B_\sigma}$$

The first set of comparative static derivatives are taken with respect to r_1, utilize $[B_{r_1}]$, and follow:

$$\frac{\partial \bar{x}_1}{\partial r_1} = \frac{|J_1|}{|J|} = \frac{\begin{vmatrix} 1 & \frac{\partial F^1}{\partial x_2} & \frac{\partial F^1}{\partial K} \\ 0 & \frac{\partial F^2}{\partial x_2} & \frac{\partial F^2}{\partial K} \\ 0 & \frac{\partial F^3}{\partial x_2} & \frac{\partial F^3}{\partial K} \end{vmatrix}}{|J|} = \frac{\overbrace{1(\underbrace{\pi_{x_2x_2}}_{(-)}\underbrace{\pi_{KK}}_{(-)} - \underbrace{\pi_{x_2K}}_{(+)}\underbrace{\pi_{Kx_2}}_{(+)})}^{\text{SOC(I)}\Rightarrow(+)} - \pi_{x_1x_2}(0) + \pi_{x_1K}(0)}{(-)} < 0$$

Necessary condition I from the second order conditions (SOC) implies the numerator is positive.

$$\frac{\partial \bar{x}_2}{\partial r_1} = \frac{|J_2|}{|J|} = \frac{\begin{vmatrix} \frac{\partial F^1}{\partial x_1} & 1 & \frac{\partial F^1}{\partial K} \\ \frac{\partial F^2}{\partial x_1} & 0 & \frac{\partial F^2}{\partial K} \\ \frac{\partial F^3}{\partial x_1} & 0 & \frac{\partial F^3}{\partial K} \end{vmatrix}}{|J|} = \frac{\pi_{x_1x_1}(0) - \overbrace{1(\underbrace{\pi_{x_2x_1}}_{(-)}\underbrace{\pi_{KK}}_{(-)} - \underbrace{\pi_{x_2K}}_{(+)}\underbrace{\pi_{Kx_1}}_{(+)})}^{\text{SOC(II)}\Rightarrow(-)} + \pi_{x_1K}(0)}{(-)} < 0$$

$$\frac{\partial \bar{K}}{\partial r_1} = \frac{|J_3|}{|J|} = \frac{\begin{vmatrix} \frac{\partial F^1}{\partial x_1} & \frac{\partial F^1}{\partial x_2} & 1 \\ \frac{\partial F^2}{\partial x_1} & \frac{\partial F^2}{\partial x_2} & 0 \\ \frac{\partial F^3}{\partial x_1} & \frac{\partial F^3}{\partial x_2} & 0 \end{vmatrix}}{|J|} = \frac{\pi_{x_1x_1}(0) - \pi_{x_1x_2}(0) + \overbrace{1(\underbrace{\pi_{x_2x_1}}_{(-)}\underbrace{\pi_{Kx_2}}_{(+)} - \underbrace{\pi_{x_2x_2}}_{(-)}\underbrace{\pi_{Kx_1}}_{(+)})}^{\text{SOC(III)}\Rightarrow(-)}}{(-)} > 0$$

The second set of comparative static derivatives are taken with respect to r_2, utilize $\lfloor B_{r_2} \rfloor$, and follow:

$$\frac{\partial \bar{x}_1}{\partial r_2} = \frac{|J_1|}{|J|} = \frac{\begin{vmatrix} 0 & \frac{\partial F^1}{\partial x_2} & \frac{\partial F^1}{\partial K} \\ 1 & \frac{\partial F^2}{\partial x_2} & \frac{\partial F^2}{\partial K} \\ 0 & \frac{\partial F^3}{\partial x_2} & \frac{\partial F^3}{\partial K} \end{vmatrix}}{|J|} = \frac{\overbrace{0 - \overbrace{\pi_{x_1x_2}}^{(-)}(\overbrace{\pi_{KK}}^{(-)} - 0) + \overbrace{\pi_{x_1K}}^{(+)}(\overbrace{\pi_{Kx_2}}^{(+)} - 0)}^{\text{SOC(II)} \Rightarrow (+)}}{(-)} < 0$$

$$\frac{\partial \bar{x}_2}{\partial r_2} = \frac{|J_2|}{|J|} = \frac{\begin{bmatrix} \frac{\partial F^1}{\partial x_1} & 0 & \frac{\partial F^1}{\partial K} \\ \frac{\partial F^2}{\partial x_1} & 1 & \frac{\partial F^2}{\partial K} \\ \frac{\partial F^3}{\partial x_1} & 0 & \frac{\partial F^3}{\partial K} \end{bmatrix}}{|J|} = \frac{\overbrace{\overbrace{\pi_{x_1x_1}}^{(-)}(\overbrace{\pi_{KK}}^{(-)} - 0) - 0 + \overbrace{\pi_{x_1K}}^{(+)}(0 - \overbrace{\pi_{Kx_1}}^{(+)})}^{\left|\pi_{x_1x_1}\pi_{KK}\right| > \left|\pi_{x_1K}\pi_{Kx_1}\right| \Rightarrow (+)}}{(-)} < 0$$

The sign of the numerator is dependent on the magnitude of terms and theory indicates the numerator must be positive in order for $\partial \bar{x}_2 / \partial r_2$ to have the expected sign. As the factor cost increases, the use of the input will decrease.

$$\frac{\partial \bar{K}}{\partial r_2} = \frac{|J_3|}{|J|} = \frac{\begin{vmatrix} \frac{\partial F^1}{\partial x_1} & \frac{\partial F^1}{\partial x_2} & 0 \\ \frac{\partial F^2}{\partial x_1} & \frac{\partial F^2}{\partial x_2} & 1 \\ \frac{\partial F^3}{\partial x_1} & \frac{\partial F^3}{\partial x_2} & 0 \end{vmatrix}}{|J|} = \frac{\overbrace{\overbrace{\pi_{x_1x_1}}^{(-)}(0 - \overbrace{\pi_{Kx_2}}^{(+)}) - \overbrace{\pi_{x_1x_2}}^{(-)}(0 - \overbrace{\pi_{Kx_1}}^{(+)}) + 0}^{\left|\pi_{x_1x_1}\pi_{Kx_2}\right| < \left|\pi_{x_1x_2}\pi_{Kx_1}\right| \Rightarrow (+)}}{(-)} > 0$$

The magnitude of terms determines the sign of the numerator and in order for the sign of $\partial \bar{K} / \partial r_2$ to be consistent with the sign of $\partial \bar{K} / \partial r_1$ (the sign of which is dictated by the SOC), and in order for later comparative statics to agree with theory, the numerator must be positive.

The third set of comparative static derivatives are taken with respect to r_3, utilize $\lfloor B_{r_3} \rfloor$, and follow:

$$\frac{\partial \bar{x}_1}{\partial r_3} = \frac{|J_1|}{|J|} = \frac{\begin{vmatrix} 0 & \frac{\partial F^1}{\partial x_2} & \frac{\partial F^1}{\partial K} \\ 0 & \frac{\partial F^2}{\partial x_2} & \frac{\partial F^2}{\partial K} \\ 1 & \frac{\partial F^3}{\partial x_2} & \frac{\partial F^3}{\partial K} \end{vmatrix}}{|J|} = \frac{\overbrace{0 - \overbrace{\underbrace{\pi_{x_1x_2}}_{(-)}(0 - \underbrace{\pi_{x_2K}}_{(+)})}^{(+)} + \overbrace{\underbrace{\pi_{Kx_2}}_{(+)}(0 - \underbrace{\pi_{x_2x_2}}_{(-)})}^{(+)}}^{\text{SOC(III)}\Rightarrow(-)}}{(-)} > 0$$

$$\frac{\partial \bar{x}_2}{\partial r_3} = \frac{|J_2|}{|J|} = \frac{\begin{vmatrix} \frac{\partial F^1}{\partial x_1} & 0 & \frac{\partial F^1}{\partial K} \\ \frac{\partial F^2}{\partial x_1} & 0 & \frac{\partial F^2}{\partial K} \\ \frac{\partial F^3}{\partial x_1} & 1 & \frac{\partial F^3}{\partial K} \end{vmatrix}}{|J|} = \frac{\overbrace{\underbrace{\pi_{x_1x_1}}_{(-)}(0 - \underbrace{\pi_{x_2K}}_{(+)}) - 0 + \underbrace{\pi_{x_1K}}_{(+)}(\underbrace{\pi_{x_2x_1}}_{(-)})}^{|\pi_{x_1x_1}\pi_{x_2K}| < |\pi_{x_1K}\pi_{x_1x_2}| \Rightarrow(-)}}{(-)} > 0$$

The condition required for the numerator to be negative is the same condition required for the sign of $\partial\overline{K}/\partial r_2$, which is consistent with the sign of $\partial\overline{K}/\partial r_1$ (the sign of which is dictated by the SOC). This condition is consistent with $\partial\bar{x}_1/\partial r_3$ also.

$$\frac{\partial \overline{K}}{\partial r_3} = \frac{|J_3|}{|J|} = \frac{\begin{vmatrix} \frac{\partial F^1}{\partial x_1} & \frac{\partial F^1}{\partial x_2} & 0 \\ \frac{\partial F^2}{\partial x_1} & \frac{\partial F^2}{\partial x_2} & 0 \\ \frac{\partial F^3}{\partial x_1} & \frac{\partial F^3}{\partial x_2} & 1 \end{vmatrix}}{|J|} = \frac{\overbrace{\overbrace{\underbrace{\pi_{x_1x_1}}_{(-)}(\underbrace{\pi_{x_2x_2}}_{(-)} - 0)}^{(+)} - \overbrace{\underbrace{\pi_{x_1x_2}}_{(-)}\overbrace{(\underbrace{\pi_{x_2x_1}}_{(-)}\underbrace{\pi_{Kx_2}}_{(+)} - \underbrace{\pi_{x_2x_2}}_{(-)}\underbrace{\pi_{Kx_1}}_{(+)})}^{\text{SOC(III)}\Rightarrow(-)}}^{(+)}}^{|\pi_{x_1x_1}\pi_{x_2x_2}| > |\pi_{x_1x_2}(\pi_{x_2x_1}\pi_{Kx_2} - \pi_{x_2x_2}\pi_{Kx_1})| \Rightarrow(+)} + 0}{(-)} < 0$$

Theory suggests that the numerator be positive so that, as with the condition required in $\partial\bar{x}_2/\partial r_2$, an increase in the factor cost leads to a decrease in input use. The interpretation of this third set of results in chapter five is quite interesting.

The fourth set of comparative static derivatives are taken with respect to P, utilize $[B_P]$, and follow:

$$\frac{\partial \bar{x}_1}{\partial P} = \frac{|J_1|}{|J|} = \frac{\begin{vmatrix} (-) & \frac{\partial F^1}{\partial x_2} & \frac{\partial F^1}{\partial K} \\ (-) & \frac{\partial F^2}{\partial x_2} & \frac{\partial F^2}{\partial K} \\ 0 & \frac{\partial F^3}{\partial x_2} & \frac{\partial F^3}{\partial K} \end{vmatrix}}{|J|} = \frac{\overbrace{(-)(\overbrace{\overbrace{\pi_{x_2x_2}}^{(-)}\overbrace{\pi_{KK}}^{(-)} - \overbrace{\pi_{x_2K}}^{(+)}\overbrace{\pi_{Kx_2}}^{(+)}}^{\text{SOC(I)}\Rightarrow(+)})}^{(-)} \overbrace{\overbrace{- \overbrace{\pi_{x_1x_2}}^{(-)}\overbrace{((-)\overbrace{\pi_{KK}}^{(-)} - 0)}^{(+)}}^{(-)} \overbrace{+ \overbrace{\pi_{x_1K}}^{(+)}\overbrace{((-)\overbrace{\pi_{Kx_2}}^{(+)} - 0)}^{(-)}}^{(-)}}^{\text{SOC(II)}\Rightarrow(+)}}{(-)} > 0$$

$$\frac{\partial \bar{x}_2}{\partial P} = \frac{|J_2|}{|J|} = \frac{\begin{vmatrix} \frac{\partial F^1}{\partial x_1} & (-) & \frac{\partial F^1}{\partial K} \\ \frac{\partial F^2}{\partial x_1} & (-) & \frac{\partial F^2}{\partial K} \\ \frac{\partial F^3}{\partial x_1} & 0 & \frac{\partial F^3}{\partial K} \end{vmatrix}}{|J|} = \frac{\overbrace{\overbrace{\overbrace{\pi_{x_1x_1}}^{(-)}\overbrace{[(-)\overbrace{\pi_{KK}}^{(-)} - 0]}^{(+)}}^{(-)} \overbrace{- (-)\overbrace{[\overbrace{\pi_{x_2x_1}}^{(-)}\overbrace{\pi_{KK}}^{(-)} - \overbrace{\pi_{x_2K}}^{(+)}\overbrace{\pi_{Kx_1}}^{(+)})}^{\text{SOC(II)}\Rightarrow(-)}}^{(+)} \overbrace{+ \overbrace{\pi_{x_1K}}^{(+)}\overbrace{(0 - (-)\overbrace{\pi_{Kx_1}}^{(+)})}^{(+)}}^{(+)}}^{\left|\pi_{x_1x_1}\pi_{KK}\right| + \left|\pi_{x_2x_1}\pi_{KK} - \pi_{x_2K}\pi_{Kx_1}\right| > \left|\pi_{x_1K}\pi_{Kx_1}\right| \Rightarrow (-)}}{(-)} > 0$$

Theory suggests that the numerator is negative so that as the market price of output rises, inputs to production increase to take advantage of greater revenue per unit of output. This is consistent with $\partial\bar{x}_1/\partial P$ (the sign of which is dictated by the SOC for a maximum). The value of x_2 could theoretically remain constant as x_1 rises if for instance $r_2 > r_1$ and Q still increases in this case.

$$\frac{\partial \overline{K}}{\partial P} = \frac{|J_3|}{|J|} = \frac{\begin{vmatrix} \frac{\partial F^1}{\partial x_1} & \frac{\partial F^1}{\partial x_2} & (-) \\ \frac{\partial F^2}{\partial x_1} & \frac{\partial F^2}{\partial x_2} & (-) \\ \frac{\partial F^3}{\partial x_1} & \frac{\partial F^3}{\partial x_2} & 0 \end{vmatrix}}{|J|} = \frac{\overbrace{\overbrace{\overbrace{\pi_{x_1x_1}}^{(-)}\overbrace{(0 - (-)\overbrace{\pi_{Kx_2}}^{(+)})}^{(-)}}^{(+)} \overbrace{- \overbrace{\pi_{x_1x_2}}^{(-)}\overbrace{(0 - (-)\overbrace{\pi_{x_1K}}^{(+)})}^{(-)}}^{(+)}}^{\text{(INDETERMINATE)}} \overbrace{+ (-)(\overbrace{\overbrace{\pi_{x_2x_2}}^{(-)}\overbrace{\pi_{Kx_2}}^{(+)}}^{(-)} - \overbrace{\overbrace{\pi_{x_2x_2}}^{(-)}\overbrace{\pi_{Kx_1}}^{(+)}}^{(-)})}^{\text{SOC(III)}\Rightarrow(+)}}{(-)} \begin{matrix} > \\ = 0 \\ < \end{matrix}$$

The sign of the numerator is indeterminate because the magnitude of the first two terms in the numerator is unknown. Theory does not provide any overriding reason for the sign of $\partial\overline{K}/\partial P$ to be either positive or negative. The sign of the derivative will likely be dependent on the magnitude of the change in P. The size of K could conceivably remain constant or decrease if the increase in revenue associated with an increase in P more than offsets any accompanying increase in the expected cost of violation as E increases with the rise in x_1 and x_2. Likewise, K could also conceivably rise if the rise in revenue from an increase in P more than offsets the increased costs of abatement. The importance of the magnitude of the change in P is illustrated in the context of the profit function by comparing the relative magnitudes of $[PQ + r_1x_1 + r_2x_2]'$ and $[r_3K + \sigma(E - \lambda)]'$, where the prime notation indicates the value of the expressions after the effect of the increase in P.

The fifth set of comparative static derivatives are taken with respect to σ, utilize $[B_\sigma]$, and follow:

$$\frac{\partial \bar{x}_1}{\partial \sigma} = \frac{|J_1|}{|J|} = \frac{\begin{vmatrix} (+) & \frac{\partial F^1}{\partial x_2} & \frac{\partial F^1}{\partial K} \\ (+) & \frac{\partial F^2}{\partial x_2} & \frac{\partial F^2}{\partial K} \\ (-) & \frac{\partial F^3}{\partial x_2} & \frac{\partial F^3}{\partial K} \end{vmatrix}}{|J|}$$

$$= \frac{(+)[\overbrace{\underbrace{\pi_{x_2x_2}}_{(-)}\underbrace{\pi_{KK}}_{(-)} - \underbrace{\pi_{x_2K}}_{(+)}\underbrace{\pi_{Kx_2}}_{(+)}}^{\text{SOC(I)}\Rightarrow(+)}] - \underbrace{\pi_{x_1x_2}}_{(-)}[\overbrace{\underbrace{(+)\pi_{KK}}_{(-)} - \underbrace{\pi_{x_2K}(-)}_{(-)}}^{\text{(INDETERMINATE)}}] + \underbrace{\pi_{x_1K}}_{(+)}[\overbrace{\underbrace{(+)\pi_{Kx_2}}_{(+)} - \underbrace{\pi_{x_2x_2}(-)}_{(+)}}^{\text{(INDETERMINATE)}}]}{(-)} \gtreqless 0$$

The magnitude of terms clearly matters here and means that the second and third terms in the numerator are sign indeterminate. The is no clear theoretical reasoning to impose a sign upon either of these terms because inputs x_1 and x_2 are common to both hog and effluent production.

$$\frac{\partial \bar{x}_2}{\partial \sigma} = \frac{|J_2|}{|J|} = \frac{\begin{vmatrix} \frac{\partial F^1}{\partial x_1} & (+) & \frac{\partial F^1}{\partial K} \\ \frac{\partial F^2}{\partial x_1} & (+) & \frac{\partial F^2}{\partial K} \\ \frac{\partial F^3}{\partial x_1} & (-) & \frac{\partial F^3}{\partial K} \end{vmatrix}}{|J|}$$

$$= \frac{\overbrace{\pi_{x_1x_1}}^{(-)}[\overbrace{\overbrace{(+)\overbrace{\pi_{KK}}^{(-)}}^{(-)} - \overbrace{\overbrace{\pi_{x_2K}}^{(+)}(-)}^{(-)}}^{\text{(INDETERMINATE)}}] - (+)[\overbrace{\overbrace{\overbrace{\pi_{x_2x_1}}^{(-)}\overbrace{\pi_{KK}}^{(-)}}^{(+)} - \overbrace{\overbrace{\pi_{x_2K}}^{(+)}\overbrace{\pi_{Kx_1}}^{(+)}}^{(+)}}^{\text{SOC(II)}\Rightarrow(+)}] + \overbrace{\pi_{x_1K}}^{(+)}[\overbrace{\overbrace{\overbrace{\pi_{x_2x_1}}^{(-)}(-)}^{(+)} - \overbrace{(+)\overbrace{\pi_{Kx_1}}^{(+)}}^{(+)}}^{\text{(INDETERMINATE)}}]}{(-)} \gtreqless 0$$

As with $\partial \bar{x}_1 / \partial \sigma$, there is no clear theoretical reasoning to expect a particular sign for this comparative static derivative and the magnitude of the first and third terms matters, therefore the sign of the comparative static derivative is indeterminate.

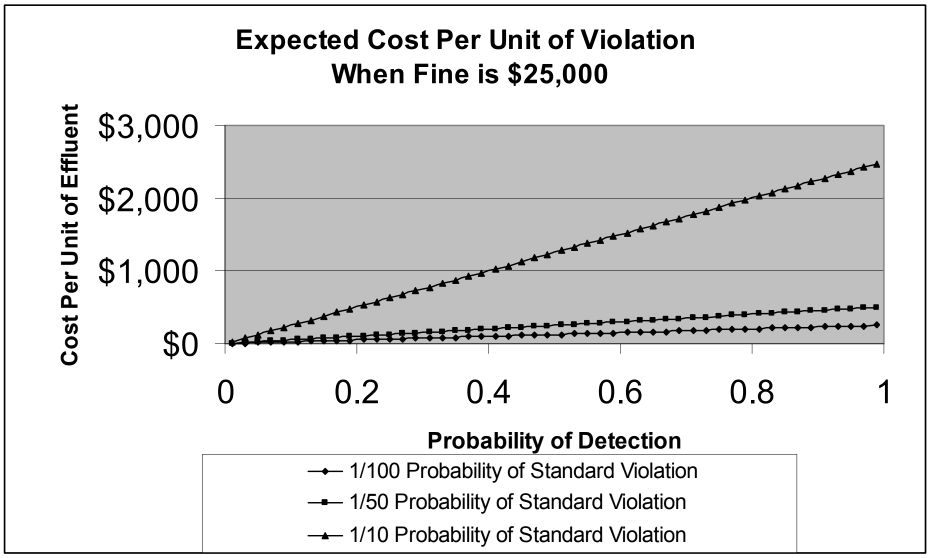
$$\frac{\partial \bar{K}}{\partial \sigma} = \frac{|J_3|}{|J|} = \frac{\begin{vmatrix} \frac{\partial F^1}{\partial x_1} & \frac{\partial F^1}{\partial x_2} & (+) \\ \frac{\partial F^2}{\partial x_1} & \frac{\partial F^2}{\partial x_2} & (+) \\ \frac{\partial F^3}{\partial x_1} & \frac{\partial F^3}{\partial x_2} & (-) \end{vmatrix}}{|J|}$$

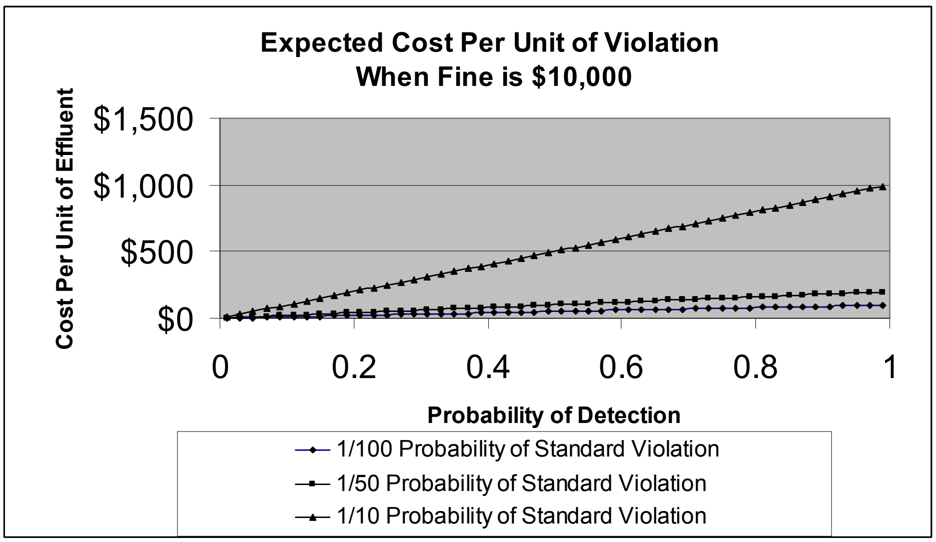
$$= \frac{\overbrace{\overbrace{\pi_{x_1x_1}}^{(-)}[\overbrace{\overbrace{\overbrace{\pi_{x_2x_2}}^{(-)}(-)}^{(+)} - \overbrace{(+)\overbrace{\pi_{Kx_2}}^{(+)}}^{(+)}}^{|\pi_{x_2x_2}|<|\pi_{Kx_2}|\Rightarrow(+)}]}^{(-)} - \overbrace{\overbrace{\pi_{x_1x_2}}^{(-)}[\overbrace{\overbrace{\overbrace{\pi_{x_2x_1}}^{(-)}(-)}^{(+)} - \overbrace{(+)\overbrace{\pi_{Kx_1}}^{(+)}}^{(+)}}^{|\pi_{x_2x_1}|<|\pi_{Kx_1}|\Rightarrow(-)}]}^{(+)} + \overbrace{(+)[\overbrace{\overbrace{\overbrace{\pi_{x_2x_1}}^{(-)}\overbrace{\pi_{Kx_2}}^{(+)}}^{(-)} - \overbrace{\overbrace{\pi_{x_2x_2}}^{(-)}\overbrace{\pi_{Kx_1}}^{(+)}}^{(-)}}^{\text{SOC(III)}\Rightarrow(-)}]}^{(-)}}{(-)} > 0$$

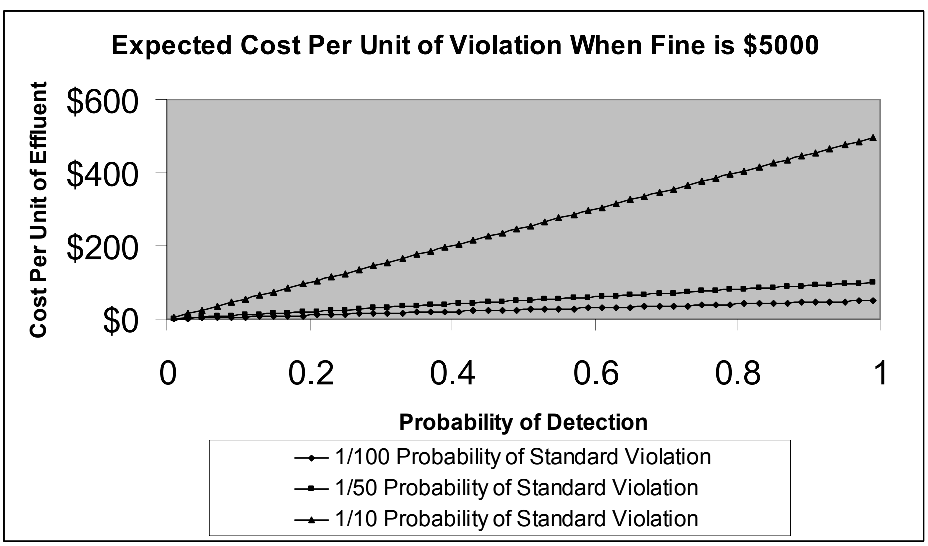
The two new restrictions or conditions imposed on the first and second terms of the numerator are necessary in order for the numerator to be unambiguously negative. Other signs for these terms would be possible if the magnitude of terms were such that the numerator remained negative, but only those conditions that lead to an unambiguous sign are considered here. The two additional restrictions imposed do not interfere with any other conditions imposed throughout the signing of the comparative statics in this appendix. Theory justifies these conditions because as the cost of evasion increases (the returns to evasion decrease) firms can be expected to engage in greater levels of abatement. This is discussed further in the interpretation of results in chapter five and conclusions based on these results are discussed in chapter six.

NOTE: In addition to the restrictions carried forward from the second order conditions for profit maximization in Appendix A, denoted above as SOC(i) in signing the comparative statics, several other restrictions on the magnitude of terms are imposed in order for the comparative static signs to be derived for analysis. The additional restrictions imposed in signing the derivatives in this appendix are consistent with one another.

APPENDIX C: EXPECTED COST OF STANDARD VIOLATION FOR DIFFERENT FINE LEVELS, PROBABILITIES OF VIOLATION AND DETECTION







APPENDIX D: ABBREVIATIONS AND ACRONYMS*

AFO	Animal Feeding Operation
BMP	Best Management Practice
CAFO	Concentrated Animal Feeding Operation
CNMP	Comprehensive Nutrient Management Plan
CWA	Clean Water Act
EPA	Environmental Protection Agency
ELG	Effluent Limitation Guidelines
EQIP	Environmental Quality Incentives Program
FSA	Farm Service Agency
MC	Marginal Cost
MFCR	Marginal Factor Cost of Regulation
ME	Monitoring and Enforcement
MR	Marginal Revenue
NMP	Nutrient Management Plan
NPDES	National Pollutant Discharge Elimination System
NRCS	Natural Resources Conservation Service
NRDA	Natural Resource Damage Assessment
SEPA	State Environmental Protection Agency
USDA	United States Department of Agriculture
WTAM	Willingness-to-Accept Manure

* A large number of acronyms are used throughout this thesis given the extensive reference to government programs, laws, and other terminology. The reader, especially one unfamiliar with the subject matter, may find this to be a helpful reference, especially in the later chapters when acronyms are used without easy reference in the body of the text to their full explanations.

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